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Effectiveness of the 30%-rule at predicting the elastic seismic demand on bridge columns subjected to bi-directional earthquake motions

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ABSTRACT

The adequacy of the 30%-rule to predict the seismic demand on bridge columns subjected to bi-directional earthquake components is examined for two North American sites in areas of moderate seismic hazard: Montreal, in the east, and Vancouver, along the west coast. For both sites, historical and simulated ground motion earthquake ensembles are considered. Time history analyses were performed on generic bridge models to determine the critical response of the columns under pairs of orthogonal seismic ground motion time histories. Response spectrum analyses were also carried out to determine the maximum response in each direction and the critical response was estimated using the 30%-rule. The results show that the combination rule is tributary of both ground motion and bridge characteristics. Results also show that the 30%-rule as currently prescribed in codes leads to an adequate estimation of the bi-directional elastic seismic demand on regular bridge columns.

1. Introduction

Ground motions produced by earthquakes can be decomposed into three orthogonal components of translation that act simultaneously, two in the horizontal plane and one in the vertical direction. In modern seismic design codes and regulations, vertical acceleration effects are typically only considered for bridges in the vicinity of active faults [1] or are indirectly accounted for by means of modified load factors on dead loads [2]. Explicit consideration of the effects of two horizontal orthogonal ground motion components is however required in most design specifications. Adequate prediction of the demand on bridge columns under multi-directional earthquake components can be achieved using dynamic time history analysis of the bridge structure: time histories of the various response quantities are obtained by applying simultaneously the two horizontal orthogonal ground motion components that are oriented at various angles with respect to the structure. Such a procedure requires multiple time history analyses making it very lengthy and computationally demanding. Appropriate ground motion pairs are also needed for the analysis.

The response spectrum dynamic analysis method has been established as an efficient and reliable alternative to multiple time history analyses. The basic form of the method gives maximum values of response parameters for individual ground motion orientations. Advanced response-spectrum-based methods have been proposed to predict the critical combination of response quantities relative to a prescribed capacity surface for structural elements whose critical responses depend on the interaction of more than one response quantities, e.g., axial load and biaxial bending moments for bridge columns [3–7]. In these methods, an elliptical envelope is determined that bounds the evolution of multiple response quantities in time. For bridge columns, that envelope is then used to compute the reinforcement ratio required to resist that demand. In the method by Menum and Der Kiureghian [6], the concept of “supreme” envelope is introduced to account for the uncertainty in the orientation of the principal directions of the ground motions with respect to the structure axes. The method has been validated by comparing the results to multi-directional time history analyses [7]. Although based on sound and rigorous principles of random vibration theory, it should be recognized that those advanced methods underlie complex theories and imply cumbersome calculations that are beyond the normal day-to-day practice for design engineering firms, especially for the common case of simple bridge structures. Until they are implemented into commercially available computer analysis programs, designers will continue to use alternative simpler procedures that have gained acceptance in the engineering community for combining the effects of ground motion components.

These simplified approaches include the percentage rule [8,9], the SRSS rule [10], or the CQC3 method [11–13]. Among these

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