Ground-motion variance from modeling of multiple rupture-directivity scenarios on the Newport-Inglewood / Rose Canyon fault system

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Abstract

We use LLNL's SW4 wave-propagation modeler to produce shaking maps and synthetic seismograms for hypothetical, nonetheless geologically plausible earthquake ruptures of the Newport Inglewood / Rose Canyon (NI/RC) fault system along the Southern California coast. We simulate a number of worst-case through-going rupture scenarios with magnitudes up to 7.4, with a focus on estimating shaking uncertainty around NI/RC due to variance in rupture directivity. To date we have modeled the fault strands as vertically dipping rectangular planes and produced a first estimate of average shaking and its potential variance at low frequencies (<1 Hz). We employ a simplified kinematic source model with parameters selected to sensibly fit recorded peak ground velocities (PGVs) of shaking from the 1992 M7.3 Landers earthquake. Overall, the results show that the placement of the hypocenter has a strong influence on the predicted ground-motion maps; PGVs increase in the direction of the rupture propagation, with the greatest amplifications (up to a factor of five) observed in the Los Angeles Basin for the northwestward rupture directivity scenarios. Given more exact locations and geometry information of the NI/RC fault system strands, we are conducting tests to see whether the resulting more complex directivity has similar effects on variance; and testing which scenarios may produce higher ground motions in the Los Angeles region. The results of this study may assist planning for earthquake resilience in Southern California coastal communities.

Motivation

SCEC has prepared a series of earthquake scenarios examining the hazards posed by the southern San Andreas fault. The Inner California Borderland hosts a similar system of strike-slip faults hundreds of kilometers long. A UNR-Scripps collaboration has detailed the Newport-Inglewood / Rose Canyon (NI/RC) fault system and the surrounding sedimentary basins with marine seismic surveys (Sahakian et al., 2017; Figure 1). Our objective is to compute shaking from scenario earthquakes and examine the hazards, and the uncertainties in the hazards, that the NI/RC fault system poses to coastal communities and critical facilities.

New Definitions of NI/RC Fault Segments

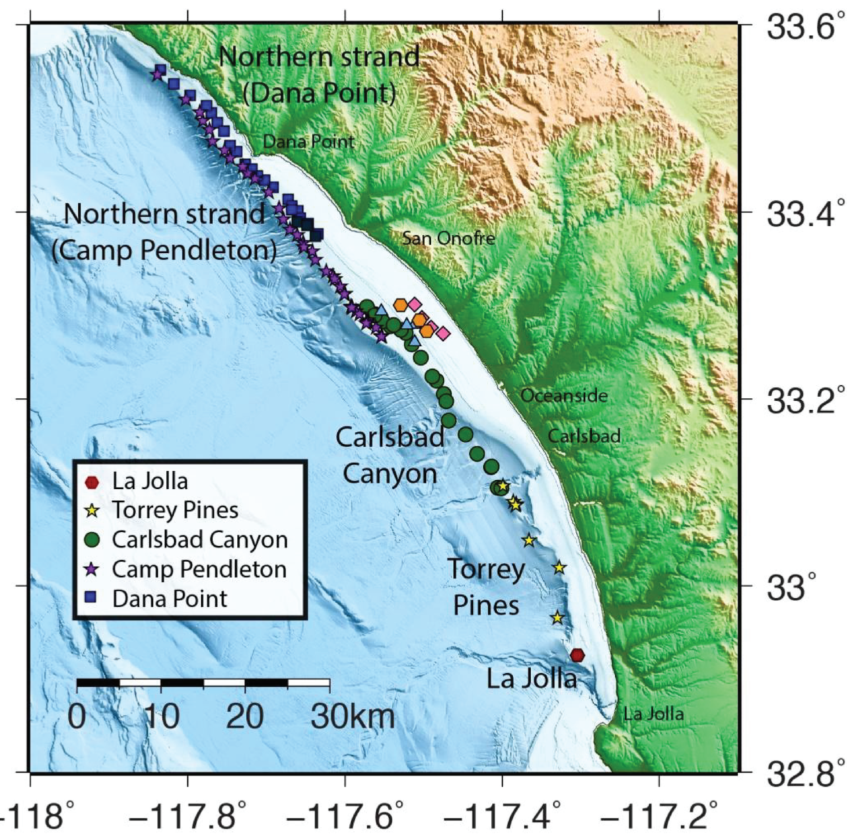

Figure 1: Locations of NI/RC fault zone segments, taken from Sahakian et al. (2017). Red hexagons=La Jolla strand; Yellow stars=Torrey Pines strand; Green circles=Carlsbad Canyon strand; Purple stars=Northern strand, Camp Pendleton splay; Blue squares=Northern strand, Dana Point splay.

Model Setup

SCEC's CVM-H version 15.1.0 defines thicknesses of onshore basins as well as basins in the offshore San Diego Trough; together with geotechnical shear velocities. Additional geotechnical data and model-assembly routines are taken from the Nevada ShakeZoning program at `crack.seismo.unr.edu/NSZ` . Our simulations do not include the surface topography or bathymetry.

We use SW4 1.1 (Sjögreen and Petersson, 2012; Petersson and Sjögreen, 2012; Petersson and Sjögreen, 2014; Petersson and Sjögreen, 2015; Petersson and Sjögreen, 2014) published under the GPL 2 license. SW4 solves the time dependent 3D viscoelastic wave equation using a node-based finite difference approach with a fourth order accuracy in time and space. The code simulates seismic wave propagation in complex three-dimensional earth models. We compiled and ran SW4 on Nevada Seismological Laboratory's Linux cluster, with seven nodes of 16 cores each.

Velocity Model Display

Maps showing sedimentary basin thickness and shallow geotechnical velocities (Figure 2) show the NSZ-assembled model. While geotechnical velocities (to 30 m depth) and basin thicknesses vary laterally in the NSZ models, basin fill and bedrock have 1D velocity, density, Qs, and Qp functions of depth only. Velocities determine Q values using the relations in Olsen et al. (2003).

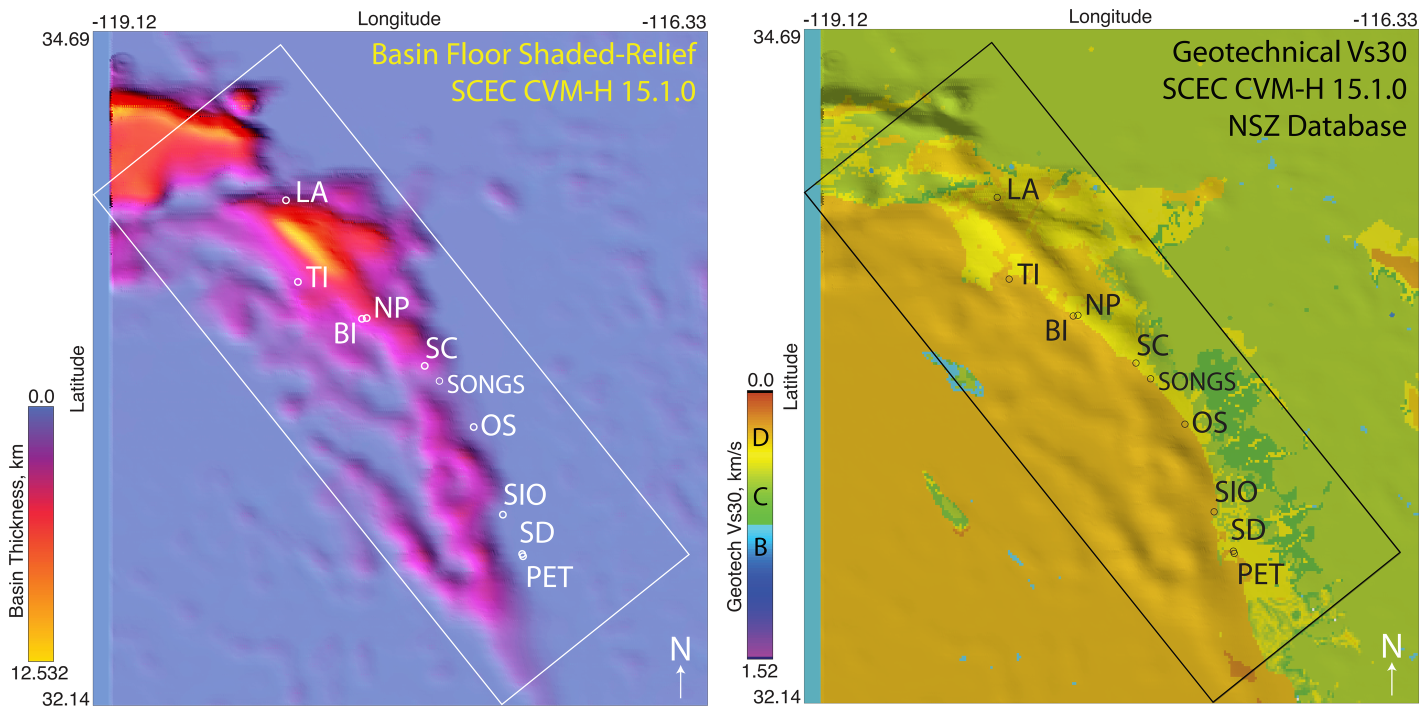

Figure 2: Maps of Southern California showing the SCEC CVM-H version 15.1.0, as rendered by Nevada Shake Zoning version 6.0.0. The tilted box shows the location of the SW4 computational grid. (***left***) Neogene basin thickness, showing the Ventura, Los Angeles, and San Diego Trough basins. (***right***) Geotechnical shear velocity averaged from the surface to 30 m depth (Vs30). LA = downtown Los Angeles; TI = Terminal Island; BI = Balboa Island; NP = Newport Beach City Hall; SC = San Clemente City Hall; OS = Oceanside City Hall; SIO = Scripps Inst. of Oceanography; SD = San Diego City Council; PET = Petco Park.

Source Calibration with Landers

To calibrate the simple fault-source parameters we will use for ruptures on the NI/RC system, we simulated the 1992 M 7.3 Landers earthquake at 0.15 Hz. We computed the peak ground velocities (PGVs) at stations that recorded Landers ground motions for a series of 19 runs in which we allowed variability in: slip distance, central frequency, hypocenter depth, and rupture velocity. Figure 3 compares selected computed and measured PGVs as a function of the distance from the fault at 18 stations.

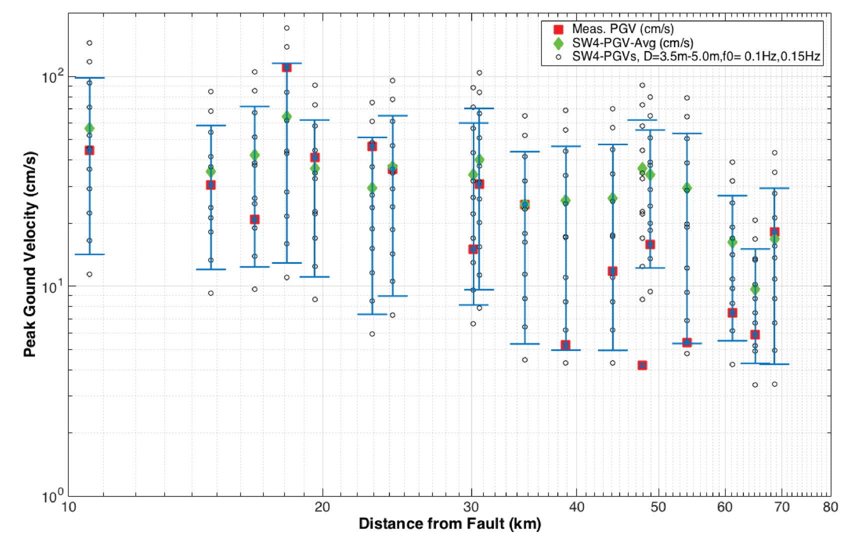

Figure 3: Log-log plot of PGV versus distance to the nearest fault rupture, for stations recording the 1992 Landers earthquake. Red squares show recorded PGV; black circles the SW4-predicted PGV under a range of rupture parameters; and green diamonds the average computed PGV at that station. Blue bars show the standard deviation of the average PGV.

NI/RC Rupture Scenarios

Based on the reasonable results from our Landers modeling, we designed a suite of NI/RC rupture scenarios to test ground-motion sensitivity to variance in rupture directivity:

Scenario	Segments Rupturing	Hypocenter Placement	Source Parameters	Number of Scenarios
CP (Unilateral Rupture)	San Diego (SD) La Jolla (LJ) Torrey Pines (TP) Carlsbad Can. (CC) Camp Pendleton (CP)	Southeast end of SD Northeast end of CP	Central frequency = 0.1 Hz, 0.15 Hz Slip distance = 2.5 m, 3.0 m, 3.5 m Rupture Velocity = 2.72 km/s Hypocenter depth = 14.5 km	**12**
CCCP (Bilateral Rupture)		Center of CC		**6**
DP (Unilateral Rupture)	San Diego (SD) La Jolla (LJ) Torrey Pines (TP) Carlsbad Can. (CC) Dana Point (DP)	Southeast end of SD Northeast end of DP	Central frequency = 0.1 Hz, 0.15 Hz Slip distance = 2.5 m, 3.0 m, 3.5 m Rupture Velocity = 2.72 km/s Hypocenter depth = 14.5 km	**12**
CCDP (Bilateral Rupture)		Center of CC		**6**

Summary

Shaking predictions for M7+ scenarios linking several segments of the Newport-Inglewood / Rose Canyon fault system will assist coastal communities in Southern California to become more earthquake-resilient. Our 3D physics-based predictions used SW4 from CIG to compute shaking at <0.5 Hz through a velocity model simplified from the SCEC CVM-H, for 36 scenarios of rupture directivity and source parameters:

1) Certain scenarios yielded Violent PGVs of >0.8 m/s within Neogene basins.
2) Shaking could vary by a factor of five, depending on rupture directivity.
3) Northwestward rupture directivity on the NI/RC system may inject Severe to Violent shaking along the deep axis of the Los Angeles Basin.
4) Computing multiple scenarios allowed prediction of the standard deviation of the average shaking. The variance is similar in magnitude to the shaking itself.

Single-Scenario Shaking Predictions

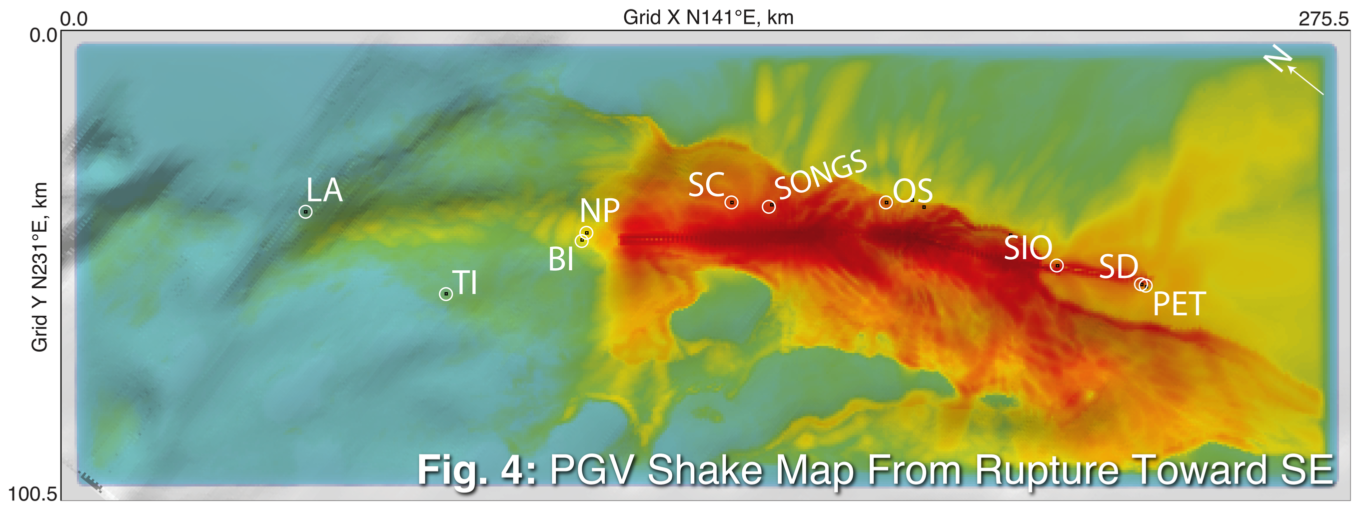

Fig. 4: PGV Shake Map From Rupture Toward SE

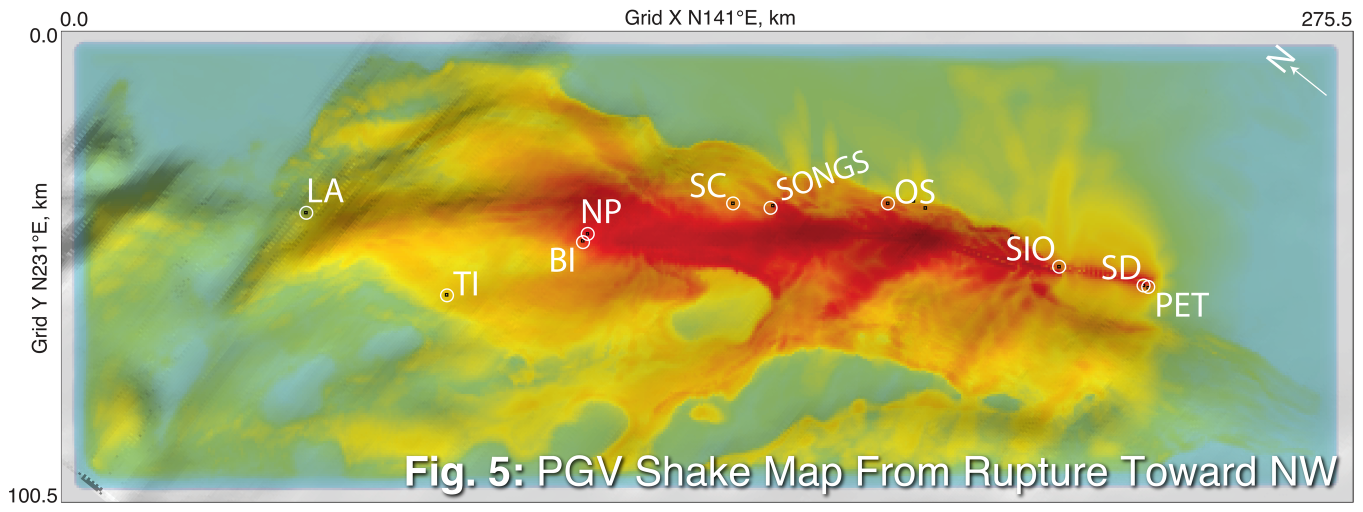

Fig. 5: PGV Shake Map From Rupture Toward NW

Multi-Scenario Average Shaking & Variance

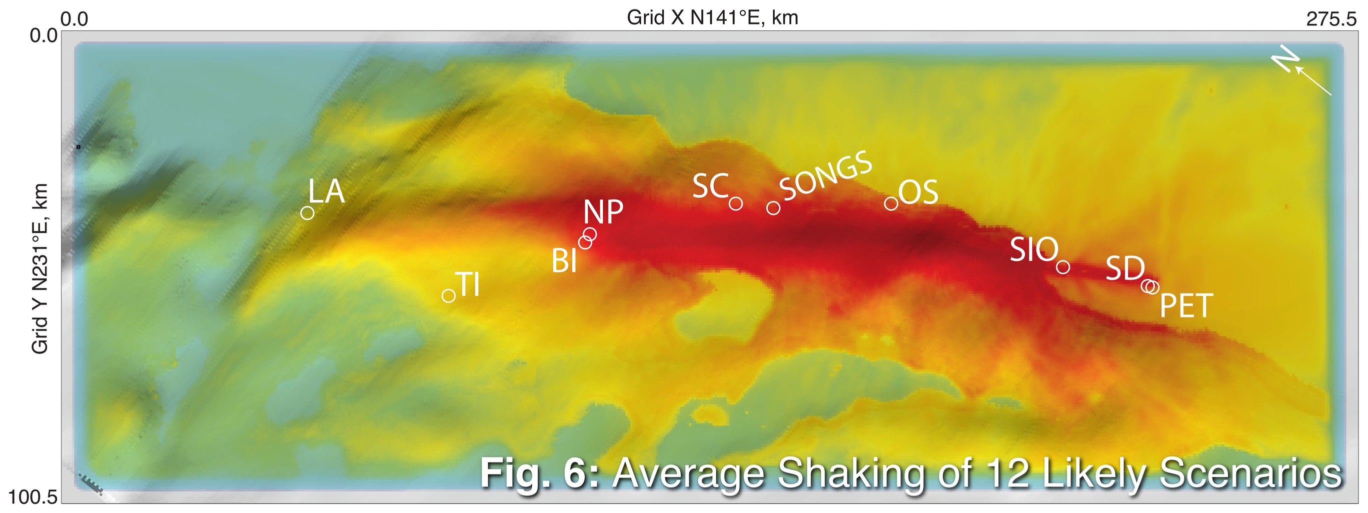

Fig. 6: Average Shaking of 12 Likely Scenarios

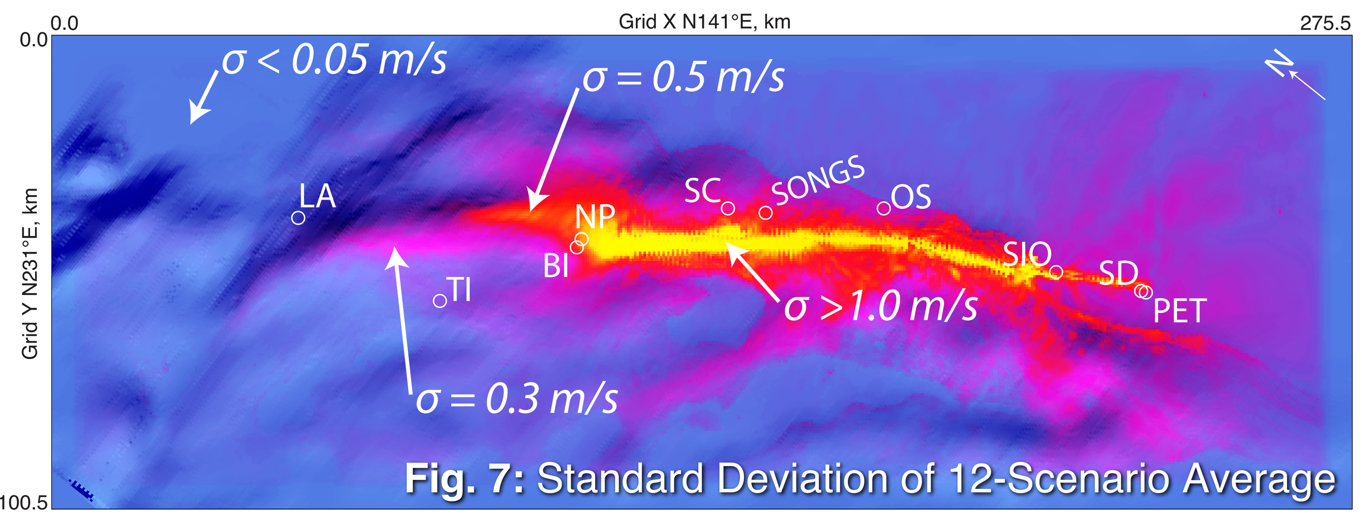

Fig. 7: Standard Deviation of 12-Scenario Average

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC. (%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL. (cm/s)	***<0.02***	***0.1***	***1.4***	***4.7***	***9.6***	***20***	***41***	***86***	***>178***
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2012)

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Acknowledgments

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