The Mechanical Effect of Pit Excavation with Protection on Adjacent Pipelines

Hao Wen¹, Kaihong Li¹, Yanjie Jia¹, Daijun Zhou¹ and Jun Ma²

¹National Pipeline Network Group Southwest Pipeline Co., Ltd. Chengdu, Sichuan, 610218, China
²Southwest Petroleum University, Chengdu, Sichuan, 610500, China
Email: 303593822@qq.com

Abstract. The normal operation of pipelines will be affected by the surrounding environment. As an outstanding problem, pit excavation with protection on adjacent pipelines has been paid more and more attention in urban infrastructure. Adding retaining structure in soft clay area can effectively reduce the influence of pit excavation on buried pipeline. In this paper, a 3D simulation model of pipeline-soil-wall coupling is established. And the effect parameters of soil, pipeline and envelope on pipeline stress distribution, axial strain and pipeline displacement are analysed. It is found that the stress of pipeline concentrated on the middle part of the pipeline after excavation with retaining foundation pit. The larger the elastic modulus and cohesive force of soil, the smaller the deformation of pipeline, while the change of Poisson's ratio is opposite. With the increase of pipeline wall thickness and distance between pipeline and diaphragm wall, the Poisson’s ratio is decreased. The internal pressure of the pipeline has hardly affected by the deformation of pipeline, but the deformation of pipeline is increased with the increase of the depth of the foundation pit. The thickness and modulus of elasticity of diaphragm wall have the same change. They are greater with the smaller of deformation capacity of pipeline. These results provide theoretical guidance for the research of foundation pit and pipeline, and provide reference basis for engineering construction.

Keywords: Pit excavation; Protection; Pipeline; Numerical simulation; Displacement; Stress and strain

1. Introduction

With the rapid development of the national economy and the rapid increase in oil and gas demand, pipeline transportation as the main method of oil and gas transportation has received increasing attention. Pipelines will be affected by the surrounding environment during normal operation, and the impact of foundation pit construction on adjacent buried pipelines has become an outstanding issues in urban infrastructure. However, the geological environment is diverse and the soil structure is complex, especially in soft soil areas. Excavation of the foundation pit will lead to unloading and change the initial stress field of the soil, cause deformation, displacement, and surface subsidence of the surrounding soil and enclosure structure, thereby adversely affecting adjacent buried buildings and underground facilities. There are two kinds of problems in foundation pit excavation and surrounding environment: the stability of foundation pit, the strength of retaining structure and the influence of surrounding surface deformation on pipeline [1]. When constructing in soft clay areas, increase the enclosure structure, which can reduce the impact of foundation pit excavation on surrounding underground structures [2].
Peck [3] divided the settlement of the soil layer behind the retaining structure into three areas according to the surface settlement and the distance of the foundation pit. Crofts, Menzies and Tarzi [4] proposed an estimation method that the horizontal displacement of buried pipeline caused by excavation is composed of four parts. They are the horizontal displacement of the pipeline caused by the expansion of the foundation pit wall into the pit; the horizontal displacement of the pipeline caused by the contact between the foundation pit wall and the retaining structure; the horizontal displacement of the pipeline caused by the deformation of the retaining structure; the backfill in the foundation pit Consolidation causes the horizontal displacement of the pipeline. Liao Shaoming [5] and others believe that the settlement value or settlement curve of each pipeline section can be analyzed from the longitudinal bending of the flexible pipeline section, the joint opening of the pipeline section and the lateral force, so as to study the deformation of the pipeline when the stratum descends. Wang Chenghua [6] and Li Dayong [7] used Hardening-Soil model and Winkler elastic foundation beam theory to theoretically analyze the displacement of the pipeline. Cai Jianpeng [8], Du Jinlong [9] and Lv Shuran [10] used finite element method to study the stress, strain and displacement changes of pipelines under the action of pipeline soil, and found that the use of enclosure structure can significantly reduce pipeline deformation and control pipeline displacement. Wang Wei [11] proposed through simulation that passive reinforcement of foundation pits is the most effective measure to protect pipeline deformation.

At present, domestic and foreign studies generally assume that the pipeline and soil are in close contact. This assumption is more accurate for pipelines with smaller diameters and better embedment, but there are large errors for large diameter oil and gas pipelines. Therefore, this paper uses numerical simulation methods to simulate the impact of the excavation of a protected foundation pit on adjacent buried pipelines, and study the soil elastic modulus, Poisson’s ratio, cohesion, and pipeline parameters among the soil parameters. The diameter-to-thickness ratio, the buried depth pipeline, the distance between the pipeline and the foundation pit, the foundation pit width, the length of the foundation pit and other factors in the foundation pit parameters affect the deformation of the pipeline. The stress and strain of the pipeline are analyzed to further improve the pipeline and foundation. The pit theoretical system provides theoretical guidance for project construction.

2. Simulation Analysis

2.1. 3D simulation model

The soil pressure on the top of the pipeline and the soil displacement that caused by the foundation pit apply the additional load to the pipeline when the buried pipeline bears the main part of the soil pressure. Because the pipeline-soil interaction has a greater impact on the mechanical properties of the CFD is used to study the stress and strain of the pipeline that after foundation pit excavation.

The shape of foundation pit is rectangular. The buried pipeline uses X65 steel pipeline. The detailed dimensions are shown in table 1. The density of the steel pipeline material is 7800kg/m³, the modulus of elasticity is E=210GPa, the Poisson's ratio is 0.3, and the yield limit is 448.5MPa. C25 is the material of the underground continuous wall. The ideal elastoplastic Mohr-Coulomb model is used to describe the relationship of rock and soil. The pipeline-soil contact algorithm that allows separation is selected to research the contact surface. In order to simplify the calculation, a 1/2 model is selected for analysis based on the symmetry of the structure. Figure 1 is a schematic diagram of a foundation pit excavation model.

Table 1. Foundation pit and pipeline size.

| Name                | Size       |
|---------------------|------------|
| Foundation pit size | 30m×30m    |
| Excavation depth    | 8m         |
| Pipeline diameter   | 660mm      |
| Pipeline wall thickness | 8mm       |
2.2 Assumptions
In order to study the mechanical properties of pipelines under the excavation to protect the pipeline, the following assumptions were made on the excavation method model before the study:

(1) The soil has the characteristics of isotropy, homogeneity and continuity, and does not mix with other sand and gravel, and does not consider the influence of groundwater;
(2) The pipeline is placed horizontally in the foundation pit, the thickness of the underground diaphragm wall is 0.6m, and the distance between the pipeline and the diaphragm wall is 4m;
(3) The pipeline is buried under a soil layer 2m deep, and the displacement along the X-axis is assumed to be horizontal.

2.3 Theoretical Comparison and Verification
The displacement curve in the deformation zone is shown in figure 2. The top of the pipeline has a vertical displacement and extends in the Z direction. And the horizontal displacement of pipeline is in the side of the pipeline and moves toward the inside of the foundation pit along the X-axis direction. The above phenomenon occurs because the soil will settle and move into the foundation pit after excavation. However, the X-axis displacement of the soil is smaller under the action of the diaphragm wall. At the same time, according to the calculation of the elastic foundation beam differential equation, the theoretical Z-axis displacement of pipeline is basically the same as the simulation model, and the error range of maximum Z-axis displacement is small. The simulation model established in this paper is more reliable and accurate.

Figure 1. Excavation model of foundation pit.

Figure 2. Pipeline displacement curve.
3. Influence of Soil Parameters

3.1. Elastic Modulus

![Pipeline stress](image1)

![Pipeline axial strain](image2)

Figure 3. Pipeline stress and strain response under the influence of different soil elastic moduli.

As the medium between pipeline and foundation pit, the pressure of earth change is caused by the excavation acts on the pipeline through the soil around the pipeline as the medium. Therefore, the stress-strain of pipeline is greatly affected by the surrounding soil parameters. Under the conditions of Poisson's ratio of 0.35 and cohesive force of 12kPa, the response of the stress-strain of pipeline with the elastic modulus of soil (10-30MPa) is studied. As shown in figure 3(a), the stress concentration area decreases with the increase of the elastic modulus. The smaller the elastic modulus of the soil, the greater the deformation of the soil, and the greater the influence of the soil on the pipeline. Figure 3(b) shows the axial strain of the pipeline. The elastic modulus is increased, the maximum axial strain of the pipeline is decreased, but the change in axial strain is smaller.

3.2. Poisson's Ratio

Under the conditions of soil elastic modulus of 10.5MPa and cohesive force of 12kPa, the stress-strain response after soil excavation is studied. As shown in figure 4(a), the Von-Mises stress is concentrated on the middle of the pipeline. The Von-Mises stress increases with the increase of Poisson's ratio, and the stress change range is about 40MPa. It can be seen from figure 4(b) that the maximum axial strain changes significantly at the symmetry plane of the pipeline. The maximum axial strain increases with the increase of the Poisson's ratio of the soil, and the rate of change also gradually increases.

![Pipeline stress](image3)

![Pipeline axial strain](image4)

Figure 4. Pipeline stress and strain response under different soil Poisson's ratio.
3.3. Cohesion
The mutual attraction of adjacent parts in geotechnical materials can be embodied by cohesion. The stress and strain response that after excavation under the action of 10-18kPa soil cohesion is studied, as shown in figure 5(a). The pipeline stress is the same as the soil cohesion. When the cohesion force is 10kPa, the pipeline stress reaches 220MPa, and when the cohesion force is 18kPa, the pipeline stress is about 54MPa. The hard soil exerts less pressure on the pipeline, because the hard soil has greater cohesion and weaker deformability. As shown in figure 5(b), the axial strain and the change of the pipeline decrease with the cohesion increases. This phenomenon occurs because the soft soil is more prone to deformation, and the excavation of foundation pit intensifies the soil deformation.

![Figure 5. Pipeline stress and strain response under different soil cohesion.](image)

4. The Influence of Pipeline Dimensions

4.1. Diameter-Thickness
The diameter-thickness of pipeline is one of the factors to impact the stability. As shown in figure 6(a), the pipeline stress reaches 152 MPa when the thickness is 8 mm, and the pipeline stress decreases to 100 MPa in 18 mm. The Von-Mises stress increases with the increase of the diameter-thickness ratio, and the stress concentrated on the axial direction. When the thickness of wall is small, the stiffness decreases and the pipeline is easily deformed. As shown in figure 6(b), as the diameter-thickness increases, the axial strain of the pipeline gradually increases, and the strain change is slightly larger than that on the lower surface.

![Figure 6. Stress and strain response of pipelines with different diameter-thickness ratios.](image)
4.2. Internal Pressure of Pipeline
When there are excavating the foundation pit, the operating oil and gas pipelines is affected by internal working pressure and soil pressure. For gas pipelines, considering that the safety factor 0.72. And the maximum working pressure $P_{\text{max}} = 0.72 \times (2y/D)$ [12]. The X-axis displacement and Z-axis displacement do not change significantly with the increase of internal pressure. This phenomenon indicates that after finishing excavating, the deformation of the pipeline is mainly caused by the action of the surrounding earth pressure. Some studies believe that the internal pressure has little influence on the deformation and axial stress, and only affects its circumferential stress [13].

4.3. Distance between Pipeline and Diaphragm Wall
The stress and strain response of the pipeline when the distance (L) between the pipeline and the diaphragm wall is 4-10m is shown in the figure 7. It can be seen from figure 7(a) that the force on the pipeline decreases with the increase of the distance. When the distance is 10m, the stress as high as 50MPa, and the amount of change is relatively large. The stress concentration area of the pipeline is significantly reduced at the edge of the foundation pit, and almost disappears when the distance is 10m. It can be seen from figure 7(b) that the variation law of the axial strain of the pipeline section is contrary to the variation law of the distance between the pipeline and foundation pit. When the distance is 10m, the pipeline strain curve is close to a straight line as a whole, and the amount of change is obvious.

(a) Pipeline stress. (b) Pipeline axial strain.

Figure 7. Pipeline stress and strain response under different distances

5. Conclusion
After the excavation of the foundation pit, the maximum stress area of the pipeline is located in the middle of the pipeline and the edge of the foundation pit. The upper surface of the pipeline is compressed at the symmetry plane and tensioned at the edge of the foundation pit, while the lower surface of the pipeline is the opposite. The overall displacement of the pipeline is manifested as settlement while moving towards the inside of the foundation pit.

After the excavation of the enclosed foundation pit, the maximum stress area of the pipeline lies in the middle of the pipeline and the edge of the foundation pit. The greater the soil elastic modulus and cohesion, the smaller the deformation of the pipeline, but the Poisson's ratio changes in the opposite way. Decrease as the pipeline wall thickness and the distance between the pipeline and the continuous wall increase. The internal pressure of the pipeline has little effect on the deformation of the pipeline, but the deformation of the pipeline increases with the increase of the depth of the foundation pit; the greater the thickness and elastic modulus of the underground continuous wall, the smaller the deformation capacity of the pipeline.

Author
Wen Hao, male, born in November 1988, engineer, received a bachelor's degree from Southwest
Petroleum University in 2011, and a master's degree from Southwest Petroleum University in 2019. He is currently sponsored by the Equipment Technology Institute of Southwest Pipeline Technology Center, and is now mainly engaged in research work such as process equipment management. Address: No. 6, Yingbin Avenue, Jinniu District, Chengdu City, Sichuan Province, 610036. Tel: 18602889005, Email: 303593822@qq.com

References
[1] Ji K X 2013 Numerical Analysis of the Influence of Foundation Pit Excavation on the Deformation of Adjacent Buried Pipelines Based on ABAQUS Tianjin: Tianjin Urban Construction University China.
[2] Ma J 2018 Study on the Influence of Foundation Pit Excavation on the Mechanical Behavior of Adjacent Buried Pipelines Chengdu: Southwest Petroleum University China.
[3] Peck R B 1969 Deep excavations and tunneling in soft ground Proceedings of ICSMFE: 225-290.
[4] Crofts J E, Menziest B K, Tarzi A I 1997 Lateral displacement of shallow buried pipelines due to adjacent deep trench excavations Geotechnique 27(2): 161-179.
[5] Liao Sh M, Liu J H 1997 Protection Technology of Adjacent Buried Buildings and Facilities Beijing: China Construction Industry Press.
[6] Wang Ch H, Duan X W 2013 Numerical analysis of the influence of foundation pit excavation on the working shape of underground pipelines Journal of Underground and Space Engineering 9(5): 1166-1172.
[7] Li D Y, Zhang T Q, Gong X N 1999 Analysis of the displacement of adjacent underground pipelines caused by deep foundation pit excavation Industrial Construction 29(11): 36-42.
[8] Cai J P, Huang M S, Qian J G, et al. 2010 DCFEM method for analyzing the influence of foundation pit excavation on adjacent buried underground pipelines Chinese Journal of Underground Space and Engineering 6(1): 120-124.
[9] Du J L, Yang M 2009 Analysis of the influence of foundation pit excavation on adjacent buried pipelines Chinese Journal of Rock Mechanics and Engineering 28(Added 1): 3015-3020.
[10] Lv Sh R, Liu H Y, Yuan X P 2010 Analysis of the influence of foundation pit excavation on the operation status of nearby underground pipelines Industrial Construction 40(1): 686-689.
[11] Wang W, Wang L, Ma D H, et al. 2009 Three-dimensional finite element analysis of underground pipelines under different protection measures affected by the excavation of adjacent buried foundation pits Journal of Beijing University of Technology 35(7): 939-946.
[12] Zhang J, Liang Z, Han C J 2014 Buckling behavior analysis of buried gas pipeline under strike-slip fault displacement Journal of Natural Gas Science and Engineering 21: 921-928.
[13] Hong Q 2012 Research on the Influence of Shield Tunnel Construction on Existing Pipelines Hangzhou: Zhejiang University China.