Longitudinal Seismic Isolation Strategies for Pipelines in Underground Utility Tunnels

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Abstract

The increasing demand for urban infrastructure has driven a significant expansion of underground utility tunnels, which house essential pipelines for water, gas, electricity, and communications. While these tunnels reduce surface disruptions and simplify urban maintenance, they face unique challenges from seismic events due to their underground placement. During earthquakes, soil-structure interactions impose additional forces that directly affect the behavior of the tunnels and the pipelines they contain (1). Past assumptions about the inherent safety of underground structures have been challenged by significant damage observed in recent seismic events, such as the 1995 Kobe earthquake, where underground systems, including pipelines, suffered failures ranging from buckling to tensile rupture (2). Existing research has primarily addressed the seismic behavior of tunnels as standalone structures, often neglecting the complex dynamics affecting internal pipelines, which differ in material properties and functions. The damage or failure of these pipelines can disrupt critical services, emphasizing the need for targeted protection strategies. Developing tailored solutions for pipeline seismic isolation within utility tunnels is crucial for maintaining functionality and ensuring public safety.

This work addresses the issue of vibration isolation for pipelines within utility tunnels, with a particular focus on isolation in the longitudinal direction of the tunnel (2). To tackle this problem, appropriate coupled one-dimensional models were developed to represent the interaction between the tunnel and the pipelines inside it, with the goal of evaluating the forces exchanged between the two structures. Special attention was given to the impact of different soil types on the pipelines' response. Following the analysis of the unprotected system's response, a vibration protection strategy based on seismic isolation techniques was proposed. This strategy combines hysteretic tuned mass dampers and impact oscillators with the pipelines to reduce the displacement demand on the isolated structure.

A significant emphasis was placed on studying the nonlinear dynamics of the system, exploring how coupling the isolated pipelines with nonlinear oscillators can beneficially reduce displacement demand. Finally, the proposed model was effectively validated against more refined finite element models, where the tunnel and pipelines were modeled as 3D assemblies of plates and one-dimensional elements. This validation confirmed the effectiveness of the seismic isolation techniques, thereby enhancing the resilience of pipelines housed in utility tunnels.

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References

(1) Hashash, Y. M., Hook, J. J., Schmidt, B., John, I., & Yao, C. (2001). Seismic design and analysis of underground structures. *Tunnelling and underground space technology*, *16*(4), 247-293.
(2) Huang, D., Zong, Z., Tang, A., Huang, Z., & Liu, Q. (2022). Dynamic response and vibration isolation of pipes inside a utility tunnel passing through nonhomogeneous soil under seismic action. *Soil Dynamics and Earthquake Engineering*, *163*, 107522.