

## GROUND MOTION TASKS IN THE TALL BUILDINGS INITIATIVE

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### ABSTRACT

The Tall Buildings Initiative (TBI) is a major multidisciplinary program coordinated by the Pacific Earthquake Engineering Research Center (PEER) in collaboration with numerous local, state and federal organizations. The goal of TBI is to address critical technical issues on seismic analysis and design of new tall buildings located in coastal California. This paper provides an overview of the TBI tasks on ground motion issues.

### INTRODUCTION

The west coast of the United States is seeing a surge in the design and construction of tall buildings (defined here as buildings 240 feet, 73 meters, or taller). For example, at the time of this writing, there are more than 100 tall buildings under construction or in various planning stages in San Francisco and Los Angeles. Many of these buildings use high-performance materials and framing systems that have not been commonly used for building construction, or that fall outside the height limits, of current buildings codes. Increasingly, nonlinear dynamic analysis is being used in a performance-based design approach to demonstrate the seismic performance of buildings that do not satisfy all the prescriptive provisions of the building code. To carry out such nonlinear dynamic analyses, input ground motions representative of the regional and local seismic hazards are needed.

The Pacific Earthquake Engineering Research Center (PEER) is leading the *Tall Buildings Initiative* (TBI) to coordinate and fund a range of short to intermediate-term projects. The final product will be a set of written guidelines containing principles and specific criteria for tall building seismic design. The document is intended to support ongoing guidelines and code-writing activities of collaborating organizations, as well as being a stand-alone reference for designers of high-rise buildings.

The TBI has formulated projects to address key ground motion issues for analysis of tall buildings. This paper provides an overview of the on-going research on ground motion issues for tall buildings.

### GROUND MOTION TASKS IN TALL BUILDINGS INITIATIVE

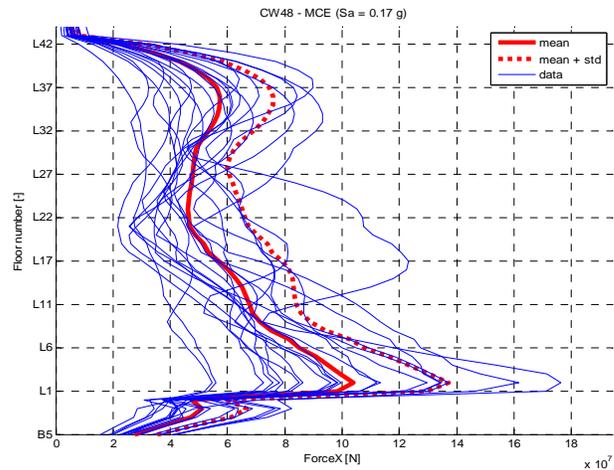
Selection and modification of ground motion time series to represent a specific hazard at a site has a large impact on the results of nonlinear response history analyses using these input motions, indicating the need to establish rational procedures for ground motion selection, scaling and modification. Validated seismological methods may be used to generate ground motion time

series that incorporate near-fault rupture directivity effects and basin effects, and appropriately represent the duration and long period energy content of these large design events.

In the TBI, there are various tasks related to ground motion issues for tall buildings. The related TBI tasks and their progress are summarized below.

**TBI Task 3 – Assessment of ground motion selection and modification procedures**

In this task, comprehensive nonlinear response analyses of realistic tall building computer models are carried out (Moehle, *et al.*, 2007). The models include various reinforced concrete core wall as well as reinforced concrete moment frames. Each building model has its own unique floor dimension and building height. The computer models are subjected to a large number of un-scaled and scaled earthquake ground motions to determine the native statistics of the responses. For example, Figure 1 shows story shears in a building model subjected to numerous ground motions. The results are also compared with those obtained using various proposed Ground Motion Selection & Modification (GMSM) procedures, and recommendation will be made about appropriate GMSM. This task is conducted in coordination with the PEER GMSM program, a separate research program dealing with GMSM for various structural systems.



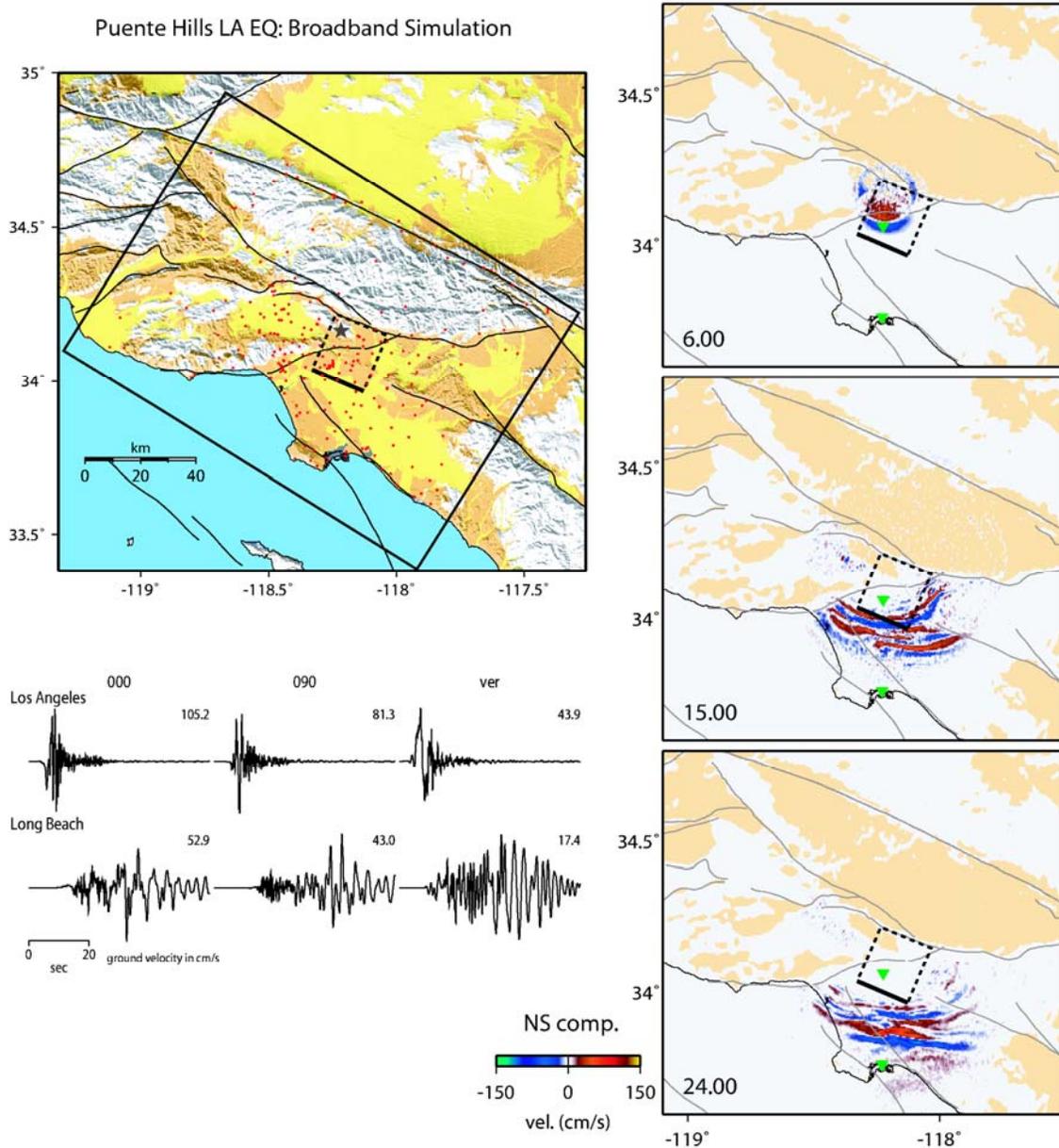
**Figure 1** – Story shears in a case study core-wall building, from nonlinear response history analysis, for ground motions scaled so the first-mode spectral acceleration matches the uniform hazard level value at the MCE hazard level (Moehle, *et al.*, 2007)

**TBI Task 5 - Synthetically generated ground motions**

Using validated broadband ground motion simulation procedures, ground motion time series are being simulated for San Francisco and Los Angeles sites for large earthquakes on the major faults in the region. The time series will be simulated for geographic areas of specific interest in San Francisco and Los Angeles. These simulated broadband time series are to contain long period effects such as rupture directivity effects and basin effects that are specific to the fault geometry and geological structure of the regions.

As an example, Figure 2 shows the results of broadband ground motion simulations (Graves and Somerville, 2006; Bozorgnia, *et al.*, 2007) for a large earthquake occurring on the Puente Hills fault system in Los Angeles (Shaw *et al.*, 2002). The top left side shows a map view of the Los Angeles region indicating the location of one segment of the Puente Hills fault. The right side shows snapshots of the wave field at times of 6, 15, and 24 seconds after the origin time of the earthquake. At 6 seconds, the main feature of the ground motion is the strong rupture directivity pulse, directed updip toward the west-southwest toward downtown Los Angeles from the hypocenter, which is located at the northwest corner near the bottom of the fault plane. The

ground motions are far weaker in other directions around the fault. At 15 seconds, this directivity pulse has propagated into the Los Angeles basin, becoming trapped within the basin and giving rise to large ground motions. This basin effect is progressively accentuated at 24 seconds. The lower set of time histories at the bottom left of Figure 2 shows the long duration and long period nature of these basin waves in Long Beach, in contrast with the much briefer and shorter period motions in downtown Los Angeles caused by the rupture directivity pulse.



**Figure 2.** Snapshots of the simulated ground motion wave field (right) from a scenario earthquake on the Puente Hills Blind Thrust fault shown as a black square (top left). The simulated ground motion velocity waveforms in downtown Los Angeles (green triangle above the fault) and in Long Beach (green triangle on the southern shore) are shown on the bottom right (Graves and Somerville, 2006).

***TBI Task 6 – Review and validation of synthetically generated ground motions***

A review of procedures and results obtained in Task 5 is carried out with the purpose of establishing a validated reference set of synthetically generated broadband ground motions. Working closely with researchers in Task 5, the goal is to ensure that the final results are based on the best available technologies and assumptions, and are properly interpreted. The review will be carried out by both seismologists and engineers.

In this task comprehensive comparisons of the simulated ground motions with the results of Next Generation Attenuation (NGA) are carried out. The NGA models are mainly based on the recorded ground motions (Power, *et al.*, 2008); therefore, this task will reveal the differences between the recorded and simulated ground motions. Example results of NGA model developed by Campbell and Bozorgnia (2007, 2008) are presented in Figure 3.

Elastic and inelastic spectra for thousands of simulated ground motions for the Puente Hills blind Thrust Fault have been computed. The on-going task is to compare the characteristics of these spectra with those of the NGA recorded motions (e.g., as presented in Figure 3). Recently Stewart, *et al.*, (2008) compared characteristics of the simulated ground motions for the Puente Hills scenario and those of the NGA. Figure 4 shows “event terms” for the simulated Puente Hills event (Stewart, *et al.*, 2008). The results are shown for spectral accelerations at several periods ranging from 0.1 to 10 sec. The dashed lines shown in Figure 4 indicate  $\pm$  one inter-event standard deviation. The simulation event terms generally fall within a reasonable range, mostly within one standard deviation (Stewart, *et al.*, 2008). Figure 5 presents the intra-event residual (versus distance) between the Puente Hills simulated ground motions and Campbell & Bozorgnia (2008) NGA empirical model. The figure shows slightly faster distance-attenuation of the simulated data relative to the NGA model (Stewart, *et al.*, 2008). The apparent bias in the distance scaling is much smaller for the Puente Hills event than for a previously investigated large magnitude southern San Andreas fault rupture.

The same process of comparison between simulation motions and NGA models will be repeated for the northern and southern San Andreas Fault and Hayward Fault in California. In addition to the elastic spectra, inelastic response spectra of the NGA database (Bozorgnia, *et al.*, 2006, 2008) will be compared with those of simulated ground motions.

***TBI Task 7 - Guidelines on selection and modification of ground motions for design***

Using findings from Tasks 5 and 6, a team of scientists and engineers will write practical guidelines for the selection and modification of ground motions for analysis of tall buildings. The recommended procedures will be applied to virtual sites in San Francisco and Los Angeles to both demonstrate the procedures and establish a sample set of validated ground motions that can be used in subsequent research or for tall-building design.

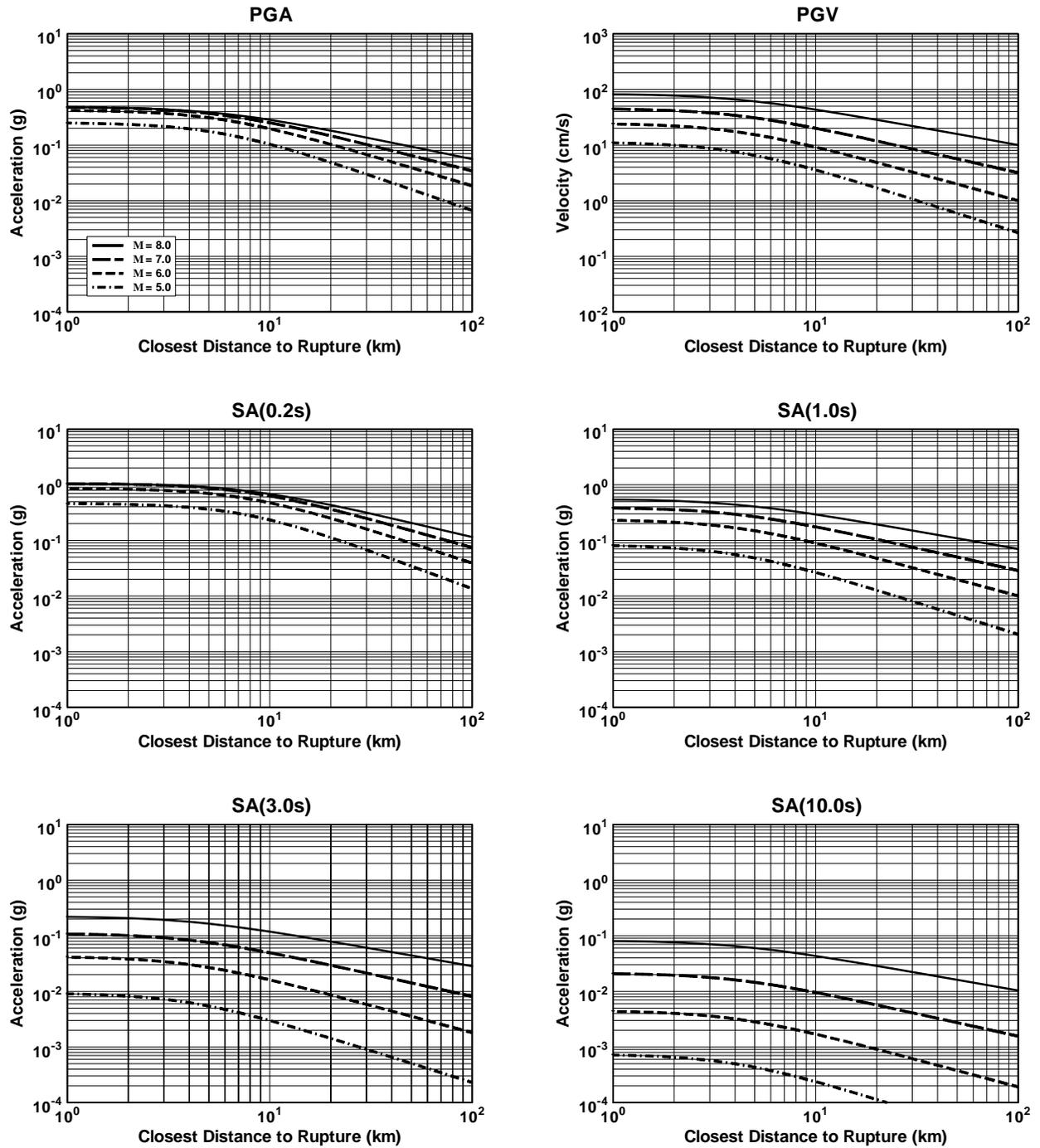
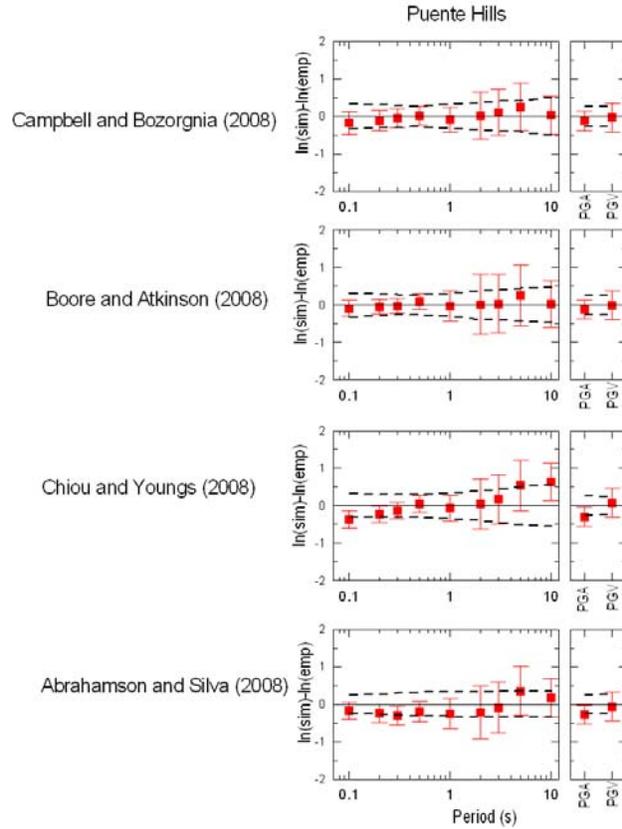
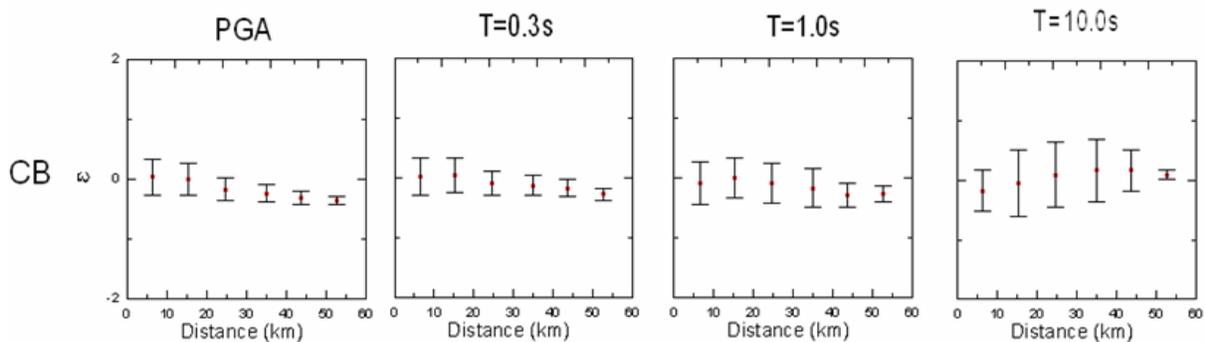


Figure 3. Example results of NGA model by Campbell and Bozorgnia (2007, 2008).



**Figure 4.** Event terms for the simulated Puente Hills earthquake as compared with those of NGA empirical models. The error bars indicate one standard deviation for the residuals. The heavy dashed line represents the inter-event standard deviations from the empirical model (Stewart, *et al.*, 2008).



**Figure 5:** The intra-event residuals of the Puente Hills simulated motions relative to the Campbell & Bozorgnia (2008) NGA model for PGA and spectral ordinates at periods  $T=0.3$ , 1.0, and 10.0 sec versus rupture distance (Stewart, *et al.*, 2008).

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