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Determining the appropriate dimensional and behavioral model for numerical modeling of the buried pipelines crossing strike-slip faults

M. R. Radaei*, M. H. Erami
Civil Engineering Department, Tehran North Branch, Islamic Azad University, Tehran, Iran

ABSTRACT: In recent decades, due to the increasing use of pipelines to transport a variety of fluids, the need to analyze and evaluate these lines at the crossing faults has increased. In this regard, many numerical studies have been carried out on buried pipes crossing faults. In most models used in previous researches, the selected characteristics for creating models were based on researchers' experiences. Therefore, naturally, the numerical results obtained from the FE analysis can be non-economic or erroneous. On the other hand, common regulations and standards for designing pipelines require special conditions and criteria in this field. Therefore, in this study, based on the existing bylaws in this field, the effect of selective pipe length and soil behavioral model on the accuracy of ABAQUS model results has been investigated. In this regard, first, the results of six models of buried steel pipeline with two different lengths and other similar conditions and then under other same and purely different conditions in terms of soil behavior model, the response of the buried pipeline crossing strike-slip fault was the basis of comparison. Finally, the review of the results shows that the unanchored length of the pipe is better for simulating the longitudinal dimension of the pipeline. Also, the behavioral model of CAP plasticity was selected as a suitable model to simulate soil behavior due to the approximation of the results with the relations of the regulations.

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1- Introduction

The behavior of buried pipelines in the face of faults was first investigated by Newmark and Hall in 1975 [1]. In the recent decade, Vazouras et al. parametrically simulated the behavior of pipelines crossing strike-slip faults using the finite element method. In their study, the pipe length for finite element analysis was considered 60 m and the Mohr-Coulomb behavioral model for soil was considered [2]. In 2015, Trifonov used the Drucker-Prager behavioral model for soil and a 50-meter pipe sample to analyze pipe stress and strain [3]. Shadabfar et al. used the Drucker-Prager model and a length 300 meters of pipe length in their modeling [4]. Finally, in 2020, Sandip et al. chose a length of 13.2 m for the pipe sample and the Mohr-Coulomb model for the soil [5], Melissianos et al. also chose a pipe length of 1500 meters in their finite element modeling [6]. As mentioned, in all the above researches, different lengths and soil behavior model have been used for modeling pipes and soil, which is based more on the use of trial and error and the experience of researchers. Also, during previous researches on the behavior of the pipeline crossing fault (after Vazouras), merely in order to reduce the computational volume and shorten the analysis time, selecting the length of the pipeline in proportion to the diameter of the pipe (e.g., 60 times the diameter of the pipe) has been very common. In other words, the selection of specifications to model these lines in previous research has no scientific support and has been done only for simplification. Therefore, naturally, the numerical results obtained from the finite element analysis can be conservative or erroneous. On the other hand, common regulations and standards for the design of pipelines as the main references, require special conditions and rules in this regard. For example, the use of unanchored pipe length for design and modeling is recommended to designers in this industry. As a result, it should be specified that the appropriate length to simulate the behavior of the pipe in the finite element analysis is the unanchored length or other cases. For this purpose, and considering the multiplicity of pipe modeling cases and the importance of executive analysis in transmission line projects, it is necessary to investigate and resolve the ambiguity in selecting the appropriate dimensional and behavioral model specifications for modeling steel pipes. Therefore, in the present study, we determine the appropriate length of the pipeline and soil behavioral model for modeling with the help of standard relationships.

*Corresponding author's email: m.r.radaei@iau-tnb.ac.ir

Table 1. Average standard pipe strain and the average strain in a ABAQUS model

No	Outside diameter(inch)	Pipe length(m)	Average strain in the pipe on standards (Eq 2)	Average finite element strain
1	30	45.72	0.01551	0.00110
2		181.63	0.00380	0.00332
3	42	64.02	0.01103	0.00191
4		281.51	0.00240	0.00267
5	56	85.32	0.00829	0.00074
6		322.49	0.00219	0.00135

Table 2. Comparison of strain obtained from numerical analysis and regulations (Eq2) for different plasticity behavior of soil

No	Outside diameter(inch)	Pipe length(m)	Average strain in the pipe on standards (Eq 2)	soil behavior model	Average finite element strain
7	30	181.63	0.00380	Mohr-Coulomb	0.00095
				Drucker-Prager	0.00762
				CAP	0.00393
8	42	281.51	0.00240	Mohr-Coulomb	0.00068
				Drucker-Prager	0.00515
				CAP	0.0030
9	56	322.49	0.00219	Mohr-Coulomb	0.00043
				Drucker-Prager	0.00470
				CAP	0.00285

2- Design Criteria and Required Definitions

Common pipeline industry standards such as ALA [7] and ASME [8] suggest the length of the pipe for any modeling or design according to Equation 1, to consider the effect of anchor points on the pipe design.

$$L_a = \frac{\pi D t_p E_p \varepsilon_y}{T_u} \tag{1}$$

To investigate the behavior of the pipe due to the fault phenomenon, according to the type of fault, Equation 2 has been presented to calculate the strain of the pipe.

$$\varepsilon = 2\left[\frac{\delta_{fax-design}}{2L_a} + \frac{1}{2}\left(\frac{\delta_{ftr-design}}{2L_a}\right)^2\right] \tag{2}$$

3- Method of Modeling

To conduct this research, first 6 pipe models in diameters of 30, 42 and 56 inches were made under the same conditions and only differ in terms of pipe length in ABAQUS [9]. The length of 3 models was 60 times the diameter of the pipe and the length of the other 3 models was selected equal to the unanchored length of the pipe (obtained from Equation 1). After performing the analysis, the average strain obtained from the numerical analysis for these 6 models was compared with the average strain obtained from Equation 2. As a result, the model whose strain is closer to the Equation 2 strain is selected as the most optimal mode for modeling the longitudinal dimension of the pipe. In the next step and to determine the most appropriate soil behavioral model for simulation, each model with 3 common soil behavioral models, Mohr-Coulomb, Drucker-Prager and CAP in ABAQUS was modeled. In these models, under other conditions of the same and only different in terms of how to model soil behavior, the response obtained from the FE analysis was again compared with the regulatory values (Equation 2) and the best model to simulate the backfill sand soil was selected.

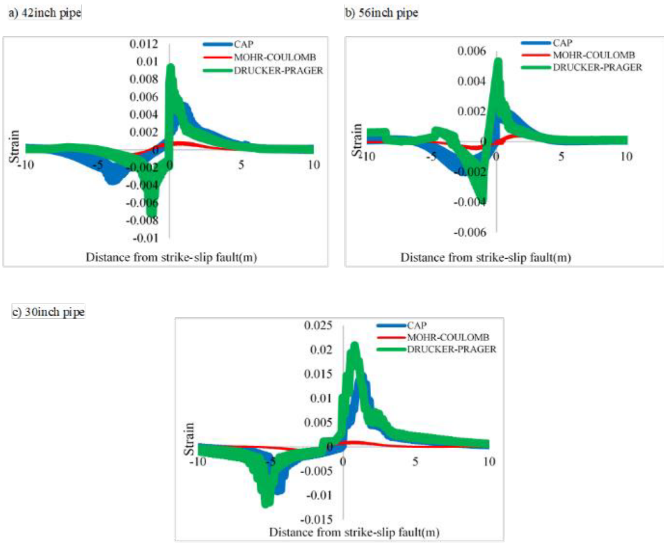

Fig. 1. Pipe strains for different plasticity behavior of soil obtained from FE analysis

4- Results and Discussion

In general, the larger the length of the pipe, the lower the maximum amount of strain in the pipe due to the movement of the fault (in the same displacement) [10]. According to the standards strains obtained in Table 1, this trend is also true for the average strain of the pipe at the fault location. In the strains obtained from numerical analysis, however, this trend is not established, i.e., with increasing the length of the model, the average strain value increases. As shown in Table 1, the average strain results of the model with an unanchored length are close to the mean strain obtained from the regulation (Equation 2) and therefore, the unanchored length of the pipeline is selected as the appropriate length for modeling the longitudinal dimension of the pipe.

The diagram in Figure 1 shows the strain that occurred for the models made in the ABAQUS in this case. Also, the results of calculating the strain of numerical analysis and the strain obtained from Equation 2 for all three modes of soil behavior model are presented in Table 2.

Considering the appropriate approximation of the results obtained from the CAP behavioral model in comparison with the results obtained from the regulatory relations, this behavioral model is introduced to properly simulate the behavior of backfill sand soil.

5- Conclusion

This study was conducted to select the appropriate pipe length and soil behavioral model for modeling. In this regard, by using the criteria in common standards as well as numerical modeling and comparing numerical results with the relationships of regulations, the following result was obtained: It was determined that for numerical modeling of pipelines, the unanchored length for the longitudinal dimension of the pipe sample should be used and selecting the length of the pipeline in proportion to the diameter of the pipe (for example, equivalent to 60 times the diameter of the pipe) or other experimental values, although they reduce the volume of calculations and analysis time, but have no scientific basis and the results are not accurate enough. Therefore, it is worthwhile for researchers in this field to use the unanchored length, which is also mentioned in most regulations. There are various behavioral models to simulate soil behavior. By conducting this research, according to the regulatory relations, it was determined that the CAP model is the most appropriate model for simulating backfill sand behavior.

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