

Preliminary Study on the Pipeline Buckling Under Thrust Faulting Using the Coupled DEM-FDM Method

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Abstract: This study aims to clarify the development of pipeline buckling during thrust faulting. Based on the coupled discrete element method (DEM) and finite difference method (FDM), the sandbox modeling shows that the cross-sectional flattening coefficient and strain increment distribution can quantitatively identify the geometry and location of the buckled pipeline, respectively. The influence of pipeline existence on the ground surface deformation was also investigated.

Keywords: Coupled DEM-FDM method, Pipeline buckling, Thrust faulting, Flattening coefficient, Strain increment.

Introduction

In 1999, the Chi-Chi earthquake damaged the Shigang Dam, and the associated pipelines were also severely affected by the fault displacement. The numerical approaches, such as the finite element method (FEM), have been adopted to investigate the pipeline performance, especially the pipeline buckling issue (e.g., Zhong et al., 2025). Moreover, the DEM method, which can capture porosity change in granular material and large deformation of the structure element, is growing rapidly in studying structure-soil-faulting interaction problems (e.g., Lin et al., 2021). This study is intended to serve as a preliminary study for evaluating pipe performance under fault movement using coupled DEM-FDM analysis.

Numerical model description

This study used PFC3D and FLAC3D as the DEM and FDM solvers. The coupling calculation logic between DEM and FDM involves using wall elements to update and transfer contact forces between the PFC spherical particles and the FLAC continuum model.

As shown in Figure 1, the dimension of the sandbox model is 3 m x 0.2 m x 0.4 m. The pipeline was buried with overburden sand 0.27 m, and the pipe direction is orthogonal to the fault plane. The thrust fault dips at 30 degrees. To simulate the fault displacement, the hanging wall was displaced quasi-statically with an offset ratio ($\Delta H/H$) of 1/15 for one stage. The simulation stops when the total displacement reaches 0.09 m.

Table 1 shows the parameters of the coupled DEM-FDM model. The parameters were calibrated against the results of laboratory sandbox tests in previous research. It is noted that the soil and pipe used in this study were characterized as dry sand and PE Pipe.

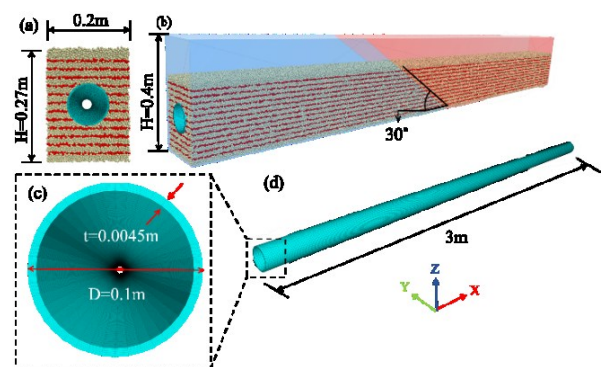


Figure 1, Setting of the numerical sandbox model.

Table 1, Parameters used in the numerical model.

Particles in DEM model	Value	Unit
Radius	0.25~0.3	cm
Density	2650	kg/m ³
Young's modules	1.5x10 ⁶	Pa
Stiffness ratio	2.0	-
Friction coefficient	0.5	-
Rolling friction coefficient	0.5	-
Pipe in FDM model	Value	Unit
Thickness, t	0.0045	m
Density	30	kg/m ³
Young's modules	2.3x10 ⁸	Pa
Poisson's ratio	0.3	-

Results and discussion

Figure 2 shows the geometry of the pipeline at the end of the thrust faulting. It can be observed that the pipeline deformed heavily at 0.2 m away from the fault tip. Therefore, the following discussions will focus on the

range of 0.3m forward and backward from this deformed area.

Figure 3 shows the pipeline displacement at the end of the thrust faulting. The y-displacement is symmetrical, but the z-displacement has differential displacement, resulting in pipeline flattening along the faulting direction. The flattening parameter f , defined by Vazouras et al. (2015), was calculated to be 0.6, indicating that flattening failure had occurred.

Figure 4 shows the strain increment of the pipeline during the thrust faulting. A "wrinkle" strain distribution pattern appeared at the pipe bottom when the offset ratio $\Delta H/H$ reached 0.317. This pattern is consistent with the strain concentration that Zhong et al. (2025) observed during the buckling initiation stage. The length of the strain increment band was approximately 0.25 m (Figure 4a). The strain increment band gradually shortened because the thrust fault movement continued to compress the pipeline (Figure 4b), eventually concentrating into a narrow strip at a specific location (Figure 4c).

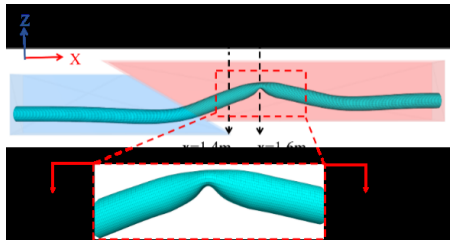


Figure 2, Pipeline geometry after thrust faulting.

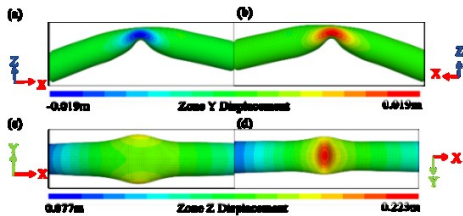


Figure 3, Pipeline displacement after thrust faulting.

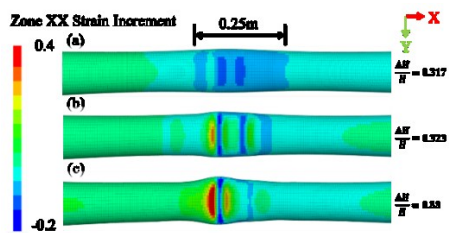


Figure 4, Pipeline strain increment during thrust faulting.

By performing curve fitting for the particle displacements on the ground surface, the fault-affected width can be precisely defined (Chang et al., 2015; Figures 5 and 6). We observed that the presence of the pipeline induced greater ground surface deformation, primarily localized around the buckling cross-section. Consequently, the resulting surface deformation profile deviated from the bell-shaped curve characterized by the pure soil model.

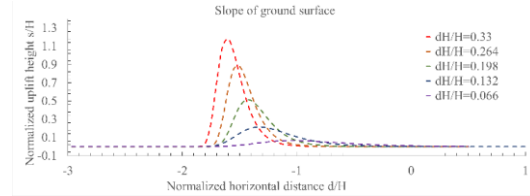


Figure 5, Slope of the ground surface without a pipeline.

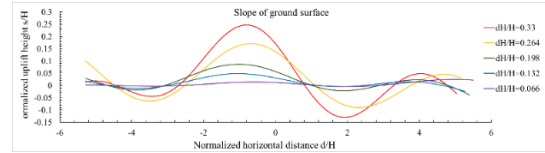


Figure 6, Slope of the ground surface with the pipeline.

Concluding remarks

- Localized buckling deformation was observed in the pipeline at approximately 0.2 m from the fault tip. This deformation caused the pipe cross-section to flatten, indicated by a flattening ratio f of 0.6.
- A strain increment band approximately 0.25 m long initiated at an offset ratio of 0.317. The pipeline’s radial compressive strain intensified, forming a narrow, localized concentration zone.
- The fault-affected width was defined using curve fitting, revealing that pipe presence caused localized uplift and non-bell-shaped surface deformation.

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