Using Rupture-to-Rafters Simulations to Quantify Seismic Risk from the San Andreas Fault

Case Studies of Tall Steel Braced Frame Buildings

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Introduction

The emergence of realistic rupture-to-rafters simulations provides us with a convenient tool for quantifying temporal risk posing existing tall buildings in southern California. We compute probabilistic economic losses given the deterministic structural response under a suite of scenario earthquakes and combine these results with the probabilities of occurrence of each scenario to produce regional annualized loss maps for a given structure over the next 30 years. This end-to-end approach comprises of four major tasks:

1. Source Model Generation
2. Ground Motion Simulations
3. Nonlinear Analysis of Structures
4. Probabilistic Economic Loss Analysis

We focus our current study on braced frame buildings in the 20-story class located in southern California and the risk posed by earthquakes on the San Andreas fault, which is capable of generating large magnitude earthquakes (7.5-8.0). We hypothesize that only earthquakes in the magnitude range of 6-8 occurring on the southern section of the San Andreas fault (Parkfield to Bombay Beach) will cause damage of any significance to structures in southern California. We generate the source models by re-sampling finite –source models from past earthquakes. We are simulating a total of 60 San Andreas scenarios with magnitudes in the 6-8 range, two unilateral rupture directivities, and various hypocenter locations. The probability of occurrence of each scenario over the next 30 years is inferred from UCERF 3.0. The ground motions for each scenario are being generated through SPECFEM3D at 450 stations across Southern California. The simulated ground motions will be used for analyzing nonlinear response of three braced-framed buildings using FRAME3D. Probabilistic economic losses will be determined at each location for each scenario. They will be combined with the 30-year probability of occurrence of each scenario to quantify the risk to these buildings across southern California associated with San Andreas earthquakes over the next 30 years. The study will provide a sound basis for short and long-term risk mitigation strategies.

1. Source Model Generation

1.1 Criteria for Selection of Source Models:

Selected source models (Table 1) are based on finite source models inferred from past earthquakes on vertically dipping right-lateral strike slip faults in the magnitude range of 6-8.

1.2 Resampling:

To ensure that the source models are capable of generation a 2s wave, they are resampled to a finer resolution (0.5 km X 0.5 km). Figure 1 illustrates a resampled source model for the 2002 Denali Earthquake (Source Modeler: Dr. Chen Ji).

1.3 Mapping and Directivity

The resampled source models are then mapped to three segments of the southern San Andreas fault (Parkfield to Bombay Beach), two at the ends and one in the middle. For each location, two unilateral rupture directivities are considered (north-to-south & south-to-north). San Andreas fault at three equally spaced hypocenter locations, with two rupture directivities (north-to-south, south-to-north). Figure 2 illustrates the rupture locations for the three scenarios using the Denali source model.

Table 1: Finite Source Models Selected for the San Andreas Study

	Earthquake	Year	M_w	Length (km)	Width (km)	Source Modeler
1	Parkfield	2004	6.00	34	15.5	Dreger et al
2	Imperial Valley	1979	6.58	42	10.4	Hartzell and Heaton
3	Tottori	2000	6.73	32	20	Semmane et al
4	Kobe	1995	6.89	50	20	Ide et al
5	Landers	1992	7.08	83	18	Cohee and Beroza
6	Hector Mine	1999	7.17	54	16	Ji et al
7	Landers	1992	7.28	78	15	Wald and Heaton
8	Izmit	1999	7.44	141	23.3	Sekiguchi and Iwata
9	Izmit	1999	7.56	173	22.5	Delouis et al
10	Denali	2002	7.89	292	20	Ji et al

2. Ground Motion Generation

Ground motions are generated at 450 analysis siteslocated on a roughly 7 km X 7 km (1/16 degree) grid using SPECFEM3D. Figure 3 illustrates the peak ground velocity and displacement maps of the three components for the three scenarios.

3. Building Analysis

The ground motions at the 450 stations will be used to compute the nonlinear response of three 18-story braced-framed buildings using FRAME3D. These buildings will be designed using the 1982 and 1997 Uniform Building Code to represent older and modern existing buildings.

4. Probabilistic Seismic Loss Analysis

Probabilistic seismic losses will be estimated based on methodology developed by the Pacific Earthquake Engineering Research (PEER) center. The central idea of the PEER methodology is to propagate the uncertainties in the following four stages of assessments: hazard analysis, response analysis, damage analysis, and loss analysis (Eq. 1). Here we are characterizing the hazard not by an intensity measure but by 3-componenet waveforms from earthquake on a specific fault. Moreover, we assume that all the uncertainty lies in the occurrence of an even (Eq. 1). The probability of each earthquake scenario is inferred from the Uniform California Earthquake Rupture forecast (UCERF) and modifications proposed by Page and Field. These studies divide the San Andreas fault into smaller sections (7 km) and provide the probability of each of these sections being involved in a certain magnitude earthquake (Figure 4). Probability of each scenario is then calculated based on the weighted average of the sectional probabilities in the scenario.

Eq. 1 : $$P(L|F) = \iiint p(L|D,F).p(D|R,F).p(R|IM,F).P(IM|F).dIM.dR.dD$$

Eq. 2 : $$P(L|F,H) = \iint p(L|D,E,F,H).p(D|E,F,H).P(E|F,H).dE.dD$$

Where:
F: Facility
H: Hazard
L: Loss
E: Event
D: Damage
R: Response
IM: Intensity Measure

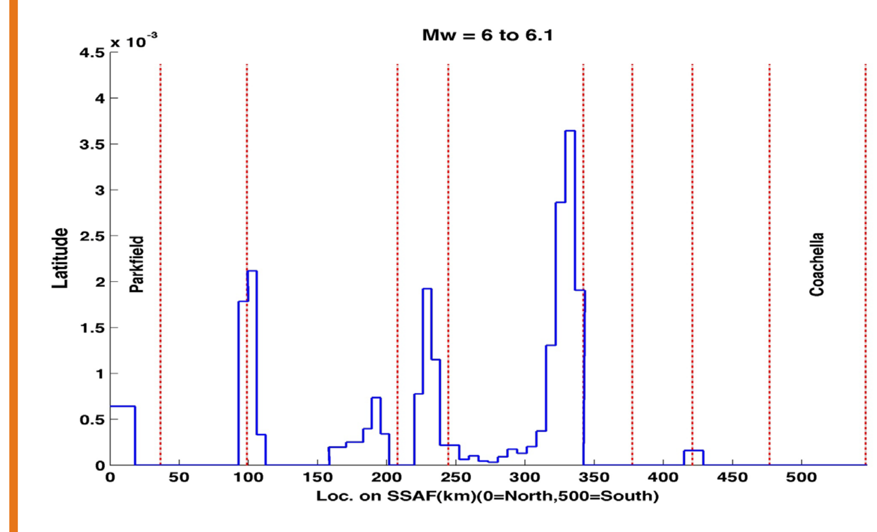

Figure 4: Probability of each 7km segment being involved in a magnitude 6 – 6.1 earthquake.

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References

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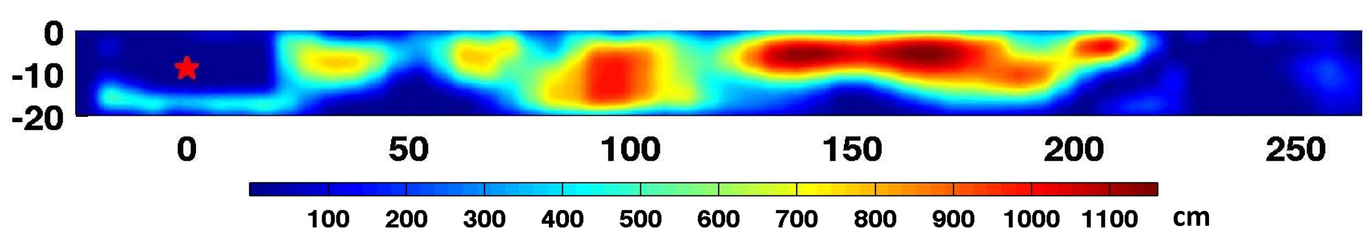
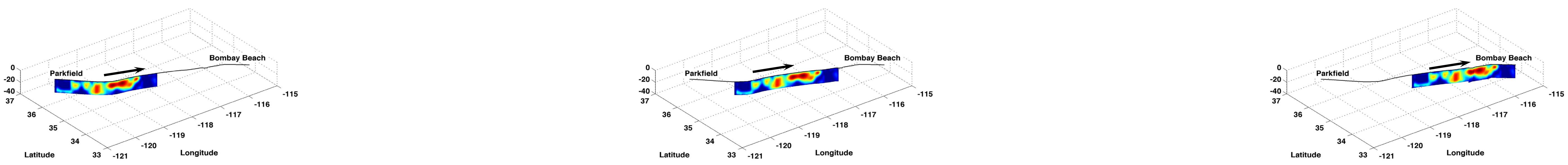


Figure 1: Slip distribution of the 2002 Mw = 7.9 Denali Earthquake (Dr. Chen Ji)

Figure 2: Three hypocenter locations for a magnitude 7.9 north-to-south rupture using the Denali finite source.



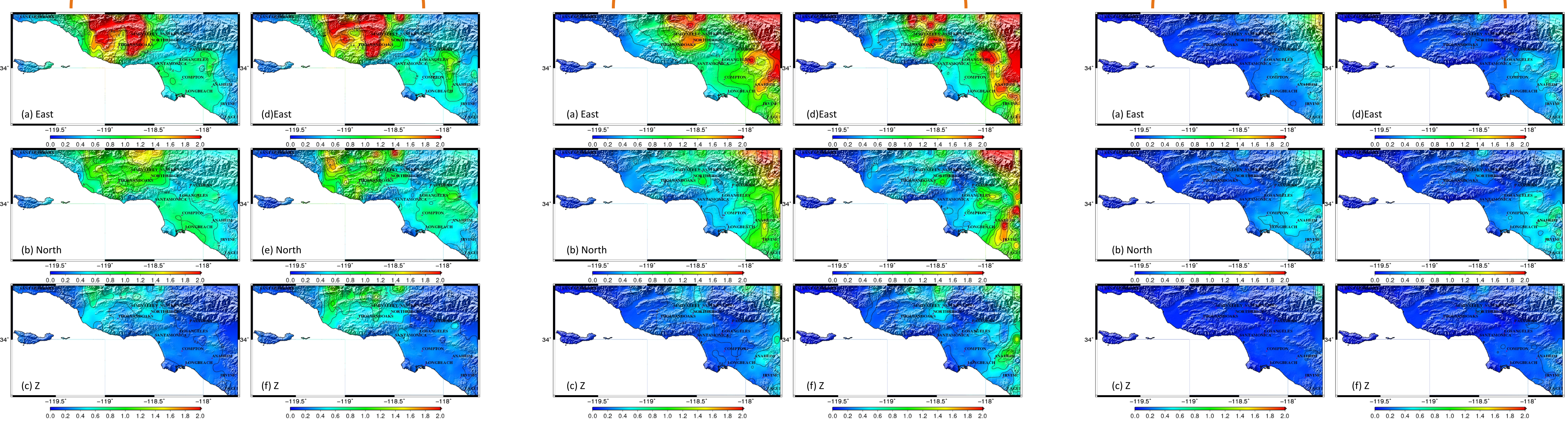


Figure 3: Three components of peak ground displacements ((a) – (c)) and peak ground velocities ((d) – (e)) for 3 hypocenter locations of Figure 2.