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# A new finite element model of buried steel pipelines crossing strike-slip faults considering equivalent boundary springs

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ABSTRACT

A new finite element model considering equivalent boundary springs was proposed to analyze the displacement and strain of the pipeline under strike-slip faults. The purpose of introducing equivalent boundary springs was to simulate the interaction of the pipeline-soil more sufficiently, because the dimension of current models was far smaller than the actual one of the interaction of the pipeline-soil. Subsequently, a closed-form solution was derived to obtain the stiffness coefficient of equivalent boundary springs. Besides, a contact model was used in the new finite element model. The proposed model was verified through the comparison of the obtained solutions to the results of a referred model with an exact solution, with minor deviations which do not exceed about 4.34%. Meanwhile, the effects of fault displacements, kinetic friction coefficients, fault slip modes and constraint conditions of pipeline ends on the displacement and strain of pipelines were investigated. The results show that local buckling occurs more easily under smaller fault displacements, while the tensile failure tends to occur under larger fault displacements. Also, larger kinetic friction coefficients are beneficial for pipeline safety, and constraint conditions of pipeline ends have a large effect on the displacement and strain of pipelines.


## 1. Introduction

At present, a substantial amount of gas-main pipelines are laid in the areas of high seismic risk, which brings the safety evaluation of buried steel pipelines at active fault crossings to be one of the most important engineering problems [1,2]. Up to now, two kinds of approaches are developed to address the pipeline behavior under strike-slip faults, including analytical methods and finite element methods. The initial analytical method was proposed by Newmark and Hall [3] and further developed in the works [4–8].

Although analytical methods can provide an approximate and fast solution, finite element models can give a more comprehensive and rigorous analysis for this problem. Takada et al. [9] used the shell model to simulate the pipeline behavior subjecting to the large fault movement. Liu et al. [10,11] developed a shell finite element model to evaluate the mechanical response of pipelines crossing the active fault. Kokavessis and Anagnostidis [12] conducted a finite element analysis of the buried pipeline crossing the strike-slip fault, where the contact element was used to simulate the interaction of the pipeline-soil. Liu et al. [13] carried out a numerical analysis to predict the axial strain and displacement of buried pipelines crossing the active fault. Abdoun et al. [14] established a finite element model to investigate the effect of different parameters on the pipeline strain under the active fault. Paolucci et al. [15] proposed a numerical model to analyze the pipeline responses under the seismic fault based on the minimization of the total dissipated energy. Vazouras et al. [16] established a finite element model of pipelines crossing the fault, mainly discussing the effects of different parameters on the axial strain and displacement of the pipeline. Joshi et al. [17] proposed a finite element model to analyze the strain and stress of pipelines under the reverse fault movement, where the pipeline was simulated as beam elements and the soil was simulated as springs along axial, transverse horizontal and transverse vertical directions. Vazouras et al. [18] proposed a practical formula of the critical compressive strain based on the finite element results, to evaluate local buckling of pipelines under the fault movement. Chaudhari et al. [19] established a finite element model to analyze the mechanical performance of the buried pipeline crossing the active fault zone, taking the material non-linearity and large deformation into account. Zhang et al. [20] proposed a numerical model to analyze the local buckling of pipelines under the strike-slip fault in soil mass layer and rock mass layer, and discussed the effects of different parameters on the tensile and compressive strains. Vazouras et al. [21] analyzed the pipeline behavior of pipelines under the strike-slip

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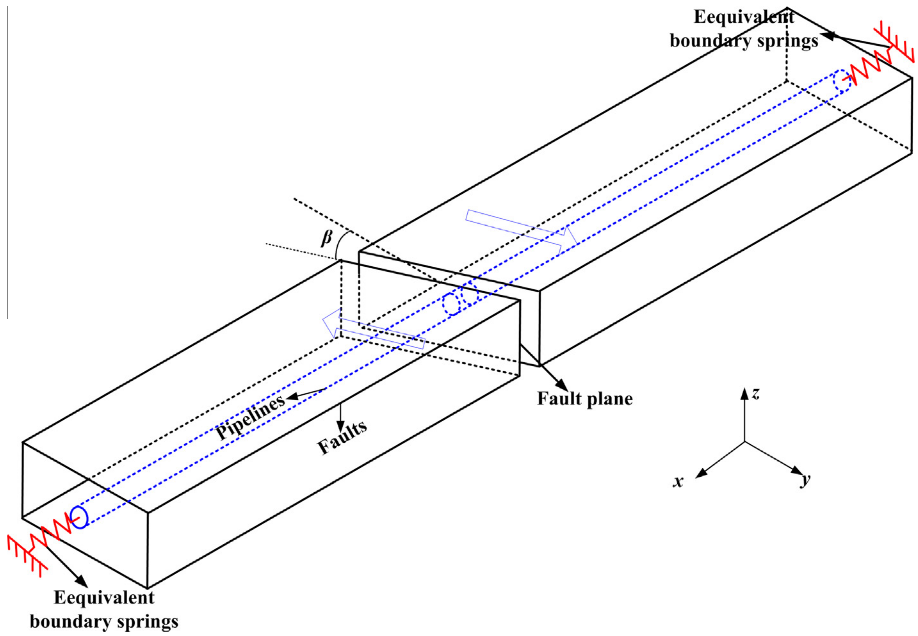


**Fig. 1.** Analysis model for pipelines crossing strike-slip faults.

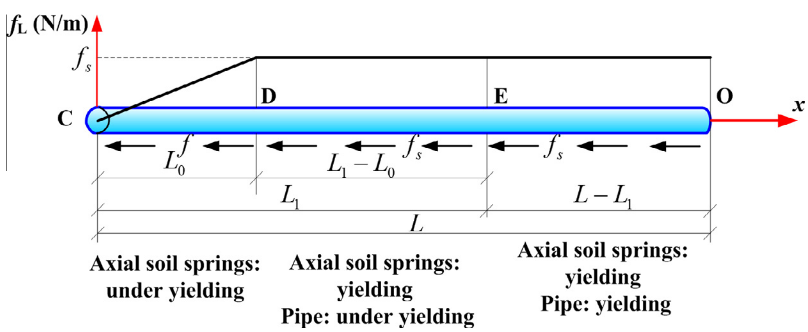


**Fig. 2.** Pipeline-soil interaction of buried pipelines.

**Table 1**
Mechanical properties of API5L-X70 steel used in the finite element analysis.

| Mechanical properties of X70 steel | Values |
|---|---|
| Yield stress ($\sigma_1$) | 485 MPa |
| Failure stress ($\sigma_2$) | 550 MPa |
| Failure strain ($\varepsilon_2$) | 3.0% |
| Elastic Young's modulus ($E_1$) | 210.00 GPa |
| Yield strain ($\varepsilon_1$) | 0.23% |
| Plastic Young's modulus ($E_2$) | 2346.57 MPa |

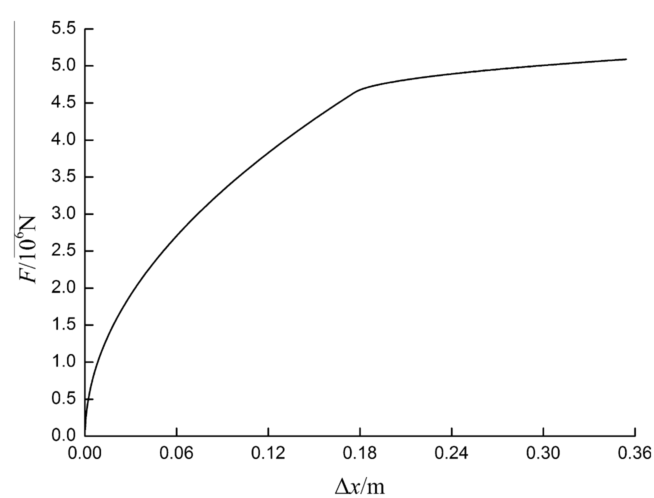


**Fig. 3.** The force–displacement relation of equivalent boundary springs.

fault using a refined finite element model that contains the detailed numerical model and the mathematical model. Uckan et al. [22] proposed a simple finite element model to deal with the response of pipelines crossing the strike-slip fault.

Although important improvements have been achieved using finite element models above, an obvious shortcoming was still mentioned, i.e., almost all the models developed are assumed the fixed constraint at the pipeline two ends, which is different to the actual condition. Taking the current models as examples, the pipeline length was commonly equal to 60 times of pipeline diameters, but the length is far smaller than the one of the interaction of the pipeline-soil, which means that the displacement still exists at the pipeline ends. In such case, the fixed constraint is not fully accurate, because it neglects the interaction of the pipeline-soil beyond the model. To overcome the shortcoming, Liu et al. [10] proposed an equivalent-boundary method to examine the mechan-