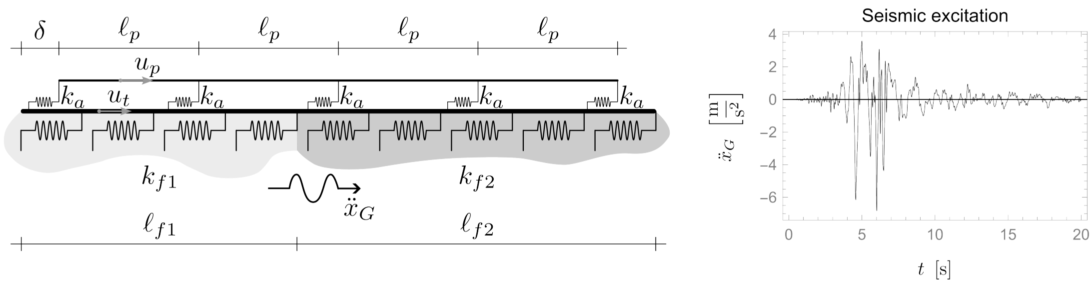
Longitudinal Seismic Vibration Protection of Pipelines in Underground Utility Tunnels

Manuel Ferretti[*], Lorenzo Mancini[*] and Angelo Di Egidio[*]
[*] *University of L'Aquila*

Abstract. This study explores vibration isolation for pipelines in utility tunnels, focusing on longitudinal vibrations. Coupled 1D models analyzed tunnel-pipeline interactions, accounting for soil types. A seismic isolation strategy using hysteretic tuned mass dampers and impact oscillators was proposed, effectively reducing displacement demands. Nonlinear dynamics demonstrated the benefits of coupling pipelines with nonlinear oscillators, validated against finite element models.

Introduction

The growing demand for urban infrastructure has led to the expansion of underground utility tunnels, which house essential pipelines like water, gas, electricity, and communication lines. Centralizing these systems reduces surface disruptions and eases maintenance. Although first introduced in Paris in 1832, utility tunnels have seen rapid global growth, particularly in dense urban areas. Being underground, these tunnels are affected by soil dynamics during seismic events, where soil movements directly impact the tunnel and its contents [1]. Major earthquakes, such as the 1995 Kobe earthquake, have shown that underground systems can suffer extensive damage, affecting not only the tunnel structure but also internal pipelines, which may buckle, fail under tension, or displace, compromising functionality and raising repair costs [2]. This highlighted the need for a specialized seismic design, particularly for internal pipelines. While much research addresses tunnel structures, the seismic response of internal pipelines remains understudied. As pipelines carrying water, gas, and other essential utilities are subjected to seismic vibrations, their structural integrity and stability are at risk, potentially disrupting service and requiring costly repairs. Consequently, there is a need for comprehensive research into vibration mitigation methods and design solutions specifically tailored to protect pipelines within utility tunnels from seismic impacts, ensuring uninterrupted service and public safety. This study addresses vibration isolation for pipelines within utility tunnels, with a focus on longitudinal isolation. Coupled one-dimensional models (Fig. 1a) were developed to represent tunnel-pipeline interactions, aiming to evaluate the forces exchanged under seismic excitation (Fig. 1b) and to analyze the impact of soil types on pipeline response.



(**a**) (**b**)

Figure 1: (a) 1D longitudinal model of the tunnel/pipeline system; (b) seismic excitation.

Results and Discussion

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. **Acknowledgement.** This work is funded by the European Union - Next Generation EU, Mission 4 Component 2 Investment 1.1, in the framework of the project PRIN 2022 PNRR, "P2022ZT5X5 - Smart Under-Ground Infra-Structures for Secure Communities and Post-Disaster Emergency Response: Eco-Friendly Seismic Protection Solutions" (CUP: E53D2301762 0001, University of L'Aquila).

References

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