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Research Paper

Numerical analysis of pipe jacking in deep soft soil based on the construction of urban underground sewage pipeline

Ji Chen [a], *Bangyao Zhong* [b], *Jianxin Yang* [b], *Xuenan Zheng* [b], *Xuegang Zhu* [b], *Qiang Tang* [a, c, d,*]

[a] *School of Rail Transportation, Soochow University. Suzhou, China.*

[b] *China Railway Tenth Group of the Fifth Engineering Co., Ltd. Suzhou, China.*

[c] *Key Laboratory of Ministry of Education for Geomechanics and Embankment Engineering, Hohai University, Nanjing, China.*

[d] *Jiangsu Research Center for Geotechnical Engineering Technology, Hohai University, Nanjing, China.*

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ABSTRACT

Pipe jacking construction in complex soil layers and soil conditions remains to be a tough issue, because various factors are supposed to be considered and the jacking parameters needs optimization. The purpose of this paper is to analyze the impact of pipe jacking on surface settlement, soil deformation and pipe-soil interaction in a numerical model of pipe jacking through deep soft soil, which is a simulated construction of urban underground sewage pipeline. The results show that the pipe jacking construction adopted in the deep soft soil layer has little effect on the surrounding soil layers. And the maximum ground settlement is only about 8 mm. The impact of pipe jacking construction in deep soft soil layer on ground settlement is about 6 times the diameter of the jacking pipe along the pipe axis. Finally, the input force needs to be selected according to the condition of the soil layer to ensure the safety of the pipe jacking construction.

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1 Introduction

With the requirements of urban environmental protection, the development of underground transportation is gradually saturated. Among the common-used construction methods, the pipe jacking makes little damage to the surface strata. As a result, the conventional open excavation is replaced by the underground excavation, which does not need to damage the ground buildings. Thus, the impact on the urban traffic and people's daily life is reduced, and the environmental pollution is also declined [1].

* *Corresponding author.*
E-mail address: tangqiang@suda.edu.cn

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Pipe jacking, which go through the area where the ground traffic is gathered, and the foundation of various underground houses and pipelines are complex. In recent years, pipe jacking construction method is applied in extensive fields. However, serious issues may appear when the geological conditions vary from one to another. Complex soil conditions and difficult construction requirements may lead to unknown incidents. Therefore, many studies have been taken to research on the improvement of pipe jacking technology, in order to be equipped for any engineering conditions.

In the construction of many pipelines such as water supply and drainage system, or power system and communication system, pipe jacking method solves many construction problems. With the further development of pipe jacking technology, the utilization rate of shallow underground space is much higher. Pipe jacking is a method of underground excavation, which does not need to excavate the ground surface, but still changes the displacement of underground soil. When the displacement of the soil around the pipeline exceeds a certain value, it will affect the soil layer on the ground. If the deformation is too large, it will even damage the surrounding buildings, their foundations and the surrounding underground pipelines. Also, the frictional resistance between the pipe wall and the soil need to be reduced [2]. In this paper, an urban underground sewage pipeline numerical model was simulated, and the purpose was to investigate the stress and deformation of the soil layers and surrounding environment during and after jacking. A series of analysis were conducted and discussed.

2 Urban Underground Sewage Pipeline Model

2.1 Simplified model

The model of sewage pipeline is depicted in Figure.1, which is 54.5 in length and approximately 28m in height. The side view of the pipeline is captured in the left. RadCylindermeshes are used for pipe jacking construction, while the meshes of soil and other materials are Brick. The pipeline is in the middle of the width, which is in symmetry, for simplify of the model. It is assumed that all types of soil are isotropic, and regardless of the connection influence between pipe jacking head and pipe. The pipe material is considered to be isotropic and linear elastic.

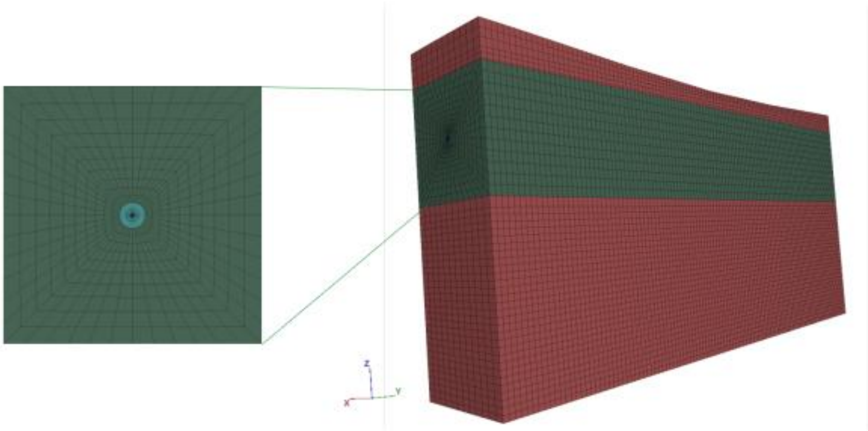
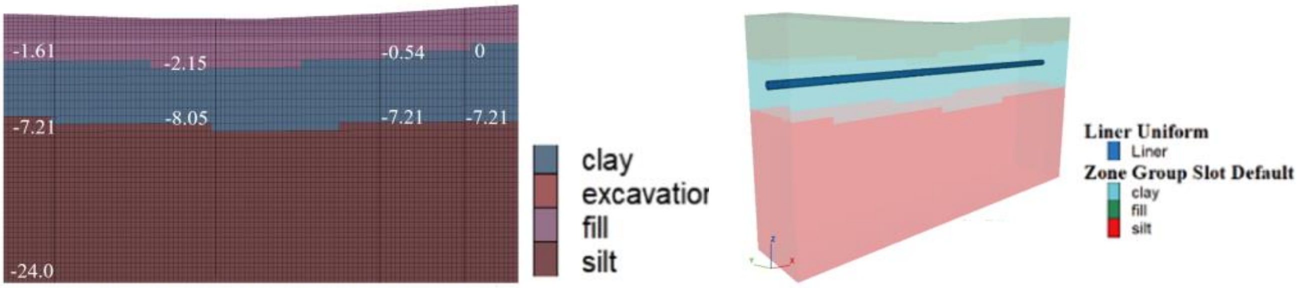


Fig. 1. Simplified pipeline model.

2.2 Soil layers and material properties

The layers of soil are illustrated in Figure.2(b). There are three types of soil, mainly composed of plain fill, silty clay and silt. The properties are shown in Table 1. The thickness of soil layer is not uniform, which is well established in the model. Figure 2(b) is the schematic diagram of pipeline.

In the numerical simulation, the density of the pipe is 2084 kg/m^3, and the elastic modulus is 15GPa. The Poisson's ratio is 0.22, and the thickness is 0.213 m. The normal modulus and tangential modulus of the coupling between the structure and soil are both 10 times with the value of the (K+4/3 G) stiffness. The properties of silty clay are similar to silt. The Es and G of silty clay are 2.71MPa and 2.08MPa separately, while that of silt are 2.15MPa and 1.59MPa. The parameters of plain fill are much higher, with 7.5MPa of Es, 15MPa of E, 7.81MPa of K and 6.36MPa of G. The cohesion reaches 21kPa and the internal friction angle is 15°.



(a) Soil layers (b) Schematic diagram of pipeline

Fig. 2.Schematic diagram of model soil layers and pipeline.

Table 1. Parameters of soil.

Layers	**Es(MPa)**	**E(MPa)**	**K(MPa)**	**G(MPa)**	**Cohesion （kPa）**	**Internal friction angle**
Plain fill	7.5	15	7.81	6.36	21	15
Silty clay	2.71	5.42	4.52	2.08	14.1	6.5
Silt	2.15	4.3	4.78	1.59	13.2	6

2.3 Boundary Conditions

In order to simulate the process of pipe jacking accurately, the boundary conditions used in the numerical simulation. The model bottom constrains the vertical (Z axis) displacement, the model lateral boundary constrains the normal displacement, and the model surface is a free boundary. Figure 3 shows the schematic diagram of the boundary conditions of the model.

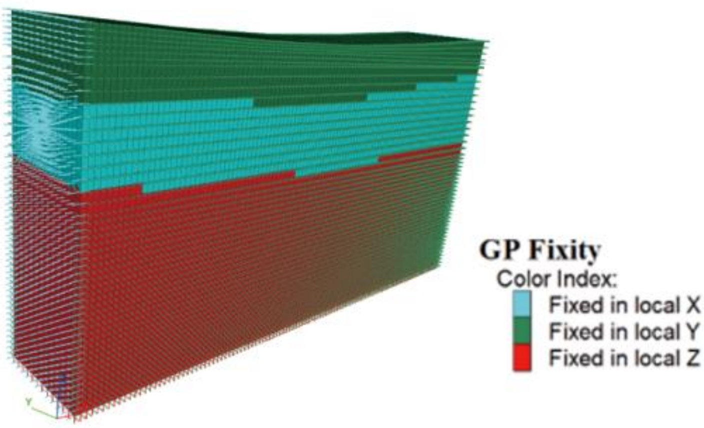


Fig. 3.Schematic diagram of boundary conditions.

The element of pipe structure is 3-node (each node has 6 degrees of freedom, 3 movement, 3 rotation) finite-element, which can not only resist shear and bending moment loads, but also simulate the separation between the pipe and the soil. The friction between the pipe and the soil can be characterized by the normal coupling stiffness, tangential coupling stiffness, and coupling friction angle between the pipe unit and the surrounding soil [3]. In Figure.4, stress of elements is analysed.

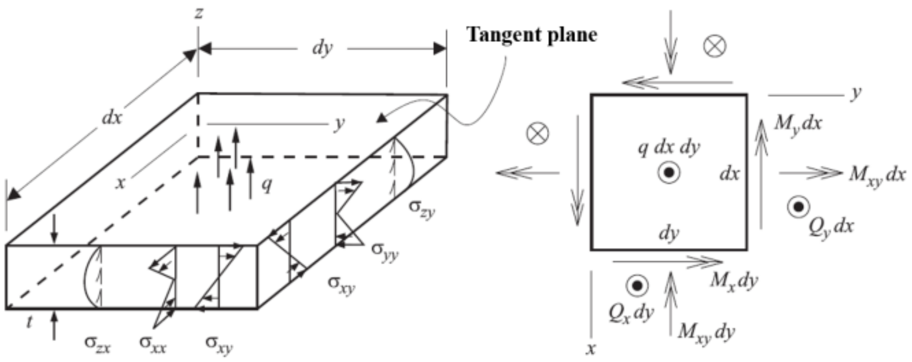


Fig. 4. Stress analysis of elements.

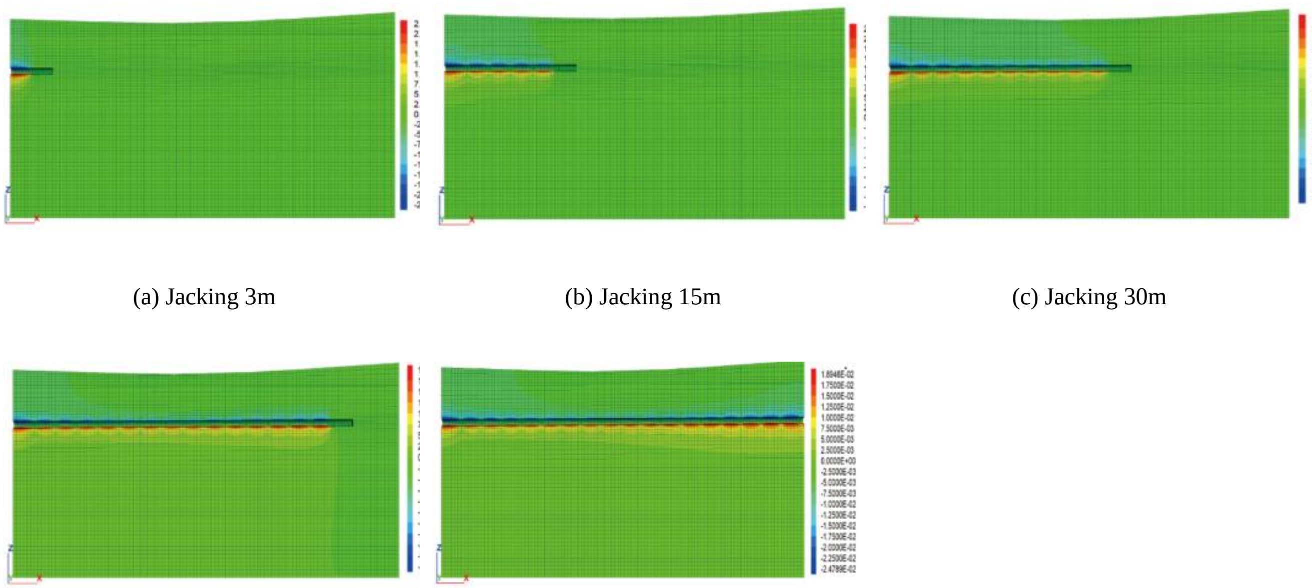
2.4 Steps of pipe jacking

The construction process of jacking under deep soft soil mainly refers to the actual construction steps. In this paper, the pipe jacking step is calculated according to the jacking distance, not the jacking force. Numerical analysis steps: step 1: initial step; step 2: excavate and jack to 3m; step 3: excavate and jack to 6m; step 4: repeat the excavation and jacking process until the whole process is finished [4].

3 Results and Discussion

3.1 Stress and deformation of soil

The soil deformation of the longitudinal section indicates that the soil displacement at the pipeline axis is the largest. It is necessary to focus on the distribution of soil deformation in the longitudinal section of the pipeline axis. The vertical displacement cloud diagram is shown in Figure.5. In this figure, (a), (b), (c), (d) and (e) are calculated by passing through the jacking pipe to 3 m, 15 m, 30 m, 45 m and 54.5 m from the start. The maximum ground settlement caused by the pipe jacking construction process is only about 8 mm.



(a) Jacking 3m

(b) Jacking 15m

(c) Jacking 30m

(d) Jacking 45m

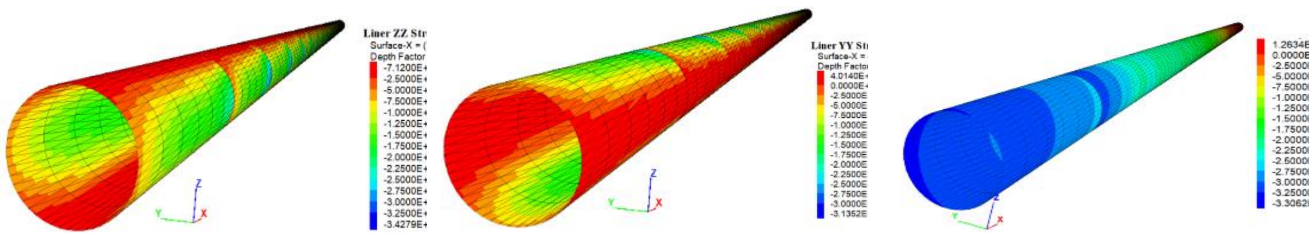
(e) Finish

Fig. 5.Settlement cloud diagram at longitudinal section of pipeline axis(y=0).

With the continuous increase of the jacking distance, the soil on the upper part of the pipeline has settled, and the soil next to the pipeline has uplifted. The jacking of the pipe underneath may cause disturbance and loss of the soil around the pipe, and the excavation of the original soil causes the decrease of effective stress [5].As a result, the impact of pipe jacking construction in deep soft soil layer on ground settlement is about 6 times the diameter of the jacking pipe along the pipe axis.

3.2 Stress and deformation of pipeline

The stress diagram of the pipeline after jacking is illustrated in Figure. 6(a) and (b), and the unit of stress and deformation are Pa and m. The vertical stress on the upper and lower positions of the pipeline is the largest, and the horizontal stress on the side of the pipeline is the largest. The maximum vertical stress and horizontal stress are relatively small. So, the pipe is basically within the range of elastic deformation, and there is no risk of damage. The vertical deformation diagram of the pipeline is shown in Figure. 6(c).

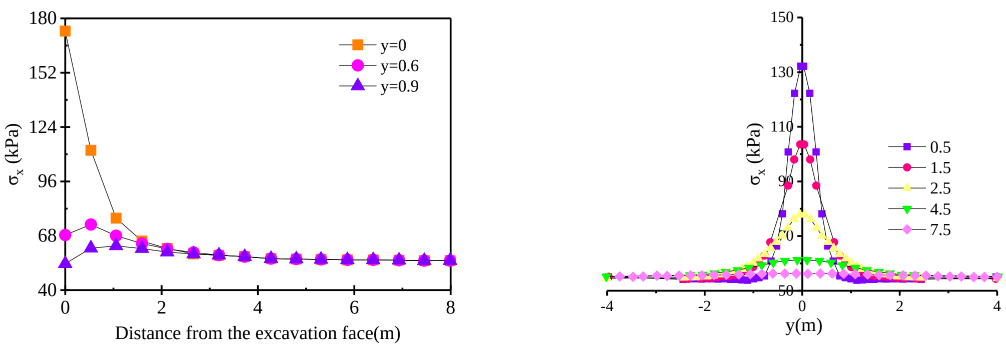


(a) Vertical stress (b) Horizontal stress (c) Deformation

Fig. 6. Stress and deformation of pipeline.

3.3 Parameter influence analysis

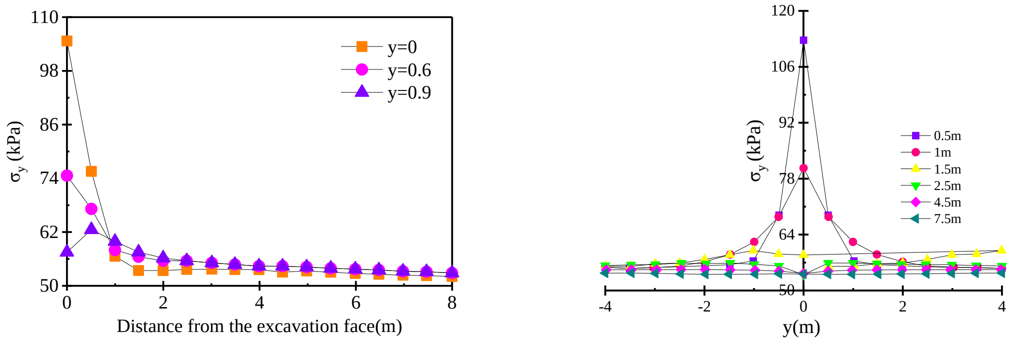
Figure 7 shows the σ_x change along the X-axis caused by the frontal force when the pipe jacking reaches 0-3m. Structures are affected by the frontal force of the jacking pipe. In addition, the influence of σ_x is mainly concentrated in the soil directly in front of the propulsion surface. The degree of influence is large but the scope of influence is small, while the stress in the place far away from the propulsion surface spreads to both sides [6].



(a) σ_x along X-axis (b) σ_x along Y-axis

Fig. 7. σ_x along X-axis and Y-axis.

The lateral additional stress generated by the force of the pipe may affect the structures on both sides of the pipe. Figures 8(a) and (b) depict the distribution of σ_y caused by frontal force at different positions along the longitudinal and transverse directions of the jacking pipe. The distribution of σ_y is obviously different from the distribution of the normal stress σ_x, in that the lateral stress σ_y has a negative value before the propulsion.



(a) σ_y along X-axis (b) σ_y along Y-axis

Fig. 8. σ_y ***along X-axis and Y-axis.***

4 Conclusions

Pipe jacking in deep soft soil was conducted in this paper. The impact of pipe jacking on surface settlement, soil deformation and pipesoil interaction are mainly considered. The main conclusions are as follows:

The pipe jacking construction adopted in the deep soft soil layer in this project is safe and effective, which has little effect on the surrounding soil layers. The maximum ground settlement caused by the pipe jacking construction process is only about 8 mm, which can effectively avoid surrounding areas.

In this project, the largest deformation of the surface caused by the construction of the pipe jacking in the deep and thick soft soil layer occurs at the start. The impact of pipe jacking construction in deep soft soil layer on ground settlement is about 6 times the diameter of the jacking pipe along the pipe axis.

It is necessary to select appropriate force according to the condition of the soil layer where the pipe jacking is conducted and the stress to ensure the safety of the pipe jacking construction.

5 Acknowledgement

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References

[1]- J. Zhang, G. Yin, Y. Li, L. Zhang, Buckling configurations of tubular strings constrained in three-dimensional curved wellbores. J. Pet. Sci. Eng. 195 (2020). doi:10.1016/j.petrol.2020.107953

[2]- Q. Tang, F. Gu, Y. Zhang, Y.Q. Zhang, J.L. Mo, Impact of biological clogging on the barrier performance of landfill liners., J. Environ. Manage. 222 (2018) 44-53. doi:10.1016/j.jenvman.2018.05.039

[3]- Q. Tang, Y. Zhang, Y.F. Gao, F. Gu, Use of Cement-Chelated Solidified MSWI Fly Ash for Pavement Material: Mechanical and Environmental Evaluations. Can. Geotech. J. 54(11) (2017) 1553-1566. doi:10.1139/cgj-2017-0007

[4]- H. Kainz, W. Reng, P. Augat, S. Wurm, Influence of total knee arthroplasty on patellar kinematics and contact characteristics. Int. Orthop. 36(1) (2012) 73-78. doi:10.1007/s00264-011-1270-2

[5]- Z. Zhong, C. Li, X. Liu, Y. Fan, N. Liang, Assessment of experimental friction parameters and contact property of pipe string for the estimation and verification of a solution for pipe stuck in the China's first rock pipe jacking. Tunn. Undergr. Space. Technol. 107 (2021). doi:10.1016/j.tust.2020.103671

[6]- Q. Tang, P.X. Shi, Y. Zhang, W. Liu, L. Chen, Strength and deformation properties of fiber and cement reinforced heavy metal-contaminated synthetic soils. Adv. Mater. Sci. Eng. (2019) 2019, doi:10.1155/2019/5746315