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Research article

Numerical study of the basic parameters effects on ground subsidence during pipe jacking operations

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English Extended Abstract

Summary

Pipe jacking is a scientific, economic and environmental solution for the construction of underground facilities that performs a key role in the implementation of projects. In this method, simultaneously with the excavation operation by the shield, the pipes are jacked using hydraulic jacks. Ground deformation during pipe jacking operations is one of the main challenges that its analysis is necessary for safety purposes and project design. Several factors affect the pattern of ground deformation during pipe jacking operations. The effect of each parameter and their sensitivity must be determined so that the ground deformation can be controlled with proper design. The study of displacement patterns in the field of layers based on numerical simulation of finite elements and finally, the analysis of their sensitivity is a subject that has been the subject of limited studies in this field. In this study, modeling details such as a conical excavation shield, increased gradient of grout injection pressure and excavation plate pressure have been considered to be close to the real state. The displacement values at the ground surface and the crown of the pipeline are analyzed. In this study, numerical simulation has been performed using the PLAXIS finite element numerical software and considering a case study. The results of numerical modeling were calibrated with the results obtained from field and theoretical studies, and then the effect of each parameter on the pattern of ground deformation as well as estimating the quantity of uplifts and their exact location were investigated. In the next step, the relationship between each parameter and ground subsidence was estimated and finally, the effect of each of the different factors was measured using sensitivity analysis and the sensitivity index of each was determined. The results show that the most sensitive factor to subsidence is the diameter of the excavated space and the least important factor is the face excavation pressure. Most subsidence occurs at the end of the excavation shield due to the conical nature of the shield and the stress relaxation. Finally, according to the results, it was determined that the relationship between the internal friction angle and the elastic modulus with the ground surface settlement is linear but indirect. The relationships of other parameters were also evaluated nonlinearly.

Introduction

Pipe jacking technique is a trenchless excavation method used to install underground installations such as water, sewage, electricity and gas pipelines using hydraulic jacks. In other words, this method is suitable for installing long pipelines [1,2]. In general, the pipe jacking technique is such that simultaneously with the excavation operations by the mechanized device, the pipes are also jacked by hydraulic jacks [3]. Many factors can affect the ground displacement pattern during pipe jacking operations, the most important of which are excavation face pressure, grout injection pressure, diameter, overburden and geotechnical parameters can

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be elastic modulus, cohesion and friction angle. Changing each of the parameters will move according to the degree of sensitivity. Therefore, estimating the ground displacement and sensitivity analysis of each parameter is of great importance in the construction of pipe jacking engineering and is also necessary for safety and planning purposes [4]. This study, based on finite element numerical simulation using PLAXIS software, analyzes the ground displacement pattern and compares the results with field and analytical studies to confirm the accuracy of the model. Finally, the effect of each of the different factors is measured using sensitivity analysis and the sensitivity index of each parameter is evaluated from the most sensitive factor to the least important factor in ground displacement. In addition, the combined effect of several parameters simultaneously on the ground displacement and the percentage of the sensitivity of the ground surface and the crown of the pipeline to changes in the parameters will be investigated. In this study, the simulation is based on field studies by Wenjie ma et al. They studied the perturbation mechanism and soil deformation pattern using stochastic environment theory [5]. Several fields, analytical and numerical studies have been presented in this field. In 1977, Scherle proposed a way to predict the movement of the ground surface during pipe jacking operations. After conducting studies, he concluded that soil movement and surface deformation are mainly due to the thrust force in the head of the excavation machine and high soil cutting [6]. In a 2005 study, Stein concluded that although slurry is injected during excavation operations, we will still have soil degradation. Therefore, the soil around the pipe may collapse, causing the ground to move and the surface to deform. Sedimentation usually occurs due to the collapse of the surrounding soil in the annular space, due to the loosening of the surrounding soil at the top of the pipeline [7]. In 2019, Zhang et al. Developed a three-dimensional finite element model using Abacus software. In this study, the effect of parameters such as soil elastic modulus, in-situ stress release rate, lateral pressure coefficients, pipeline elastic modulus and buried depth in the amount of ground displacement were investigated. They also analyzed the effects of tunnel excavation on pipeline movement and provided a relationship between each of the parameters and the surface subsidence, which determines the sensitivity of each parameter in the subsidence. Finally, a relationship between maximum surface subsidence and pipeline deformation for different relative stiffness of the pipe and soil was proposed. The results of this analysis were in the order of correlation of the parameters which were presented as Es> P> H> K0> Ep. Therefore, the elastic modulus of the soil has the highest sensitivity in the pipeline subsidence and the subsequent stress release rate will have the greatest impact in this regard. Pipe elastic modulus also has the least effect on pipeline subsidence [8]. Xianmin et al. In 2019, with a comprehensive and fundamental analysis, concluded that the diameter of the pipe and the elastic modulus of the soil are the most sensitive to subsidence, followed by the depth of location and compression pressure, and finally the release of in situ stresses [9].

Methodology and Approaches

In 2021, Wenji ma et al. Analyzed the pattern of soil deformation caused by pipeline operations in a case study of an electricity transmission pipeline in China. In this project, there are seven soil layers. In addition, there are sewer, water and gas pipes around the pipeline [5].

In this descriptive-interventional study, based on the finite element numerical simulation and using the PLAXIS 3D software, the ground deformation pattern was studied and analyzed. Thereafter, the results obtained from field and experimental studies were compared with the results of numerical modeling to confirm their accuracy. Finally, the effect of each factor was examined using sensitivity analysis, and we provided the sensitivity index of each parameter from the most sensitive to the least important factor influencing the ground deformation.

Results and Conclusions

The results indicate that, compared to other variables, the diameter has the most sensitivity and the excavation face pressure has the least sensitivity to the ground surface subsidence. So, core caution should be taken in the initial studies. Of course, it should be noted that the pressure of the excavation face also has the greatest effect on the ground surface uplift in front of the tunnel face. The soil in front of the excavation face is mainly subjected to a positive thrust force. Therefore, a certain uplift will occur. The maximum uplift

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occurs at a distance of about 8 m in front of the excavation face and then gradually decreases. A decrease in the cohesion of soil layers leads to an increase in subsidence, and if this decrease is in the range of 90% of the initial value, subsidence will increase significantly. It should be noted that the sensitivity of the soil layer through which the pipeline passes (1-Silty Clay) is -0.062 and has the highest value compared to the other layers. Therefore, this layer is more important than cohesion changes.

Figures, Tables and Images

Surface displacement during pipe jacking operations under the influence of diameter and overburden parameters is shown in Figure 1. Due to the conical nature of the excavation shield, it can be stated that the most displacement will be at the end of the shield. The relationship of each of the studied parameters with the ground subsidence is summarized in Table 1.

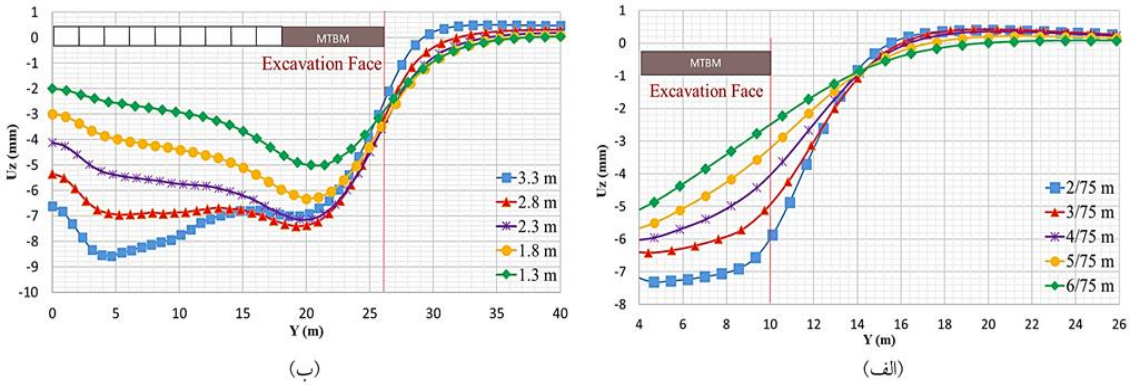

Fig. 1. Impact of diameter and overburden on ground displacement (a: overburden, b: Diameter)

Table 1. Relationship of each parameter with ground subsidence

Overburden	$U = 0.0483\ O^3 - 0.803\ O^2 + 4.5689\ O - 14.807$
Diameter	$U = -0.9147\ d^3 + 6.5632\ d^2 - 16.54\ d + 7.4327$
Grout pressure	$U = 8\times10^{-6}\ G^3 - 0.0029\ G^2 + 0.3367\ G - 19.114$
Face excavation pressure	$U = -2\times10^{-5}\ P^2 + 0.0088\ P - 9.3396$
Elastic modulus	$U = 0.0724\ E - 8.582$
Friction angle	$U = -0.013\ \phi - 8.57$
Cohesion	$U = 0.2367\ Ln(C) - 7.6371$

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