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Comparative Time-Frequency Analysis of the Seismic Response of Underwater Rail and Mountain Road Tunnels.

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Extended Abstract

The evaluation of the seismic response expected at road and rail tunnels is a critical factor in ensuring the structural integrity and safety of such critical infrastructures. However, these underground infrastructures are far less investigated than their above-ground counterparts (e.g. bridges and viaducts). Furthermore, it is also much less common to find case studies with fully dynamic monitoring systems; even less in active seismic areas.

The dynamic behaviour of man-made tunnels differs substantially according to several factors such as their design and, most importantly, the different geological conditions. Indeed, tunnels excavated at shallow depths in soft soils are generally expected to be more vulnerable to earthquake loads than those bored through dense soil or hard rock. That derives from the kinematic loading induced by the surrounding materials, with their different stiffnesses and amplification effects, by the depth, and other factors. Nevertheless, few direct comparisons, based on experimental recordings, are available in the current scientific literature; for instance, Cui & Ma [1] tested tunnel portal sections located in the soft-hard rock junctions with laboratory shaking table tests; Tsinidis et al. [2] summarised the main empirical findings for different tunnel typologies and soil characteristics; and Cilingir et al. studied the effects of depth on the seismic response of square [3] and circular [4] tunnels – but only with scaled-down laboratory experiments and numerical simulations.

To shed light on these aspects, the seismic responses of one underwater rail tunnel and two nearby road mountain tunnels to the same seismic event have been investigated. More specifically, the recordings of the Mw=4.4 Berkeley Earthquake of 04 January 2018 aftermaths on the Bay Area Rapid Transit's so-called Transbay Tube (between Oakland and San Francisco, California, USA) and Bore 3 and 4 of the Caldecott tunnel system (between Oakland and the town of Orinda) have been considered. Furthermore, these represent some examples of 'Cut-and-Cover' (Transbay) vs 'Bored' (Caldecott) underground structures, which are known to behave differently under comparable seismic inputs [5]. For completeness' sake, these case studies have also been compared to the response of a nearby above-ground infrastructure, the famous Bay Bridge, to the same earthquake. In particular, the time-frequency analysis and the Arias Intensity build-up curves of selected acceleration time series, captured at key locations near the tunnel portals and at mid-length cross-sections, allowed us to discern similarities and differences in the dynamic response of these above- and below-ground infrastructures.

Based on recent and ongoing studies [6], [7], the results experimentally confirmed, considering a true, real-scale seismic event, the expected hierarchy of seismic resilience. That is to say, both shallow tunnels in soft ground and deep tunnels in hard rock can be considered generally safer than aboveground structures [8], [9], with the latter being even safer, even if never completely earthquake-proof, than the former [10]. These insights will help structural and geotechnical engineers to better address the challenges posed by designing tunnels in soft soils and hard rock capable of withstanding seismic events.

References

[1] G. Cui and J. Ma, "Shaking table test on the seismic response of the portal section in soft and hard rock junction," *Sci Prog*, vol. 104, no. 3, Jul. 2021, doi: 10.1177/00368504211031393.

[2] G.Tsinidis, F. de Silva, I. Anastasopoulos, E. Bilotta, A. Bobet, Y. M.A. Hashash, C. He, G. Kampas, J. Knappett, G. Madabhushii, N. Nikitasj, K. Pitilakisk, F. Silvestri, G. Viggiani, R. Fuentes., "Seismic behaviour of tunnels: From experiments to analysis," *Tunnelling and Underground Space Technology*, vol. 99, p. 103334, May 2020, doi: 10.1016/J.TUST.2020.103334.

[3] U. Cilingir and S. P. G. Madabhushi, “Effect of Depth on the Seismic Response of Square Tunnels,” *Soils and Foundations*, vol. 51, no. 3, pp. 449–457, Jun. 2011, doi: 10.3208/SANDF.51.449.

[4] U. Cilingir and S. P. G. Madabhushi, “Effect of depth on seismic response of circular tunnels,” *Canadian Geotechnical Journal*, vol. 48, no. 1, pp. 117–127, Jan. 2011, doi: 10.1139/T10-047.

[5] G. Lanzano, E. Bilotta, and G. Russo, “Tunnels under seismic loading: a review of damage case histories and protection methods,” in *Strategies for reduction of the seismic risk*, Naples: Publisher StreGa, 2008, pp. 65–75.

[6] M. Dalmasso, M. Civera, V. De Biagi, C. Surace, and B. Chiaia, “A Comparative Analysis of the Seismic Response of a Nearby Tunnel and Bridge,” in *proceedings of the 18th World Conference on Earthquake Engineering (WCEE2024)*, 2024.

[7] M. Dalmasso, M. Civera, and B. Chaia, “The seismic response and resilience of nearby underground infrastructures,” in *IABMAS 2024*, Copenhagen, Jun. 2024.

[8] E. Bilotta, G. Lanzano, S. P. G. Madabhushi, and F. Silvestri, “A numerical Round Robin on tunnels under seismic actions,” *Acta Geotech*, vol. 9, no. 4, pp. 563–579, May 2014, doi: 10.1007/S11440-014-0330-3.

[9] M. Corigliano, L. Scandella, C. G. Lai, and R. Paolucci, “Seismic analysis of deep tunnels in near fault conditions: A case study in Southern Italy,” *Bulletin of Earthquake Engineering*, vol. 9, no. 4, pp. 975–995, Aug. 2011, doi: 10.1007/S10518-011-9249-3.

[10] S. Sharma and W. R. Judd, “Underground opening damage from earthquakes,” *Eng Geol*, vol. 30, no. 3–4, pp. 263–276, Jun. 1991, doi: 10.1016/0013-7952(91)90063-Q.