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Numerical Simulation of Transverse Deformations of Buried Pipelines Due to Slope Instability

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ABSTRACT: Buried pipelines are used to transport water, liquid fuel, gas, oil, etc. and they must remain in service in all circumstances such as permanent transverse ground deformation caused by slope instability. In the literature, modeling of soil-pipe interaction is carried out mostly by using soil-equivalent spring, and instead, continuum modeling is rarely used. In the modeling problem, the main question is the estimation accuracy of the pipe deformation. In this paper, it is tried to study the deformational behavior of a pipe installed over an unstable slope. In this study, the simulation was performed by using a continuum approach by using FLAC 3D software, which is based on finite difference method. The effect of parameters such as pipe diameter and thickness, width of the slope, soil cohesion and soil internal friction angle on pipe deformation were investigated. The simulation results indicate that the maximum displacement of the transverse ground and pipe occurs in the center of the area and reaches zero in the sides. The forces/stresses in the pipe are symmetric to the center of the model and reach a maximum value in the center. Furthermore, as the ground movement increases, the pipe maximum strain increases linearly while it remains constant anymore at larger ground deformation which is called critical deformation. By comparison of the numerical results with those of analytical methods for a large-scale physical test, it can be said that the numerical model can more precisely predict the pipe deformation and forces/bending moments. Parametric studies show that some solutions such as an increase in the diameter of the pipe, increase in thickness of the pipe wall and a decrease in the slope angle can effectively reduce the displacements and forces imposed in the pipe.

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1. INTRODUCTION

Slopes are affected by various factors such as earthquakes, landslides and unstable fluidity, and this instability causes the mass of soil to tilt to move. This displacement can cause Permanent Ground Deformation (PGD) and cause damage to buried pipes.

There are two methods for modeling the soil-pipe interaction problems. In the first method, soil equivalent springs are used to model this interaction. In the second method, the soil environment is considered as a continuum and the interaction between soil and pipe is modeled as a contact (interface) element. The permanent deformation of the ground occurs transverse directions when the ground's motion is perpendicular to the axis of the pipe. The buried pipe is shown in Figure 1 under the PGD, in which w is the width of the PGD and δ is maximum deformation of PGD.

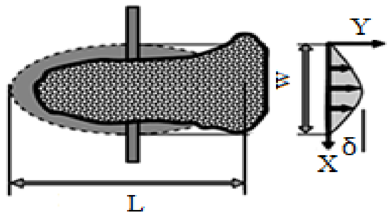

Fig. 1. Buried pipe under the transversal PGD

2. METHODOLOGY

In order to investigate the behavior of a pipe under transverse PGD, Liu and O'Rourke [1] considered the buried pipe in the soil as a beam in the ABAQUS. An assumed slope geometry is considered according to Fig. 2 in which the width

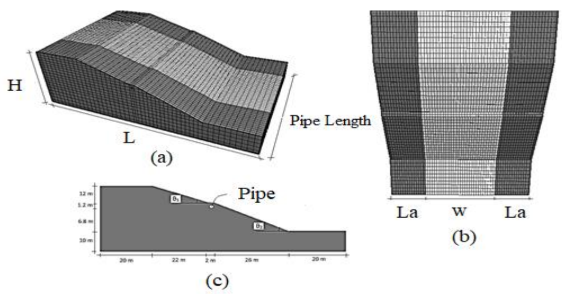

Fig. 2. An assumed slope geometry; (a) Transverse view, (b) Plan, (c) Slope section

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Table 1. Geometric characteristics of the slope

Pipe Diameter (m)- D	0.61
Pipe Thickness (m)- t	0.0095
Pipe Length (m)	60
$\boxtimes_1$	20
$\boxtimes_2$	25
W (m)	30
L_a (m)	15

Table 3. Geometric features

D (m)	0.325
t (m)	0.008
L of pipe (m)	32
w of PGD (m)	16
La (m)	8

Table 4. Soil parameters

parameters	Out of PGD	PGD area
C (kPa)	13.73	5.03
γ(kN/m^3)	19	21
φ	4.9	3.5

of the slope includes the region of lateral deformation (W) and the anchor length (for the pipe) of each side (L_a). A pipe is located at a depth of 1.2 m from the ground.

The geometric characteristics of the slope and the pipe are in accordance with Table 1.

In order to cause the slope to be unstable, it is assumed that due to environmental factors, the slope is saturated. Using the equilibrium method, Michalowski [2] presented diagrams for calculating the coefficient of stability of the slope. The safety factor with this method is equal to F.S = 0.85. In another way, Bishop and Morgenstern [3], using a slice method, with this method F.S = 0.75. Based on the results, it is assured that the slope is considered unstable. To simulate soil behavior, the Mohr-Coulomb elasto-plastic model has been used. In order to create landslide and the fall of its soil mass, the slope is divided into three different regions. Landslide in the middle region causes cross-sectional movement of the soil and pipe. The middle region is an area subjected to the permanent displacement of the PGD. The soil parameters for boundary and PGD regions are presented in Table 2. The buried pipe steel X52 are also assigned to the pile element in FLAC 3D.

To simulate a real issue, Wenkaia et al. [4] examined the impact of a large-scale landslide on a gas test pipeline. According to Wenkaia et al. [4], soil excavation was performed step by step, which caused the landslide in the slope. The geometry of the simulated model in the FLAC 3D is shown in Figure 3. Geometric features are given in Table 3.

Table 2. Soil parameters

parameters	PGD region	Lateral regions
C (kPa)	1 ~ 5	3,5
γ(kN/m^3)	18.7	
φ	35	

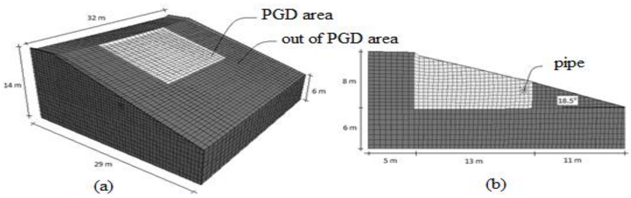


Fig. 3. Geometry of the simulated model

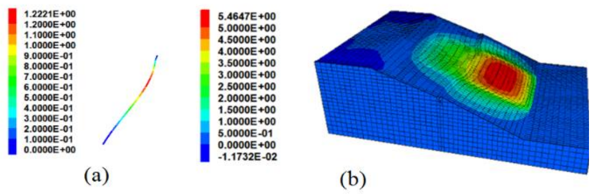


Fig. 4. The displacement of (a) the pipe and (b) the slope (in meters)

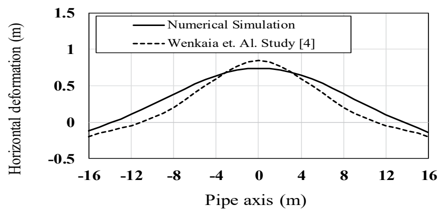


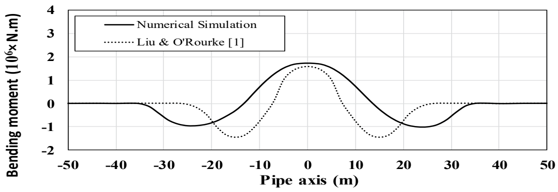
Fig. 5. Horizontal deformation axis the pipe

The Mohr-Coulomb model has been used to simulate soil behavior. Soil parameters are considered in the PGD area and outside of the PGD, as shown in Table 4. The buried pipe is considered steel and L245NB type with a yield stress of 245 MPa.

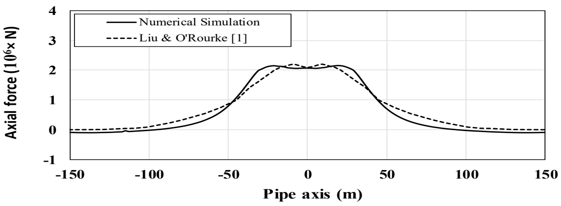
3. RESULTS AND DISCUSSION

The simulation results of FLAC model are compared with the beam-spring method by Liu and O'Rourke [1]. According to Figure 4, the maximum displacement of the ground and pipe occurred at the center of the model, the amount of soil displacement decreases and this value reaches zero in the margin of the model.

Figure 5 shows the horizontal displacements of the pipe during the numerical simulation of the present study with



(a)



(b)

Fig. 6. The distribution (a) the bending moment (Mz) and (b) the axial force (Fx) along the pipe for δ = δcr

the field study of Wenkaia et al. [4]. In both methods, the horizontal displacement of the maximum of the pipe in the center of the area occurred.

Figure 6 indicates the distribution of the bending moment and axial force in the pipe for a W=30 m and L_a=200 m compared with the beam-spring method by Liu and O'Rourke [1]. According to Figure 5, the bending moment and axial force along the pipe and for both numerical methods are symmetric to the center of the PGD region.

4. CONCLUSIONS

The most important results are:

1. The maximum displacement, bending moment and axial force of the ground and the pipe occurs at the center of the PGD region and reaches zero in the margins.

2. By increasing the displacement of the ground, the maximum strain of the pipe is linearly increased, where the critical deformation is changed, the maximum strain of the pipe remains constant.

3. By increasing the diameter or thickness of the pipe, the pipe deformation decreases and the displacements, strains and tensions created in the pipe can be reduced to some extent and the pipes are retrofitted against transverse PGD.

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