# VECTOR-VALUED INTENSITY MEASURES FOR PROBABILISTIC SEISMIC DEMAND MODELING OF V-SHAPED PIER BRIDGES UNDER COUPLED HORIZONTAL-VERTICAL GROUND MOTIONS

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***Abstract***

V-pier bridges have been increasingly used in long-span bridge systems because the inclined pier legs can effectively reduce the effective span length and improve the force-transfer mechanism of the superstructure. Owing to this distinctive structural configuration, however, the seismic response of V-pier bridges is strongly affected by the combined action of horizontal and vertical ground motions (GMs). This issue becomes particularly important for performance-based seismic assessment, because the vertical component may significantly alter the force demand and deformation pattern of the piers, bearings, and abutments.

Reliable probabilistic seismic demand models (PSDMs) for these bridges therefore require appropriate intensity measures (IMs) that can properly characterize the combined effects of horizontal and vertical seismic excitations. Conventional scalar IMs are generally insufficient for this purpose, as they describe the ground-motion intensity using only one parameter and may not capture the different contributions of the horizontal and vertical components. In this study, a vector-valued IM framework was adopted to develop planar PSDMs for V-pier bridges subjected to coupled horizontal and vertical GMs.

The study focused on a long-span V-pier bridge, for which nonlinear numerical analyses were performed to establish the seismic demand database. A total of 33 scalar IMs, covering acceleration-, velocity-, displacement-, and duration-related ground-motion characteristics, were selected for both horizontal and vertical components. These scalar IMs were paired to generate 1089 horizontal-vertical vector-valued IM candidates. Planar PSDMs were then developed for key engineering demand parameters (EDPs), including bearing deformation and the curvature ductility demands of the V-pier legs.

A distinct feature of this study is that the candidate vector-valued IMs were evaluated not only using the traditional criteria of efficiency, practicality, proficiency, sufficiency, and relative sufficiency, but also using a newly proposed criterion termed independence. This criterion quantifies the correlation between the two components of vector-valued IM and is used to reduce redundancy in GM characterization. By incorporating independence into the IM evaluation framework, the selected vector-valued IMs are expected to provide both strong predictive capability and complementary information on the horizontal and vertical seismic excitations.

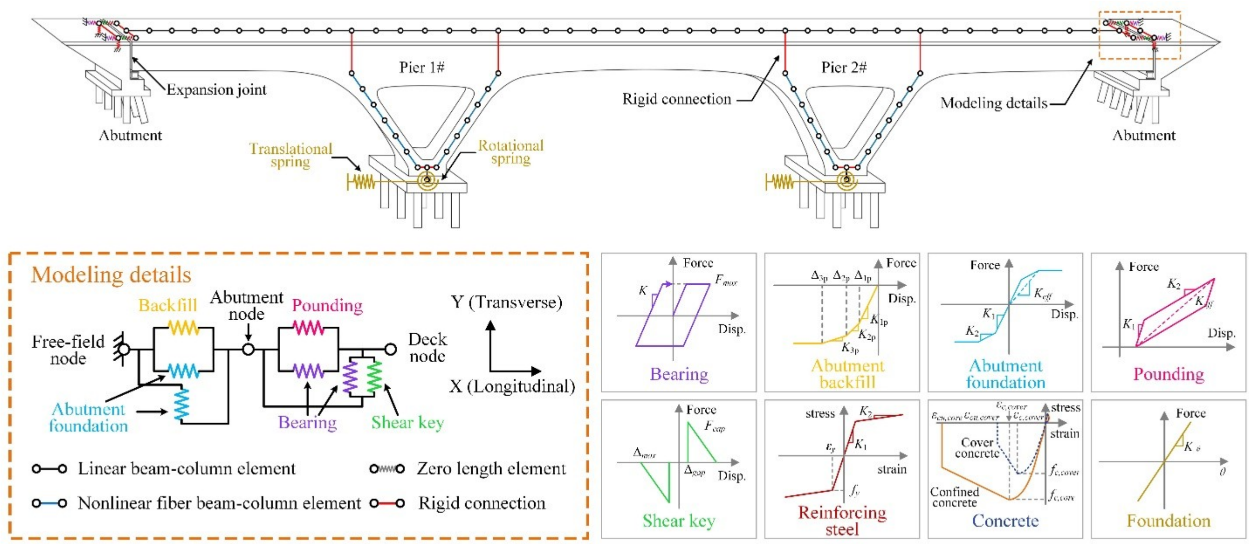


Figure 1- Details of bridge model.

The evaluation results indicate that different bridge components are controlled by different types of ground-motion characteristics. The abutment response is governed primarily by horizontal velocity-related IMs, whereas the seismic demands of the bearings and V-pier legs require vector-valued IMs that combine horizontal structure-specific spectral measures with vertical duration-related parameters. The optimal IMs were identified as [$S_{d-20}$, $VAratio$], [$S_{d-10}$, $SD_{5-75}$], and [$S_{d-20}$, $SD_{5-95}$] for the

bearing, inner V-pier limb, and outer V-pier limb, respectively. The modelling procedure, IM evaluation framework, component-specific ranking results, and implications for performance-based seismic assessment of V-pier bridges will be presented.

***Keywords:*** *V-shaped pier bridges; Coupled horizontal and vertical GMs; Vector-valued IMs; Probabilistic seismic demand model; IM selection; Numerical analysis.*