Response of Bridge Structures subjected to Spatially Varying Earthquake Ground Motions

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Extended Abstract

Earthquake ground motion inevitably varies across the multiple supports of bridge structures. This variation excites certain structural response modes that would not be triggered by uniform ground motion excitation, leading to specific response mechanisms and distinctive damage patterns, as observed in all major earthquakes as shown in Figure 1. Although extensive research has been conducted to model the spatial variability of ground motion and to investigate its effects on bridge responses, significant challenges remain. These include the difficulty of reliably modeling spatial variations in ground motion, the absence of robust methods for design analysis of bridge structures, and a lack of guidance for performing scaled model tests of bridge structures subjected to spatially varying ground motions using multiple shake tables. This talk discusses the current status and challenges in modelling ground motion spatial variations, development of methodologies for reliable and efficient design analysis, and the design of scaled model tests of structures subjected to spatially varying ground motions.

It is widely recognized that ground motion spatial variations are influenced by the seismic source, wave propagation path, and local site conditions. Ground motion time histories are typically treated as realizations of a random process, with spatial variations modeled through a phase shift and a coherency loss, accounting for time delays and reduced cross-correlations between motions at multiple bridge supports due to seismic wave propagation. The spatial phase shift depends on frequency, time, and azimuth, and fluctuates because of numerous uncertainties. At present, no reliable method exists for accurately modeling the phase shift; current practice assumes a constant apparent wave velocity when calculating the spatial time delay.

Similarly, spatial ground motion coherency loss varies significantly, even for ground motions recorded at the same sites from different earthquakes. Although over 100 coherency loss functions have been proposed based on recorded spatial ground motions, there is no reliable guide for selecting an appropriate function for modeling spatial variations. In current research and practice, the coherency loss function is often chosen arbitrarily, which can yield unreliable representations of ground motion spatial variations and lead to inaccurate predictions of structural responses.

To address this issue, we have compiled available coherency loss functions, grouped them by site conditions, and derived the mean and standard deviation coherency loss functions as shown in Figure 2. These provide guidance for selecting coherency loss functions in modeling ground motion spatial variations, specifically, using the mean or the mean plus/minus one standard deviation. This approach enables determination of a statistical range of the effects of coherency loss on ground motion spatial variations and, consequently, on structural responses.

Although most major seismic codes acknowledge the need to account for ground motion spatial variations, only the European Eurocode 8-2, the Algerian RPOA, and the Italian NTC provide specific methods for predicting structural responses to spatially varying ground motions. These methods generally predict structural response in three steps: (i) dynamic response based on the assumption of uniform ground motion, allowing the use of conventional response spectrum and spectral analysis methods; (ii) quasi-static response based on assumed uneven support movements; and (iii) SRSS combination of the dynamic and quasi-static responses to obtain the total response. While these approaches are straightforward to implement in design analysis, they do not necessarily yield accurate predictions of structural response. In this presentation, our recently proposed multiple support response spectrum method will be introduced. Compared to the Eurocode approach, our method provides more accurate structural response predictions, as shown in Figure 3.

In the presentation, a recently developed guide for scaled multiple shake table test procedure will also be briefly introduced.

Unseating damage, Ava bridge 2025 Myanmar earthquake

Pounding damage, Wuxi bridge 1999 Taiwan ChiChi Earthquake

Torsional response, 2010 Chile earthquake

Figure 1. Typical bridge damages associated to spatially varying earthquake ground motions

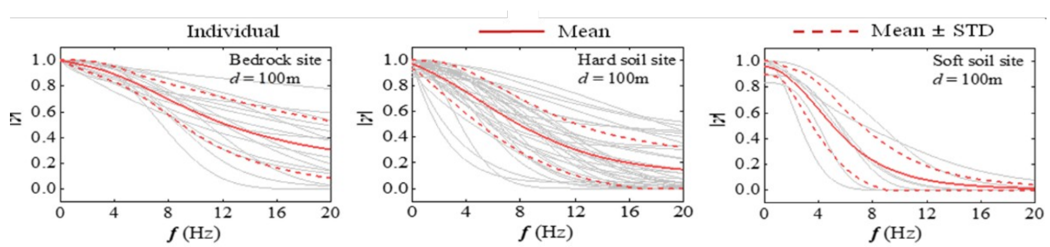
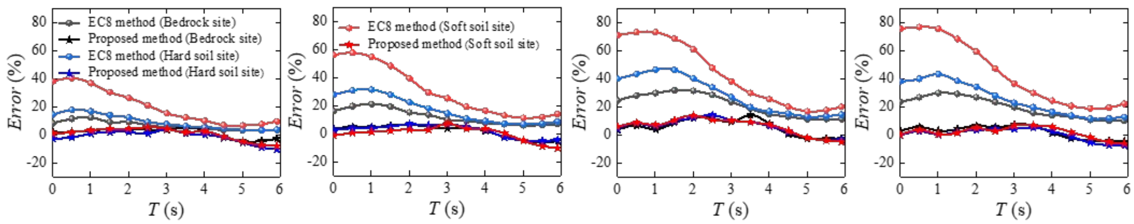


Figure 2. Typical mean and mean ∓ one standard deviation coherency loss for bedrock (Vs≥750 m/s), hard soil (250 m/s<Vs<750 m/s) and soft soil site (Vs≤250 m/s)



(a) 100m-100m-100m-100m-100m (b) 200m-100m-100m-100m-200m (c) 200m-200m-200m-200m-200m (d) 300m-200m-100m-100m-300m

Figure 3. Relative response prediction errors of a four-span bridge using the proposed method and the Eurocode 8-2 method