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Fragility Functions of Buried Steel Natural Gas Pipelines Exposed to Landslide Displacements

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Extended Abstract

Pipeline systems constitute an indispensable type of infrastructure due to their vital function in transporting essential resources, including gas, water, and data. Given their widespread nature, pipeline systems may cross unstable slopes, thereby exposing them to potential deformations caused by slope movements.

Deformations in pipeline systems triggered by slope movements can reach critical levels, ultimately leading to pipeline failures. Enhancing the resilience of these systems against slope displacements requires proper assessment of the displacements magnitude, as well as of the vulnerability of the pipelines affected.

This study presents a 3D finite element model of pipe–trench systems developed using Plaxis 3D, following Tsinidis et al. [1]. The study aims at analysing comprehensively the impact of landslide-induced deformations on the axial behaviour of pipelines, including potential buckling phenomena. The final target is the development of analytical fragility functions for assessment of pipelines against landslide-induced deformations.

Solid elements are used to simulate the backfill, while plate elements are employed to simulate the pipeline structure. A linear elastic model is utilized to represent the backfill behavior surrounding the pipeline, whereas for the pipeline a linear elastic-perfectly plastic material is utilized. To account for the pipeline's continuity, Tsinidis et al. [1] incorporated nonlinear springs at both ends of the pipeline. Due to the limitations of Plaxis 3D, these springs were modeled using a soil material with properties that replicate the response of the original springs.

The model provides a detailed simulation of localized buckling modes and captures the contact interactions between the pipeline and the surrounding backfill. This is particularly important as the shear behaviour at the backfill-pipe interface plays a crucial role in determining the magnitude of shear stresses transmitted along the pipeline's perimeter during loading. The integration of these shear stresses offers a comprehensive assessment of the axial loading experienced by the pipeline.

Key factors influencing the vulnerability of buried steel natural gas pipelines, including pipeline diameter, wall thickness, burial depth, internal pressure, backfill compaction level, pipe–soil interface friction properties, and the characteristics of surrounding backfill, are systematically examined.

Eventually, analytical fragility functions are developed based on differential permanent ground deformation. The pipeline material is modelled as linear elastic-perfectly plastic, meaning that it does not exhibit strain hardening beyond the yield point. As a result, the limit state for pipeline failure is defined by the onset of buckling, which corresponds to the yielding strain. This assumption provides a conservative estimate of the pipeline's structural integrity under landslide-induced displacements, as any strain exceeding the yield point is considered indicative of structural failure.

References

[1] G. Tsinidis, L. Di Sarno, A. Sextos, and P. Furtner, “Seismic fragility of buried steel natural gas pipelines due to axial compression at geotechnical discontinuities,” *Bulletin of Earthquake Engineering*, vol. 18, no. 3, pp. 837–906, Oct. 2019, doi: 10.1007/s10518-019-00736-8.