MULTI-FAULT RUPTURE FOCAL MECHANISM SIMULATION USING SPECTRAL ELEMENT METHOD AND ITS APPLICATION TO SEISMIC ANALYSIS OF A MULTI-SPAN CONTINUOUS HIGHWAY BRIDGE

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Extended Abstract

Multi-fault ruptures occurring at dense fault regions have been recognized as one of the leading causes of strong earthquakes, such as the Mw 7.9 Wenchuan and Mw 7.8 Turkey earthquakes. While the seismic responses of bridges under sequential earthquakes (i.e., mainshock-aftershock sequences) have been extensively studied, the effects of multiple sequential ground motions induced by a multi-fault rupture within a single earthquake remain largely unaddressed. Unlike mainshock-aftershock events that have distinct time intervals allowing structural shaking to subside, multi-fault systems do not release all accumulated strain simultaneously, triggering successive ruptures in a very short timeframe. Current seismic design codes typically consider only single-fault rupture events without explicitly accounting for multi-fault ruptures. This gap in knowledge leaves bridge structures potentially vulnerable, as multiple sequential ground motions may cause severe cumulative damage.

To address this knowledge gap, a systematic numerical investigation was conducted to explore the spatial and temporal distribution of multi-fault rupture-induced ground motions and their impacts on bridge structures. A 3-D homogeneous velocity model with two adjacent vertical strike-slip faults was developed using the spectral element method (SEM) (Figure 1). Parametric analyses were performed to investigate the effects of four key fault-setting parameters: fault-to-fault distance, fault-to-fault angle, horizontal location of the nucleation zone, and initial shear stress on the fault plane. The seismic response sensitivity of a multi-span continuous highway bridge under these generated ground motions was then examined.

What is particularly unique about this study is the identification of distinct characteristics in multiple sequential ground motions and their specific impact mechanisms: (1) ground motions in fault-overlapping regions exhibit obvious multiple acceleration sequences and velocity pulse-like components due to forward directivity effects, leading to a rapid accumulation of energy; and (2) different fault parameters selectively control specific sequences of the ground motion. Specifically, the fault-to-fault distance and angle significantly govern the latter phase of the sequential ground motions, whereas the location of the nucleation zone and initial shear stress primarily dictate the front phase. Such ground motions can significantly amplify the seismic responses of the bridge, increasing damage by 25% compared to traditional single-sequence ground motions.

Based on these observations, this study provides a comprehensive understanding of how multi-fault ruptures aggravate structural damage through energy superposition. The results demonstrate that a small fault-to-fault distance and angle have the potential to cause significantly greater seismic damage, as the structural shaking caused by the front fault rupture often does not subside before the subsequent fault ruptures occur.

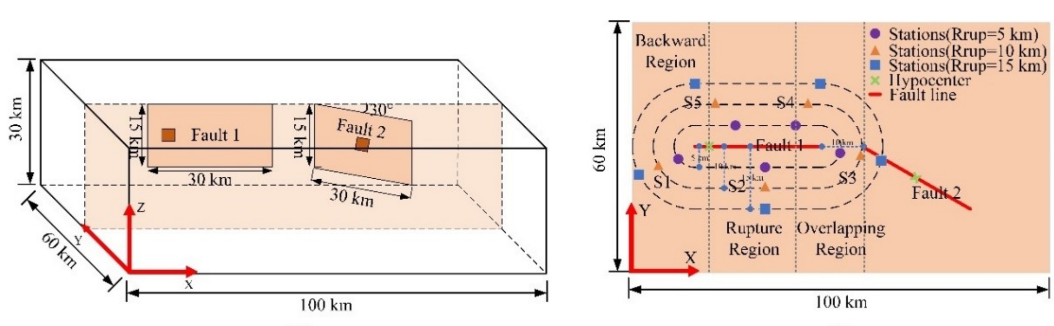

Figure 1- Multi-fault rupture model: (A) A schematic diagram showing the positioning of two vertical strike-slip faults system; (B) The location of each station with different fault distances around Fault 1

The highlights of the dynamic rupture modeling, spatial distribution analysis of seismic waves, parametric sensitivity studies, and structural damage assessments will be presented. The findings offer a crucial foundation for recognizing the potential influence of sequential ground motions, ultimately enhancing the seismic design of highway bridges in dense fault regions.

Keywords: Multi-fault rupture; multiple sequential ground motion; damage index; seismic response sensitivity; parametric analysis.