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EFFECTS OF SIMULATED MAGNITUDE 9 EARTHQUAKE MOTIONS ON STRUCTURES IN THE PACIFIC NORTHWEST

N. Marafi[1], M. Eberhard[2], J. Berman[3], E. Wirth[4], A. Frankel[4], and J. Vidale[5]

ABSTRACT

The Cascadia Subduction Zone (CSZ) produces long-duration, large-magnitude earthquakes that could severely affect structures in the Pacific Northwest (PNW). The impact of synthetic M9.0 CSZ earthquakes on buildings in the Pacific Northwest is studied using eight reinforced concrete wall archetypes that range from 4 to 40 stories. These archetypes were subjected to an ensemble of simulated ground-motions from 30 M9 earthquakes for a location in Seattle that overlies a ~8km deep sedimentary basin and an equivalent location outside the basin. Long-period (1-7s) ground motions are strongly amplified in the CSZ synthetics within the Seattle Basin, leading to a 6-fold increase in deformation demand (inter-story drift) compared to an equivalent out of basin site. The variability in demand was also found to be much larger inside the basin than outside the basin.

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ABSTRACT

The Cascadia Subduction Zone (CSZ) produces long-duration, large-magnitude earthquakes that could severely affect structures in the Pacific Northwest (PNW). The impact of synthetic M9.0 CSZ earthquakes on buildings in the Pacific Northwest is studied using eight reinforced concrete wall archetypes that range from 4 to 40 stories. These archetypes were subjected to an ensemble of simulated ground motions from 30 M9 earthquakes for a location in Seattle that overlies a ~8km deep sedimentary basin and an equivalent location outside the basin. Long-period (1-7s) ground motions are strongly amplified in the CSZ synthetics within the Seattle Basin, leading to a 6-fold increase in deformation demand (inter-story drift) compared to an equivalent out of basin site. The variability in demand was also found to be much larger inside the basin than outside the basin.

Introduction

The Cascadia Subduction Zone (CSZ) produces long-duration, large-magnitude earthquakes that could severely affect structures in the Pacific Northwest (PNW). The long-period (1-7s) components of these ground motions from these earthquakes are amplified by deep sedimentary basins that underlie Seattle and several other cities around the Puget Sound. The effects of long duration and basin amplification are not well-studied for the CSZ because no recordings are available for M8-9 CSZ earthquakes. For these reasons, this study relies on an ensemble of simulated ground-motions [1] to evaluate the impact of an M9 earthquake on structures in the PNW.

Ground Motion Intensity

The effects of deep basins are quantified using spectral acceleration. Figure 1 shows the maximum direction (RotD100) response spectra for the 30 simulated M9 scenarios for Seattle and for a location outside the Puget Lowland basin (La Grande, WA) that is located 80 km south of Seattle. Both locations are ~100 km away from the rupture plane. In Seattle, the median spectral acceleration (Fig. 1a, solid black line) is shown to be close to the MCE_R (red line) typically considered in building design. For La Grande, however, the median S_a values are much lower than the MCE_R (Fig 1b). Figure 1 also shows the 16th and 84th percentile S_a as dashed lines, which show that the variability in spectral acceleration is much larger inside the basin (Seattle) than the variability outside the basin (La Grande). These median S_a observed in these motions are similar to the MCE_R that is typically considered in design. However, the variability in S_a is larger than what is typically considered in non-linear analysis conducted in performance-based design.

An M9 earthquake on the Cascadia Subduction Zone has a recurrence interval of about ~500 years. The 475-year uniform hazard spectrum shown in Figure 1 (blue line) is much lower than the median M9 spectra. However, for a location outside the basin the median S_a values appear to be much closer to the 500-year UHS.

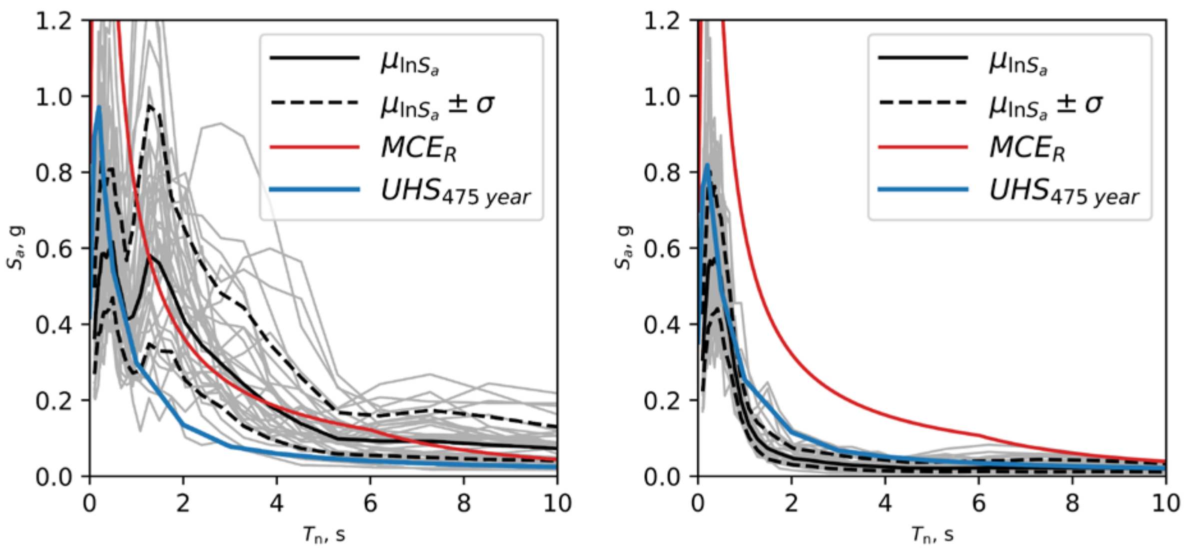

Figure 1. Response Spectra for motions in (a) Seattle, WA (inside basin) and (b) La Grande, WA (outside basin).

Subduction zone earthquakes are expected to be much longer than crustal earthquakes. Figure 2 shows the median 5-95% significant duration for the 30 realizations as a function of closest distance to rupture for the 30 realizations. A M9.0 CSZ earthquake is expected to produce motions that are around 110s long (in terms of $D_{s,5\text{-}95\%}$) in Seattle ~100 km from the rupture plane. The deep Seattle basin was not found to significantly increase synthetic ground-motion durations.

Archetype Development

The effects of these simulated motions were evaluated for a set of archetypical reinforced concrete (RC) wall structures that were designed according to the current Seattle building code. These archetypal structures were designed to represent 4 to 40-story buildings. Figure 3 shows a typical floor plan for an RC wall archetype. Here, the impact of the M9 motions using 2-dimensional OpenSees [2] models of the RC core in the uncoupled direction. Modeling of the cores was based on a methodology that has been previously validated using various quasi-static cyclic tests of RC structural walls [3].

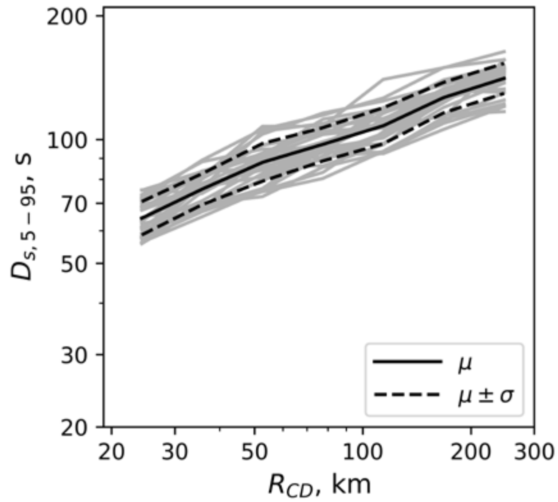

Figure 2. Significant duration (5-95%) with respect to closest distance for the 30 M9 realizations.

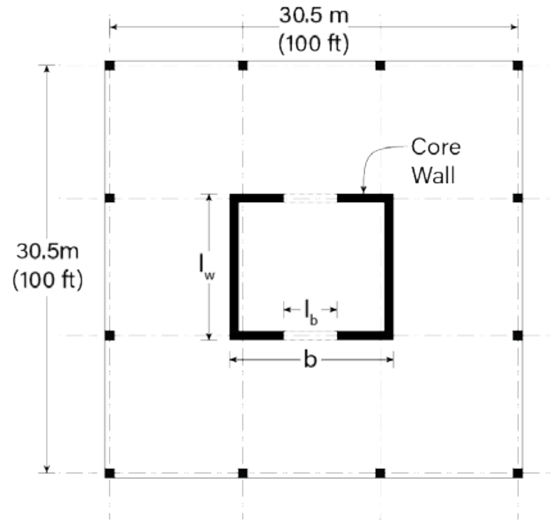

Figure 3. Typical floor plan for an RC Wall Archetype

Impact on Structural Response

The deformation demands on the buildings were evaluated for 30 possible rupture realizations for a location in downtown Seattle and for La Grande (a location outside the basin). Figure 4 shows the maximum inter-story drifts in each story for the 24-story archetype. The median, 16^{th} and 84^{th} percentile maximum inter-story drifts are computed using ground-motions from all 30 realizations in Seattle (shown as black lines) and La Grande (shown as gray lines). Figure 4 and 5 shows that the inter-story drifts are much larger inside the basin (Seattle) as compared with a location outside the basin (La Grande). Additionally, the structure's deformation demands differed widely among the different scenarios as indicated by the large variability (shown in Figure 4 and 5) in inter-story drift.

For all archetypes, the deformation demands in terms of inter-story drifts is shown in Figure 5. The deformation demands due to the inside-basin motions (Seattle) exceeded those outside the basin (La Grande) by a factor of ~3-4. This increase in deformation demand is attributed to basin amplification of the long-period component of the motion causing higher spectral accelerations and damaging spectral shapes. These motions are also much longer (~100s) than those typically observed in crustal earthquakes and therefore may cause additional deformation once the structure yields. The peak inter-story drifts varied with period where the effects of the basin amplified spectral periods that greatly resonated with 12-story structures.

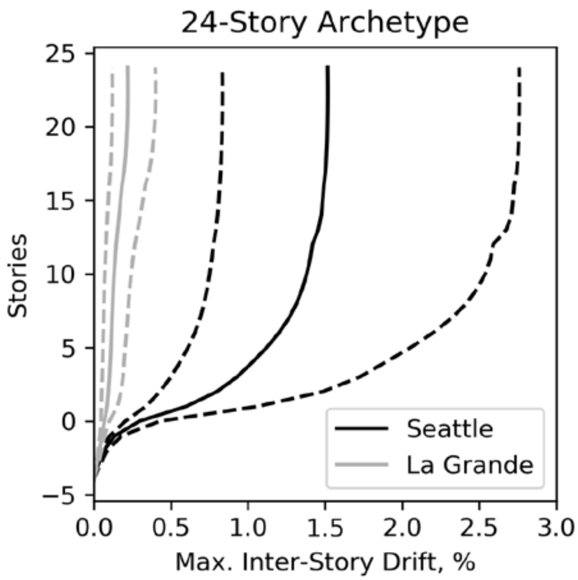

Figure 4. The maximum inter-story drift at each story for 30 M9 CSZ realizations in Seattle and in La Grande.

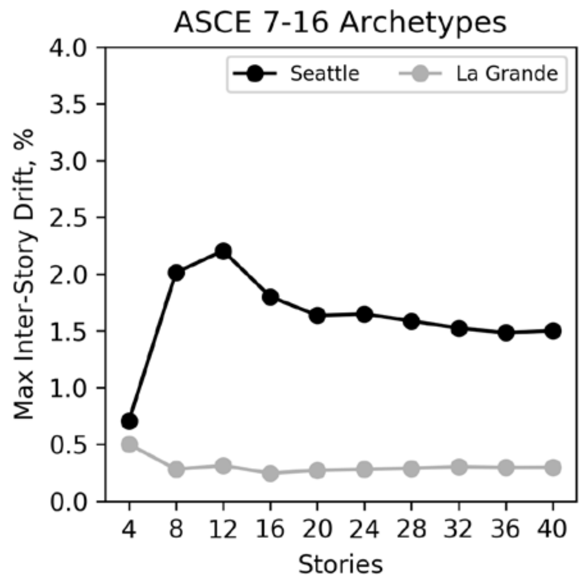

Figure 5. Maximum inter-story drifts with respect to number of stories in archetype.

Conclusions

Synthetic M9 earthquakes on the Cascadia Subduction Zone are shown to result in large deformation demands on RC wall archetypes in terms of the maximum inter-story drift. The maximum inter-story drifts demands were found to be ~3 times larger in Seattle, which overlies a deep sedimentary basin, than motions simulated outside the basin. This variability in deformation demand is attributed to amplifications in low-frequency waves that would increase the spectral accelerations at long periods. In addition, the variability in deformation demand is found to be much larger inside than outside the basin.

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