Transverse seismic isolation of pipelines in underground utility tunnels for enhanced earthquake protection

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Abstract

The expansion of underground utility tunnels plays a vital role in consolidating essential infrastructure, such as water, gas, electricity, and communication pipelines, into centralized networks. This approach minimizes surface-level disruptions and facilitates easier maintenance, particularly in densely populated urban environments. Traditionally, underground structures were assumed to be inherently safer than their above-ground counterparts, but events like the 1995 Kobe earthquake have challenged this belief. Damage to underground tunnels and their internal systems during such seismic events has highlighted the need for more focused research into the vulnerabilities of these structures. While the resilience of tunnels themselves has been thoroughly investigated, studies addressing the seismic protection of the internal pipelines remain comparatively scarce.

Earthquakes pose significant risks to pipelines within utility tunnels through two primary mechanisms. The first mechanism involves longitudinal seismic effects, where forces act along the pipeline's length, as noted in previous research (1). The second mechanism involves transverse seismic effects, where seismic forces act perpendicular to the pipeline's length (2). This study concentrates on the latter, with a specific focus on vibration isolation strategies that enhance the transverse seismic resilience of pipelines housed within utility tunnels.

A simplified mechanical model is utilized to simulate the interaction between the tunnel and its contents under transverse seismic excitation. To streamline the analysis, the tunnel is modeled as infinitely long, limiting the investigation to a single representative cross-sectional plane. The tunnel's cross-section is assumed to be rigid, with its motion described by three displacement parameters: two translational and one rotational. The surrounding soil is treated as a compressive-only medium, reflecting its inability to sustain tensile forces.

Within the tunnel, the pipelines are mounted on an internal frame, also assumed to be rigid. This frame is connected to the tunnel via flexible connectors that permit only horizontal motion. As a result, the internal frame-pipeline system introduces an additional degree of freedom, requiring one more displacement parameter. To mitigate seismic impacts, a hysteretic mass damper, modeled as a one-dimensional mechanical system, is attached to the internal frame. This damper is designed to limit horizontal displacement between the

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internal frame and the tunnel, thereby enhancing the behaviour of the system. Overall, the mechanical model representing the tunnel-content system is five-dimensional, encompassing the combined dynamics of the tunnel, internal frame, and damper.

A comprehensive parametric study was conducted, utilizing various recorded earthquake excitations to assess the system's response. Absolute acceleration measurements were taken at critical points within the tunnel, both with and without the implementation of internal isolation mechanisms.

The results underscored the efficacy of the internal isolation strategy. Moreover, they demonstrated that the use of a nonlinear hysteretic mass damper significantly reduced the horizontal displacement of the internal frame structure. Further research into the optimization of damper characteristics could yield even greater resilience against seismic events.

This study contributes valuable insights into the field of seismic protection for underground utility tunnels, emphasizing the importance of considering the dynamic behavior of internal pipelines. It underscores the need for innovative isolation strategies to safeguard critical infrastructure in seismically active regions, paving the way for more robust and resilient urban utility networks.

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