DRISI

CALTRANS DIVISION OF RESEARCH, INNOVATION AND SYSTEM INFORMATION

TRANSFORMING IDEAS INTO SOLUTIONS

Research Notes

Stochastic-Based Models for Three Components of Ground Motions for Seismic Design of Structures

Developing and validating stochastic models for three components of synthetic earthquake ground motions to improve seismic design accuracy.

Geotechnical/ Structures

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Project Title: Stochastic-Based Models for Three Components of Ground Motions for Seismic Design of Structures

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WHAT IS THE NEED?

This project aims to develop a comprehensive stochastic model capable of generating all three components of synthetic earthquake ground motions—two horizontal and one vertical—to advance seismic design and analysis. The California Department of Transportation's (Caltrans) current synthetic motion generation method is limited to horizontal components. This project will extend and validate the model using updated earthquake records to accurately represent magnitude, duration, and frequency characteristics essential for realistic seismic simulations.

By integrating the new vertical ground motion model into Caltrans' Risk-Based Seismic Design framework, the project will substantially enhance the accuracy and reliability of bridge performance assessments, particularly for complex and long-span structures. Addressing current modeling limitations and establishing correlations between vertical and horizontal motion data will reduce uncertainty, improve design efficiency, and strengthen Caltrans' ability to ensure structural safety under realistic seismic conditions.

WHAT ARE WE DOING?

The project involves developing a stochastic model for generating vertical earthquake ground motions and validating the existing horizontal component models using updated earthquake records since 2010. This work will enhance Caltrans' synthetic motion generation tool, improving the accuracy and reliability of seismic risk assessments and bridge design, particularly for complex and long-span structures sensitive to vertical motions.

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The scope of work includes four main tasks. First, a literature review will examine existing stochastic modeling methods, Ground Motion Prediction Equations (GMPEs) for vertical components, and horizontal–vertical correlations using the NGA-West2 data. Next, the team will develop and validate synthetic vertical ground motions reflecting recorded spectral characteristics, including high-frequency content and vertical-to-horizontal (V/H) ratios. The horizontal model will be validated against enhanced earthquake databases, and a final report will document the model development, validation process, and recommendations for implementation.

WHAT IS OUR GOAL?

The objective is to develop a method to generate three components of synthetic earthquake ground motions specified by earthquake conditions such as magnitude, duration, and location. This effort includes developing a new stochastic model for the vertical component and validating the effectiveness of the existing model for the two horizontal components by incorporating new ground motion records.

WHAT IS THE BENEFIT?

By developing a comprehensive stochastic model that incorporates both vertical and horizontal earthquake ground motions, Caltrans can improve the accuracy and reliability of seismic risk assessments and bridge design for complex structures, including long-span and seismically isolated bridges. This advancement strengthens public safety, enables more efficient and cost-effective design, reduces uncertainty in structural evaluations, and enhances the overall effectiveness of Caltrans' Risk-Based Seismic Design framework.

WHAT IS THE PROGRESS TO DATE?

The research team is identifying a clear path to improving vertical ground-motion simulation accuracy for Caltrans bridge design. A quantitative bias assessment across 3,243 NGA-West2 records confirmed that the existing stochastic model performs reliably for horizontal components but exhibits systematic prediction errors for vertical motions, particularly at short periods, due to limitations in its single-mode Evolutionary Power Spectral Density (EPSD) formulation. The team is transitioning to a multi-mode time–frequency energy model, with Short-Time Fourier Transform (STFT)-derived EPSDs showing improved capture of multi-peak vertical energy patterns. Model development and calibration will be prioritized, followed by validation against ground-motion databases and GMPEs.