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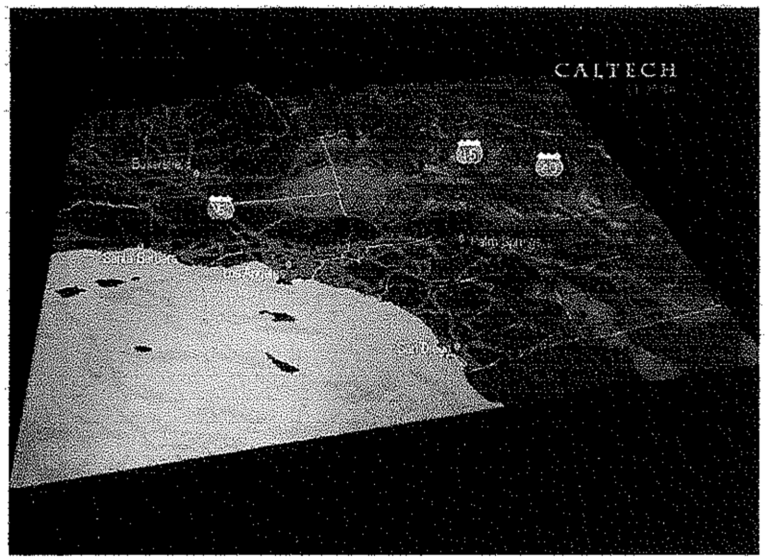

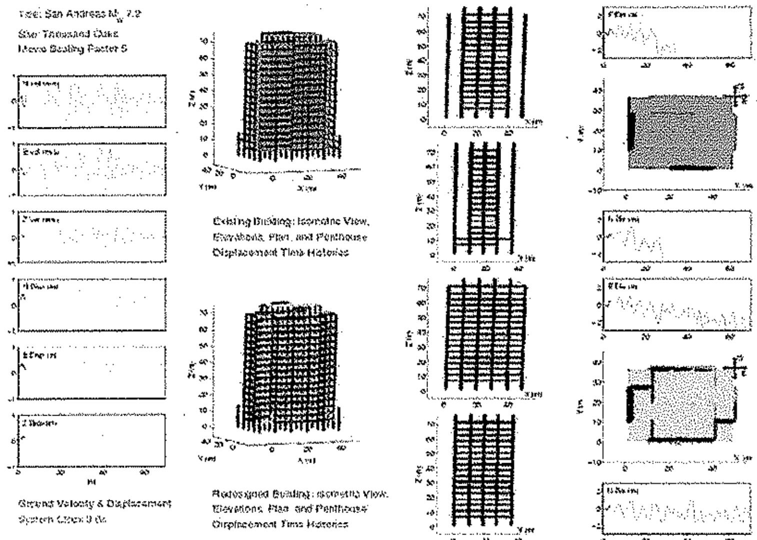

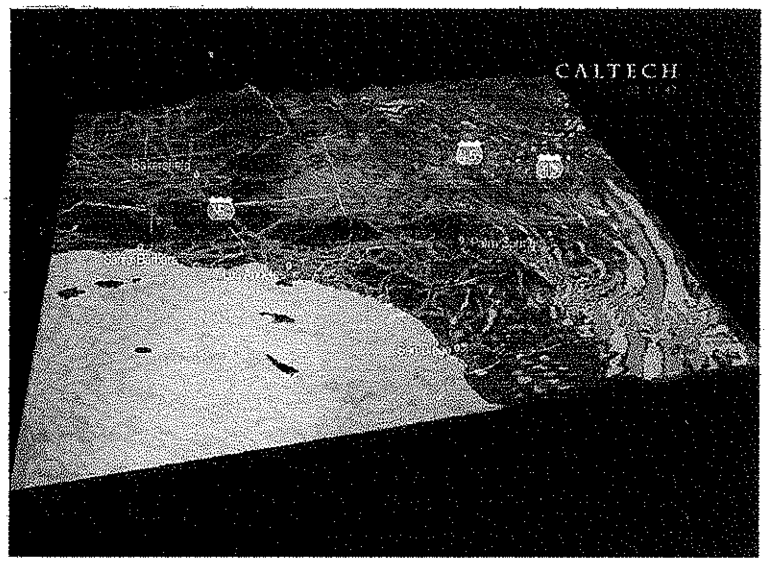

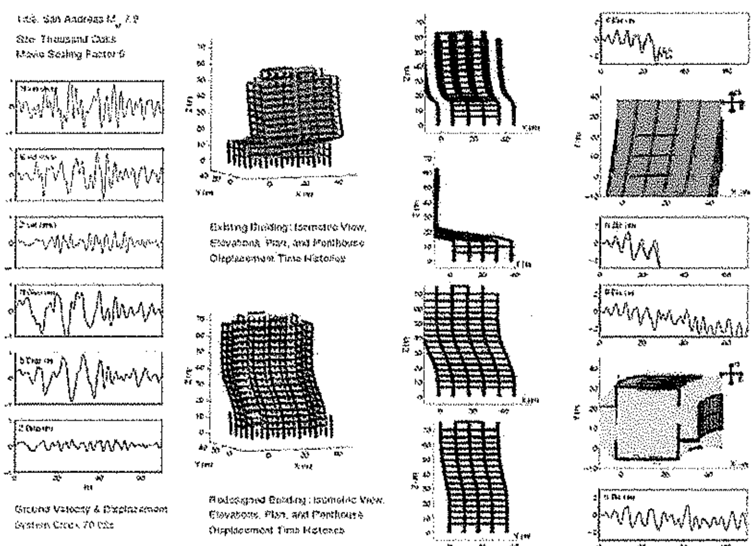

ABOVE PHOTOS: Terrain of S. California, Cities and Counties marked. Parkfield off maps, to North.

TOP Photo: Start of Seism.
BOTTOM Photo: Seism passed City. Time 11:47

ABOVE EXHIBITS: Seismic Waves and Structural Responses. Existing Building in Red. Code-amendment Building in Yellow.

TOP Exhibit: Start of Seism.
BOTTOM Exhibit: Building Shape at Time 70:02.

STRUCTURAL RESPONSE OF EXHIBIT-BUILDING UNDERGOING 7.9 SEISMIC WAVE FROM PARKFIELD CALIFORNIA

See accompanying Article by Swaminathan Krishnan

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consultants to technical management

June 20, 2008

STATEMENT of J.H. McQUISTON on
IMMEDIATE DANGER INHERENT in LOS ANGELES

Honorable Chairman and Members of the Committee:

Enclosed is a dissertation revealing specifically **the danger of assuming B&S can control the safety of Buildings in Los Angeles, regardless of permissions granted by planning actions.** Uncoordinated planning permissions for a structure **will put the safety of its inhabitants and those adjacent to it at mortal risk.**

Though the dissertation posits an earthquake on the San Andreas fault **175 miles** away, its movie, enclosed, shows **the Canoga Avenue structure will be totally destroyed, causing probable deaths.**

The dissertation's analysis represents the technical expertise of our region's "best and brightest brainpower". But note that their calculation even **under-estimated the damage to the Canoga tower by the Northridge quake,** and that "Northridge" **pales in intensity to those predicted for the Los Angeles area.**

B&S earthquake code-restrictions *cannot* constrain a builder *enough* to make this area, this building, the building occupants, and the nearby area safe. That is what the enclosure *proves.*

There is **no way the City may deny** a proposed project compliant with Los Angeles B&S Code, **except by denying variances from planning-code restrictions.** Currently **there is a substantial risk to the City,** since there exists **no caution preventing over-dependence on the B&S Code to protect the safety of people.**

And **safety** is what **people expect our City to provide.**

Being a registered engineer, and having worked on seismic issues, I know how *difficult* it is to provide safe buildings in the Los Angeles area. **But some areas here are more suitable than others for high-rise, dense residences. The fault-traces of our three major fault systems, including Hollywood, are not safe areas for buildings having ten to twenty stories.**

Better Hollywood-fault uses are low-rise residential, or commercial and industrial uses, where the **probability of death and/or dismemberment** is less a **certainty.**

Los Angeles needs to act quickly to establish "zones of high risk", having prudent zoning restrictions, in order to protect **itself and its stakeholders and populace** from physical and financial harm.

Respectfully submitted,

J.H. McQuiston, P.E.

encl: Krishnan, *et al* Performance Report
from *Earthquake Spectra,* Nov 2006
c: Interested parties

Case Studies of Damage to Tall Steel Moment-Frame Buildings in Southern California during Large San Andreas Earthquakes

by Swaminathan Krishnan, Chen Ji,* Dimitri Komatitsch, and Jeroen Tromp

Abstract On 9 January 1857, a large earthquake of magnitude 7.9 occurred on the San Andreas fault, with rupture initiating at Parkfield in central California and propagating in a southeasterly direction over a distance of more than 360 km. Such a unilateral rupture produces significant directivity toward the San Fernando and Los Angeles basins. Indeed, newspaper reports of sloshing observed in the Los Angeles river point to long-duration (1-2 mm) and long-period (2-8 sec) shaking. If such an earthquake were to happen today, it could impose significant seismic demand on present-day tall buildings. Using state-of-the-art computational tools in seismology and structural engineering, validated using data from the 17 January 1994, magnitude 6.7 Northridge earthquake, we determine the damage to an existing and a new 18- story steel moment-frame building in southern California due to ground motion from two hypothetical magnitude 7.9 earthquakes on the San Andreas fault. Our study indicates that serious damage occurs in these bnildings at many locations in the region in one of the two scenarios. For a north-to-south rupture scenario, the peak velocity is of the order of 1meter/sec in the Los Angeles basin, including downtown Los Angeles, and 2 meters/sec in the San Fernando valley, while the peak displacements are of the order of 1meter and 2 meters in the Los Angeles basin and San Fernando valley, respectively. For a south-to-north rupture scenario the peak velocities and displacements are reduced by a factor of roughly 2.

Introduction

The risk of earthquakes in southern California arises from two sources: well-mapped-out faults such as the San Andreas, Newport-Inglewood, and Santa Monica-Hollywood-Raymond faults that have some form of surface expression, and the network of blind-thrust faults hidden deep inside the Earth that includes the Northridge fault and the Puente Hills fault underneath downtown Los Angeles. While the San Andreas strike-slip fault system has the potential for large (moment magnitude ~8) earthquakes, typically every 200-300 years (Sieh, 1977, 1978a), the blind-thrust faults have the potential for more moderate magnitude (~7) earth- quakes (Shaw and Suppe 1996). Fortunately, in modern history the urban areas of southern California have thus far been spared from the strongest shaking generated by large strike-slip earthquakes. The magnitude 6.7 earthquake of 17 Jan uary 1994, on the Northridge blind-thrust fault, however, caused 57 deaths and econoniic losses in excess of $40 billion (Eguchi *et al*, 1998; Petak and Elahi. 2000). This earthquake exposed the vulnerability of steel moment-resisting frame buildings to fracture (SAC, l995a, b, c). These buildings resist lateral forces from an earthquake through bending in rigidly connected (welded) beams and columns. Because of certain construction practices and the use of nonductile weld material, however, a significant number of connections fractured in some of these buildings. Many of the moment- frame buildings in southern California were constructed be fore 1976 (EQE International, Inc., 1995), when the understanding of the nature and power of earthquake forces and their effects on buildings was inadequate.

Therefore the question arises as to what would happen to the many tall steel buildings in the Los Angeles and San Fernando basins if a large earthquake were to occur on the San Andreas fault. Can we estimate damage and consequent losses in these buildings?

There have been many improvements in building codes and construction practices since 1994, and buildings designed according to the latest code (1997 Uniform Building Code, UBC97, ICBO, 1997), termed "new/redesigned buildings" in this article, are *expected* to perform far better than existing buildings, defined as those designed using codes preceding the UBC97. in large earthquakes. **Will they. in fact, perform better** and, if so, **is this performance adequate**?

Before we can answer these questions, we need to be able to answer more fundamental questions: for example,

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what kind of shaking would be experienced in this region during such an earthquake? What would the *frequency content* of the shaking be? What about the *amplitude and duration* of significant shaking? We have a qualitative feel for the extent and intensity of ground shaking from newspaper reports (Agnew and Sieh, 1978; Meltzner and Wald, 1998) following the magnitude 7.9 earthquake of 9 January 1857 on the San Andreas fault. However, we **need estimates of the ground-motion waveforms** for performing quantitative seismic-hazard assessment in a rigorous manner.

In this study we combine state-of-the-art computational tools in seismology and structural engineering to perform a 3D simulation of the rupture of a 290-km section of the San Andreas fault, the generation and propagation of the resulting seismic waves, the subsequent ground shaking in the Los Angeles and San Fernando basins, and the **resulting damage to two 18-story** steel moment-frame buildings in the region. Each of these parts requires simulation at very different temporal and spatial scales that are best performed using task-specific software.

Seismic-wave propagation can be modeled in a linear viscoelastic manner, whereas building damage has to be modeled in a nonlinear fashion. A decade ago, Heaton and colleagues (Heaton *et al*, 1995; Hall *et al*, 1995; Hall, 1998) simulated the near-source ground motions of a magnitude 7.0 thrust earthquake on a spatial grid of 60 km by 60 km using a vertically stratified crustal model that approximates the rock properties in the Los Angeles basin, and then modeled the response of a 20-story steel-frame building and a three-story base-isolated building. Olsen *et al* (1995) and Graves (1998) simulated seismic-wave propagation generated hy a magnitude 7.75 earthquake on a different section of the San Andreas fault.

Here we integrate many aspects of the earthquake-structure problem including the finite-source model of a real earthquake (Ji *et al*, 2002, 2003), seismic- wave propagation in a 3D Earth model (Komatitsch and Tromp, 1999; Komatitsch *et al*, 2004; Liu *et al*, 2004), and 3D nonlinear damage analyses of buildings using three-component ground-motion waveforms (Carlson, 1999; K.rishnan, 2003a), validating these procedures using real data from a recent earthquake.

Model Domain and Building Characteristics

The seismological domain of our analysis includes all of southern California and extends north into the central valley beyond Parkfield, but we restricted the engineering analysis to the main sedimentary basins of San Fernando, Los Angeles, and San Gabriel (Fig. 1).

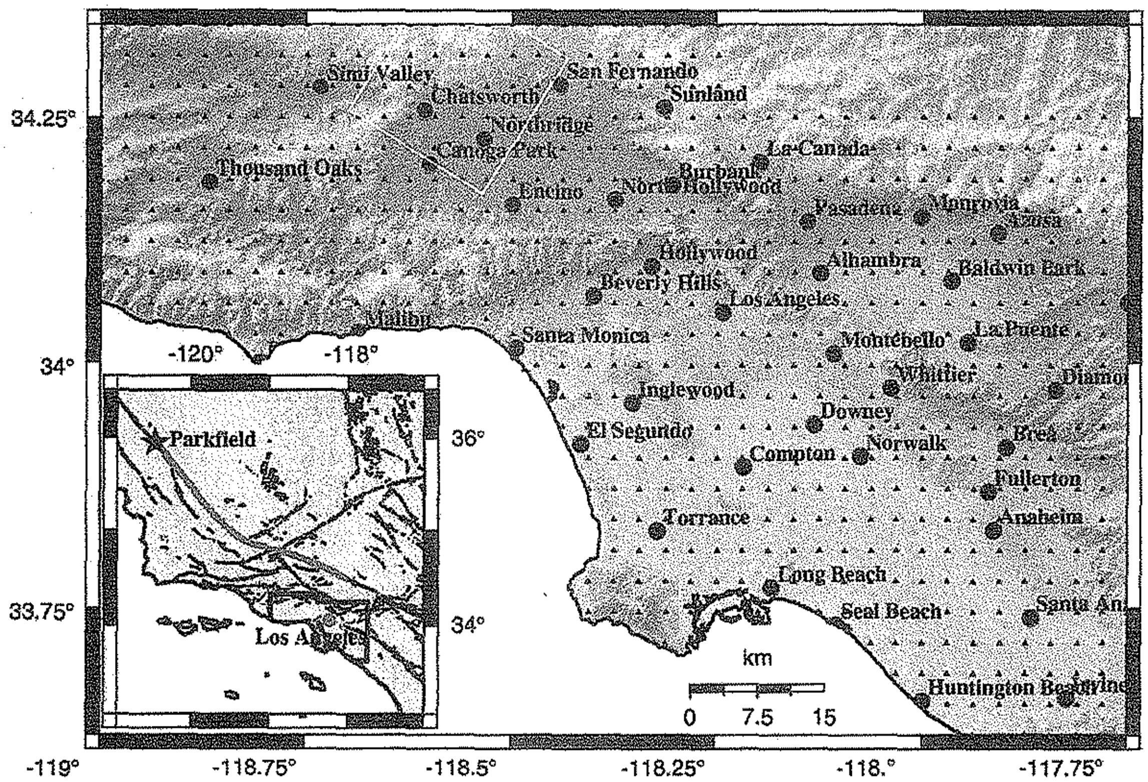
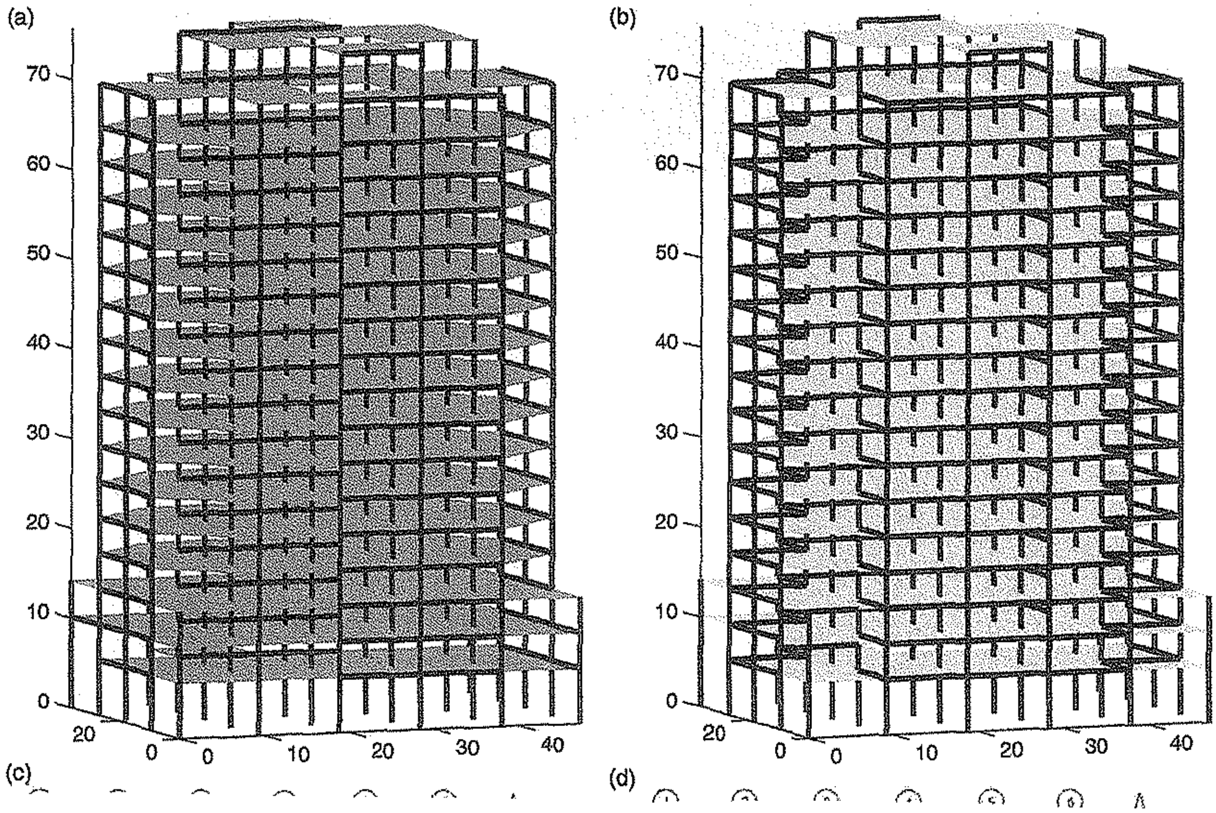


Figure 1. Geographical scope of the simulation. The color scheme reflects topography, with green denoting low elevation and yellow denoting mountains. The filled triangles represent the 636 sites at which seismograms are computed and buildings are analyzed. The white box is the surface projection of the Northridge fault. The red line in the inset is the surface trace of the hypothetical 290km rupture of the San Andreas fault that is the primary focus of this study. The area enclosed by the blue polygon denotes the region covered by the 636 sites.

For the scenarios considered in this study, ground motions south of Irvine going toward San Diego are unlikely to be strong enough to warrant a detailed engineering analysis. The solid circles in the figure denote some of the major cities in the region. We have divided the region using a grid spaced at 1/32 of a degree (i.e., about 3.5 km) each way, with a total of 636 analysis sites.

Also shown in the figure is the surface projection of the Northridge fault that ruptured during the 17 January 1994 earthquake. The inset illustrates the region of interest in relation to the San Andreas fault rupture scenarios under consideration.



Errata

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Having said this, **no detailed analyses have been performed to confirm the safety** of high-rise buildings

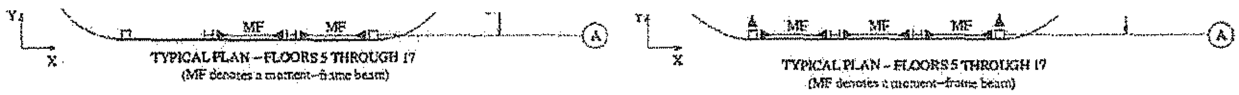


Figure 2. Structural models of the two buildings under study: (a) Isometric view of the existing building (designed using the 1982 Uniform Building Code), (b) isometric view of the new building (redesigned using the 1997 Uniform Building Code), (c) plan view of a typical floor of the existing building showing the location of columns and moment-frame (MF) beams, and (d) plan view of a typical floor of the redesigned (new) building showing the location of columns and moment-frame beams. Note the greater number of moment-frame bays in the redesigned building.

Many types of buildings in southern California are at **risk of sustaining damage** during strong ground shaking from a large earthquake on the San Andreas fault. These include the **numerous non-ductile concrete** buildings and unreinforced masonry buildings spread across Los Angeles. At the same time, the large-amplitude long-period, long- duration seismic waves that can be expected from a large San Andreas earthquake can excite the dominant long-period modes of tall buildings, especially those in the mid-height, 15-30 story, range.

40 stories and taller during either large distant earthquakes or **moderate near-source earthquakes** that could generate large displacement pulses at great velocities. It is generally *assumed* that these buildings, usually with dual structural systems offering greater redundancy or with tubular structural systems that can counter strong wind forces, will be able to resist shaking from a distant earthquake fairly well.

Within the I 5-30-story class there are more steel buildings than reinforced concrete ones; for example, in 1993, there were 190 steel buildings above 8 stories compared with 121 concrete buildings (EQE, 1995) in the Los Angeles and Ventura Counties; for buildings in the midheight range this ratio is likely to have been more skewed toward steel. This is a prototype study, and in such an analysis it is important to target buildings that have already been investigated in detail, and whose behavior is well understood, so that a proof of concept can be established.

Steel moment-frame buildings have been studied extensively since the Northridge earthquake (SAC, l995a, b; Carlson, 1999; Krishnan, 2003b). Based on these considerations, we have chosen 18-story steel moment-frame buildings as the focus of this study. In particular, we have selected two buildings (Fig. 2).

The base building is an **existing 18-story steel moment-frame building** located on Canoga Avenue in Woodland Hills that suffered significant damage (moment-frame connection fractures) during the 1994 Northridge earthquake. This building has been the subject of detailed study by many research groups since the Northridge earthquake (SAC, 1995b).

The second building is similar to the base building, but the structural system (lateral force-resisting system) has been **redesigned according to the current** building code, UBC97 (1CBO, 1997). The 1997 code regulations specify larger design forces (to account for near-source effects) and call forgreater redundancy in the lateral force-resisting system. This results in a greater number of bays of moment frames (a single bay of a one-story moment frame consists of an assembly of two columns and a single beam spanning from column to column; for a 20-story building this assemblage would be replicated for each story, one on top of the other). As a result, the dynamic properties of the two buildings are significantly different. In general, the redesigned building can be *expected* to perform better than the existing building in the event of an earthquake. The description of the two buildings, the design methodology for the new building, and the detailed comparison of the two buildings in terms of dynamic properties, static strength, and ductility, have been presented in an online report (Krishnan *et al*, 2005).

Numerical Simulation of Ground Motion

The two techniques adopted by seismologists to simulate ground motion consist of either a deterministic or an empirical approach. In the deterministic approach, the elastic wave equation is solved numerically in a realistic 3D Earth model and the ground motion is directly computed without any additional assumptions. In the case of the Los Angeles basin, the **accuracy and frequency limitations depend on the quality** of the 3D Los Angeles **basin** model, which has improved steadily during the past decade, and on the **numerical resolution** of the 3D seismic wave propagation simulation.

For our study, we have used one of the two well-accepted 3D southern California Earth models, the Harvard-LA model (Süss and Shaw, 2003), the other being the SCEC Community Velocity Model (Magistrale *et a!*, 1996, 2000; Kohler *et al*, 2003). Both models allow us to model the basin response down to a shortest period of approximately 2 sec (Komatitsch *et al*, 2004). The Harvard-LA sedimentary basin model (which includes the crust and the upper mantle) is constrained by hundreds of petroleum industry well logs and more than 20,000 km of seismic-reflection profiles. A **limitation** of both Earth models is that the top soil layer, also called the **geotechnical layer, is not included** because of lack of sufficient data and the numerical complexity associated with low shear-wave speeds in this layer, which would requite a very dense numerical grid to ensure correct sampling of the corresponding seismic wavelengths. This typically softer layer may have the **effect of amplifying the ground motion** (Haskell, 1960; Anderson *et al*, 1996).

Having said this, the buildings that we analyze are long-period structures most affected by long-period waves with wavelengths far greater than the depth of the unmodeled soil layer; these waves simply do not see the layer, and as a result, the effect of the top soil layer on the simulated ground motion (with periods longer than 2 sec) is *likely* to be insignificant. Furthermore, maps of the geotechnical layer do not currently exist for southern California. A final limitation is that 3D seismic-wave **propagation codes that can handle a geotechnical layer are currently not available**. Including the geotechnical layer, when a model becomes available, will require the consideration of very high frequencies and much higher resolution, and therefore the numerical cost would be high.

The second commonly used seismological approach consists of generating broadband ground motion through empirical methods that combine a stochastic approach at high frequencies with a deterministic approach at low frequencies (*e.g*, Graves and Pitarka, 2003; Graves, 2005). These methods are still nascent in their development. They are tailored for a given earthquake and have to be retuned on a case-by-case basis. Being empirical, they cannot be proved or validated consistently for various types of earthquakes.

In this study, we take a deterministic approach to simulate ground motion based on the spectral-element method (*e.g*, Komatitsch and Tromp, 1999). The numerical simulations, which account for 3D variations of seismic-wave speeds and density, topography and bathymetry, and attenuation, are carried out using our open-source seismic-wave propagation package SPECFEM3D (www.geodynamics.org). The methodology adopted therein has been shown to reliably model ground motion down to a period of approximately 2 sec, using data from recent earthquakes (Komatitsch *et al*, 2004: Liu *et al*, 2004). The simulations **do not consider scattering** of the wave field from city buildings (e.g, Clouteao and Aubry, 2001).

Building Damage Analysis

The nonlinear time-history analyses of the building models are carried out using a finite-element program, FRAME3D (Krishnan. 2003a: see www.frame3d.caltech.edu for details). The particular 3D elements used by the program to model beams, columns, and joints in buildings have been shown to simulate damage accurately and efficiently (Krishnan, 2003b). Material nonlinearity resulting in flexural yielding, strain hardening, and ultimately rupturing of steel at the ends of beams and columns, and shear yielding in the joints (also known as panel zones) is included (Krishnan and Hall, 2006a,b).

When the forces from an earthquake displace a building laterally (A), the gravity loads (P) acting vertically downward **cause a second-order overturning moment** on the structure about its base, in addition to the overturning moment caused by the lateral forces themselves. This is termed the P - A effect and can lead to **global instability of the building**. The FRAME3D program incorporates geometric nonlinearity, which enables the modeling of the global stability of the building, accounting for P - A effects accurately.

The fracture mode of failure is included in connections, but **local flange buckling in beams and columns is not.** Column splices can he incorporated into the model, but they are excluded in this study. Soil-structure interaction (SSI; e.g, Stewart *et al*, 1998; Trifunac *et al*, 2001) is not included in the analyses. Dynamic nonlinear SSI is not a well-understood phenomenon because of the lack of recorded data and the difficulty in designing accurate numerical tools to study it.

One of the few real-world examples of extensive SSI research is a 14-story reinforced concrete storage building in Hollywood constructed in 1925 (Serino, 1989; Fenves and Serino, 1990; Trifunac *et al*, 2001). These studies indicate that the change in various structural-response parameters in this building during the 1 October 1987, magnitude 5.9 Whittier Narrows earthquake due to SSI could have been up to 20%. SSI is an active area of research and should be incorporated into future studies of this kind.

Assessing Building Damage

The primary structural-response parameter that is used to evaluate structural performance is the interstory drift, which is the difference in displacement between the top and bottom of a story normalized by its height. The interstory drift is a **good indicator of how far the building is from P -. A instability and collapse**. It is also closely related to the plastic rotation demand on individual beam-column connection assemblies; that is, the greater the yielding in the beams, columns, and joints, the greater this interstory drift would be, reducing the stability of the building.

Because there are **very few usable data** to assess the performance of tall buildings based on calculated drifts, we take an empirical approach proposed by the Federal Emergency Management Agency (FEMA). For rehabilitation of existing buildings, FEMA 356 (FEMA, 2000a) defines three performance levels:

Immediate Occupancy (TO) refers to a post-earthquake damage state in which very limited structural damage has occurred. The risk of life-threatening injury as a result of structural damage is very low, and although some minor structural repairs may be appropriate, these would generally not be required prior to re-occupancy.

Life Safety (LS) is a post-earthquake damage state that includes damage to structural components but retains a margin against onset of partial or total collapse.

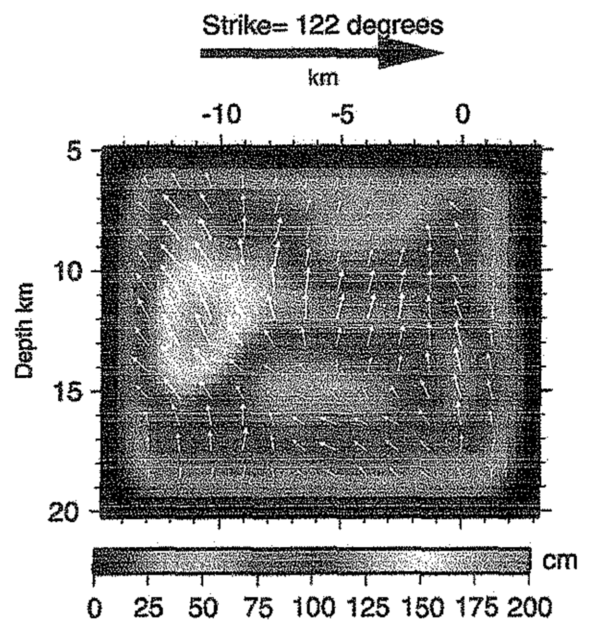
Collapse Prevention (CP) refers to a post-earthquake damage state that includes damage to structural components such that the structure continues to support gravity loads but **retains no margin against collapse.** For existing buildings, the interstory drift limits for the **IO**, **LS**, and **CP** performance levels specified hy FEMA are **0.007, 0.025, and 0.05**, respectively. For the design of new steel moment-frame buildings, FEMA 350 (FEMA, 2000b) defines only two performance levels, the **IO** and **CP** levels. For buildings **taller than 12 stories**, the interstory drift limits for these levels as specified therein are **0.01 and 0.06**, respectively.

In the existing building, we also take into account the fracture mode of failure in the beam-to-column connections that was widely observed during the Northridge earthquake. The details of the fracture models can be found in Krishnan *et al* (2005). The fracture index representing the percentage of connections in the building that fractured is also used in this study to assess existing building performance. Since the Northridge earthquake, this defect has been corrected and we do not *expect* this mode of failure to happen in buildings built recently or today.

Validation of Numerical Procedures

The magnitude 6.7, 1994 Northridge earthquake was widely recorded at seismic stations in southern California. Although many research groups have determined kinematic fault models by fitting seismic- waveform data (e.g, Hartzell *et al*, 1996; Wald *et al*, 1996), we use a wavelet transform approach (Ji *et al*, 2002) that can extract more information about slip heterogeneity by simultaneously considering both the time and frequency characteristics of the waveforms. The resulting finite-source model is shown in Figure 3. Using the spectral-element method (e.g., Kornatitsch and Tromp, 1999) we simulate ground motion generated by our finite-source model of the Northridge earthquake.

Figure 3. Slip model for the 17 January 1994, magnitude 6.7 Northridge earthquake determined with a wavelet transform approach. The star denotes the hypocenter and the white arrows denote the slip vector. The dip angle of the fault is 40 degrees (see Fig. 1 for the surface projection of the fault).



For the Northridge simulation, in addition to the 636 sites considered in this study, we compute seismograms at seismic stations in southern California that actually recorded the shaking during the earthquake. The synthetic seismograms (red) are compared against the recorded data (black) at distant stations (Fig. 4a) and at nearby stations north of the fault (Fig. 4b). All the waveforms are lowpass filtered at a corner period of 2 sec. The synthetic seismograms capture the large pulses at the nearby stations, and there is a very good match in most waveforms corresponding to distant stations.

Although there is sufficient ground-motion data to validate the seismological component of our procedure, the same is not true of tall-building performance. Not many tall buildings in the region were instrumented at the time. One building that was instrumented was the previously described 18-story steel moment frame building in Woodland Hills built in 1984. **Many connections** in the lateral force-resisting moment frames of this building **fractured** (SAC, 1995b). There was a three-component accelerometer on the 18th floor of the building that recorded the floor acceleration (Darragh *et al*, 1994). Unfortunately, the closest free-field seismometer was the Oxnard Boulevard station (WHOX) in Woodland Hills, located about 800 meters away from the building.

We analyze the building model for shaking from the recorded three-component ground motion (Darragh *et al*, 1994) using FRAME3D. The computed displacements at the 18^{th} floor in the north-south and east-west directions are compared with the corresponding measured displacements in Figure 4c and d. The computed peak displacement in the north-south direction is within 5% of the measured displacement, but the peak displacement in the east-west direction is **off by a factor of 2**. There is a minor lengthening of the period in the measured displacement that is not captured by the computed displacements. Also, the measured displacement attenuates faster than the computed displacement.

These **differences could be due to any or all of the following** factors: the ground motion used in the analysis was not recorded at the base of the building but 800 m away; the instrument at the roof was maintained by the

These **differences could be due to any or all of the following** factors: the ground motion used in the analysis was not recorded at the base of the building but 800 m away; the instrument at the roof was maintained by the owner of the building and its reliability is therefore uncertain; rocking of the building about its base (due to the finite stiffness of the soil), which is not included in the fixed-base *structural* model, could contaminate the displacement record measured at the roof and the observed period may actually be a combination of purely translational and rocking modes; as damage accumulates in a building during an earthquake, (nonhysteretic) damping increases significantly. In our structural model, while hysteretic damping is modeled accurately in a nonlinear fashion, nonhysteretic supplemental damping is considered to be viscous and linear, and as damage accumulates, it does not increase correspondingly. Greater details, including the comparison of observed and computed distributions of fractures in the various moment frames, can be found in Krishnan *et al* (2005).

From this description, the limitations of our validation studies are obvious. Whereas the validation is based on the magnitude 6.7 Northridge earthquake, the scenario earthquakes simulated below are of magnitude 7.9 (*i.e*, with energy release about two orders of magnitude greater). Similarly, the source mechanism of the Northridge earthquake was a thrust mechanism that did not break the surface, whereas the San Andreas simulation has a strike-slip source mechanism with surface break. Furthermore, the amount of data collected during the Northridge earthquake, especially with regard to buildings, is fairly limited, and this restricts the extent to which the numerical procedures can be convincingly validated.

Having said this, validation is a critical element of studies such as this and data from future earthquakes will inevitably play a *crucial* role in improving the numerical procedures.

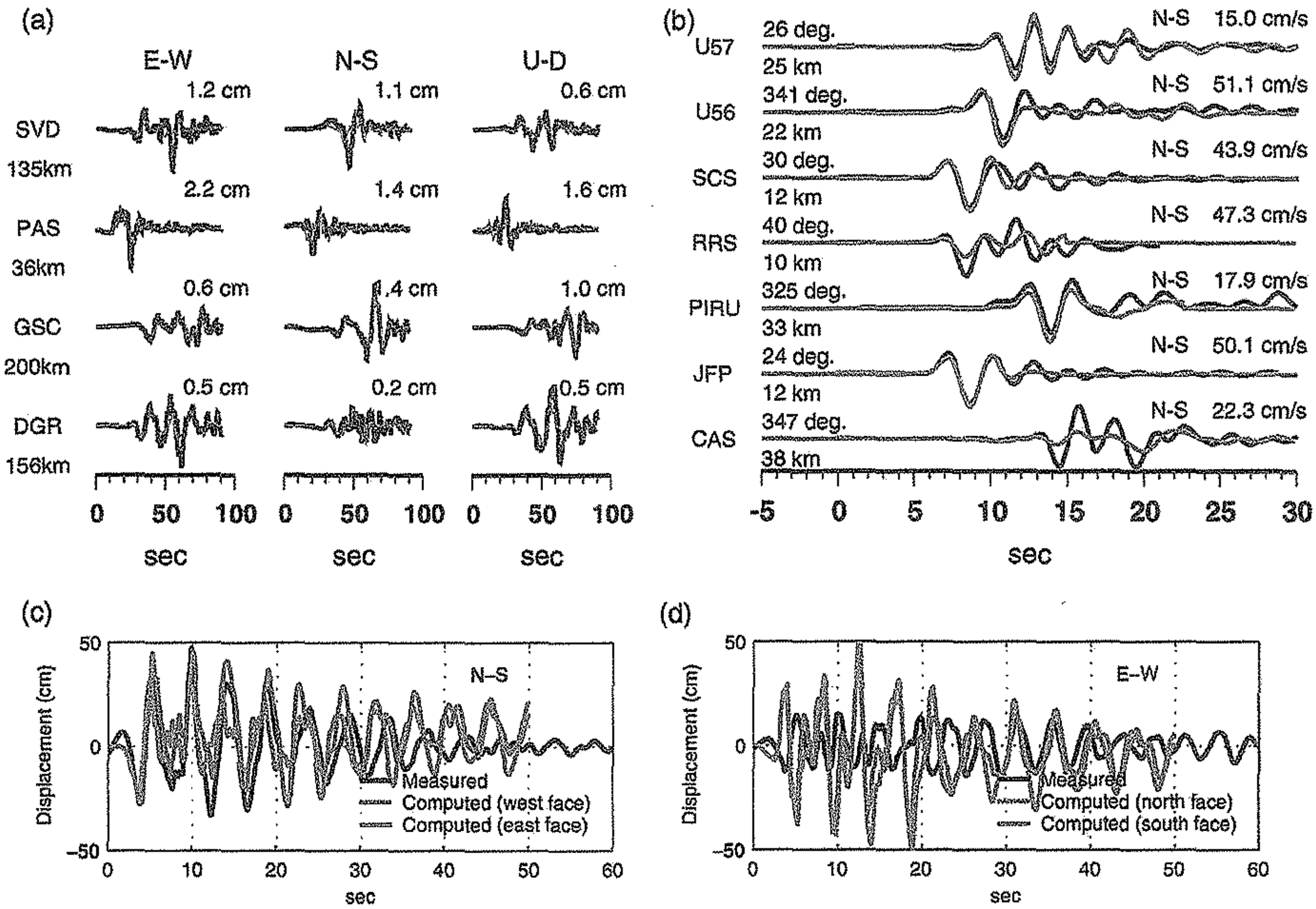


Figure 4. Simulation of the 17 January 1994, magnitude 6.7 Northridge earthquake. (a) Data (black) versus synthetic seismograms (red)—distant stations. (b) Data versus synthetic seismograms—nearby stations north of the rupture. (c) and (d) Measured 18th floor north-south and east-west displacements versus corresponding computed displacements using the unfiltered WHOX record (station located 0.5 mile from building)—existing building in Woodland Hills.

Effect of Excluding Ground Motion High-Frequency Content

As mentioned earlier, ground motion simulated using SPECFEM3D in the Los Angeles basin has been shown to be accurate down to a period of approximately 2 sec. Because of this limitation, all the computed broadband time histories are lowpass filtered with the corner period at 2 sec (in practice, bandpass filtered between 2 sec and 1000 sec). The filtered ground-motion records are used as input to the building analysis software. However, building response is a function of the entire frequency band of the ground motion with the building's higher modes corresponding to shorter periods excited by high-frequency ground motion. The question arises, therefore, as to what the **effect of excluding** the high-frequency ground motion is on the response of the considered buildings. Because dominant modes of tall buildings of the type considered here have periods greater than 2 sec it is *theorized* that the effect of the higher frequencies on the ground motion *may not have a significant* impact on their response. To confirm this, we perform the following study: we take a total of 13 three-component records from the 21 September 1999, magnitude 7.7 Chi-Chi earthquake in Taiwan, and the 25 September 2003, magnitude 8.3 Tokachi-Oki earthquake in Japan. We lowpass filter these records with a corner period of 2 sec We then compare the responses of the existing and redesigned buildings to the filtered and unfiltered records.

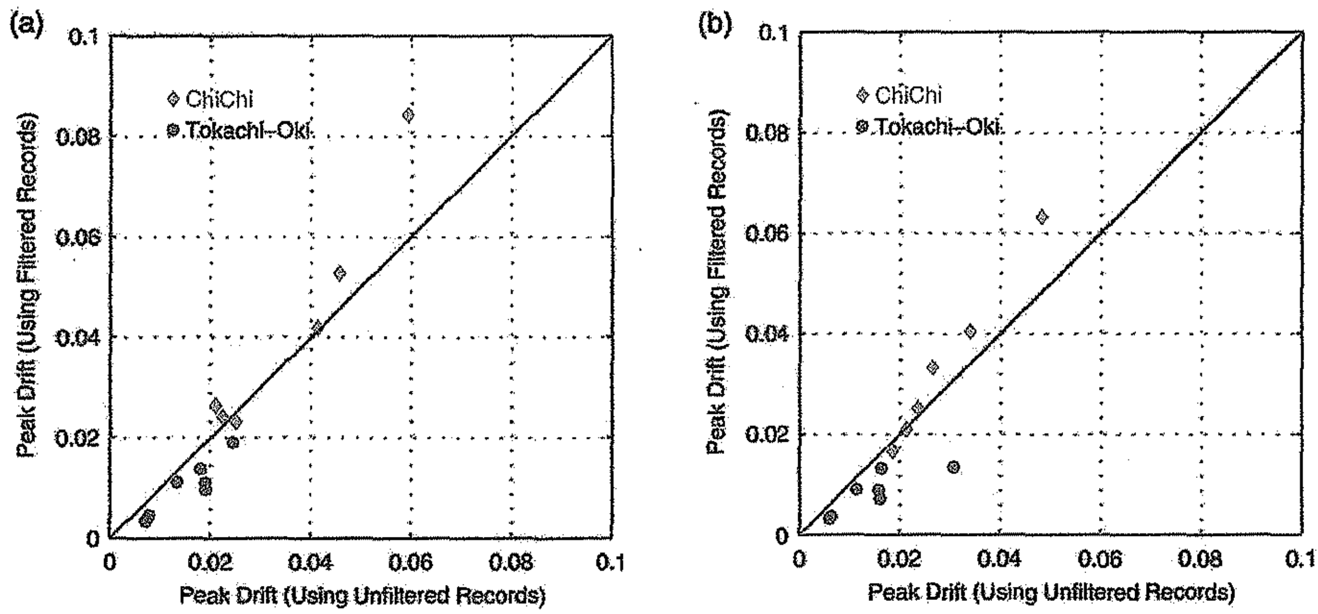


Figure 5. Analyses of the existing and redesigned buildings subject to 13 unfiltered and lowpass-filtered records from the 21 September1999, magnitude 7.7 Chi-Chi earthquake in Taiwan, and the 25 September 2003, magnitude 8.3 Tokachi-Oki earthquake in Japan: computed peak drifts in the building using filtered records versus those using unfiltered records The close alignment of the points with the diagonal indicates that the effect of higher-frequency ground motion (periods (≤2 sec) on the response of the tall buildings considered in this study is not significant and can be safely ignored.

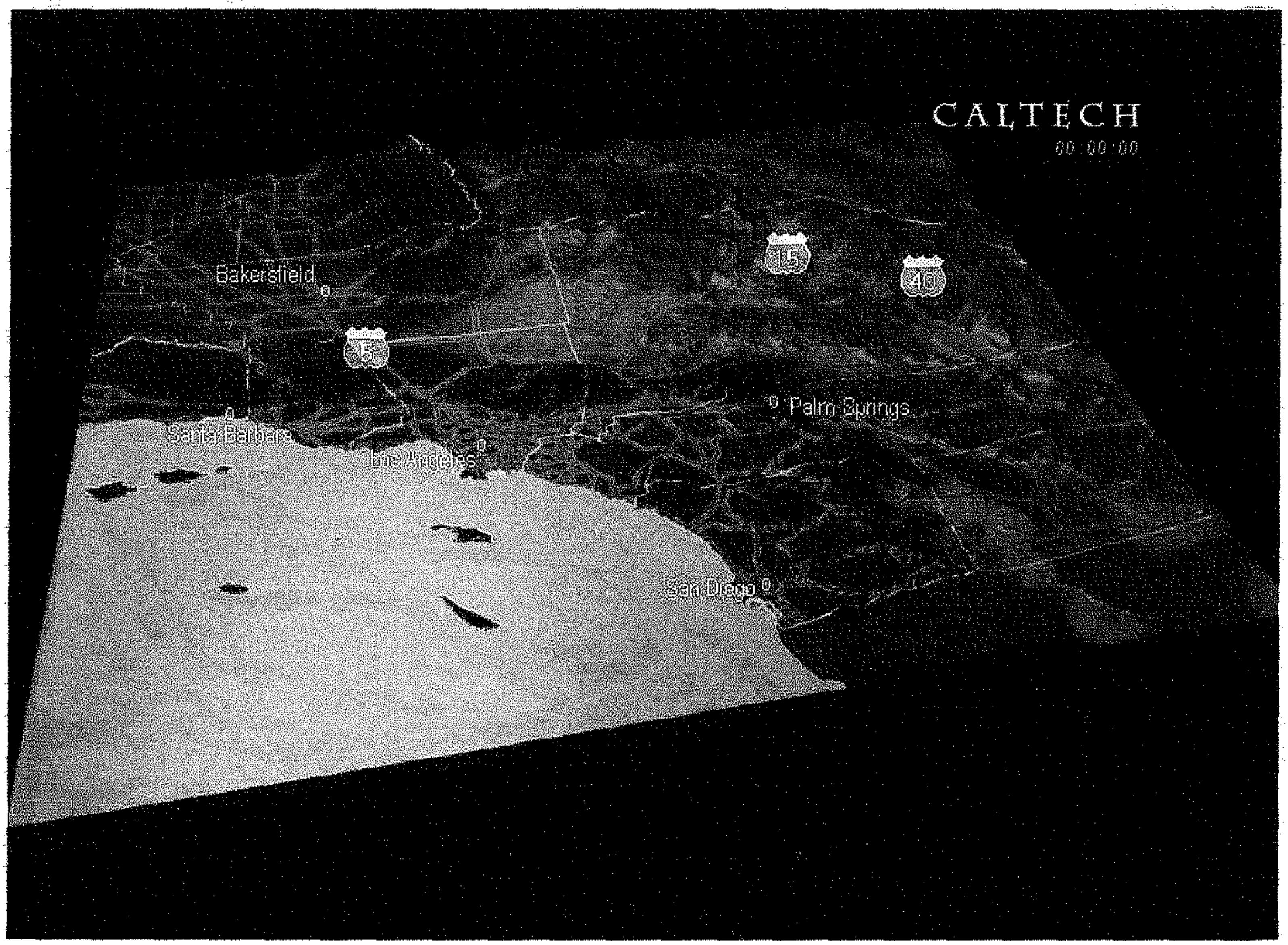
Shown in Figure 5 are the peak drift ratios computed in the existing and redesigned buildings using the filtered records plotted against those computed using the corresponding unfiltered records. If the high frequency g round motion had no effect whatsoever on the response of the building, then all the points would fall on the diagonal. The fact that all the points are aligned quite closely with the diagonal indicates that the effect of high frequency ground motion (the range of frequencies not included in our simulation) on the tall-building response (for the buildings considered here) is not significant and can be safely ignored.

In essence the initial S wave damages the tall building, and this leads to a softening of the structure, thus shifting the natural frequency spectrum of the building further into the long period regime, reducing even more the effect of the high-frequency content in the ground motion.

San Andreas Simulation: North-to-South Rupture Source Model

For the San Andreas simulations it is critical to have a realistic source model (slip distribution in time along the fault). The Denali fault system in Alaska is geometrically similar to the San Andreas fault. On 3 November 2002, a magnitude 7.9 earthquake occurred on this fault system. It initiated as a magnitude 7.1 thrust event on the Susitna Glacier fault, quickly changed to a strike-slip mode of rupture, and propagated southeastward along the Denali fault for 218 km before jumping to the Totschunda fault and continuing further for about 76 km.

CASE STUDY ILLUSTRATIONS
These are stopped-motion pictures of Seismic Responses
See Krishnan: Case Studies of Tall Steel Moment-Frame Buildings in So. Calif.



1. So. Calif. At Start of 7.9 Quake at Parkfield, CA (NW of Bakersfield)

CASE STUDY ILLUSTRATIONS

These are stopped-motion pictures of Seismic Responses

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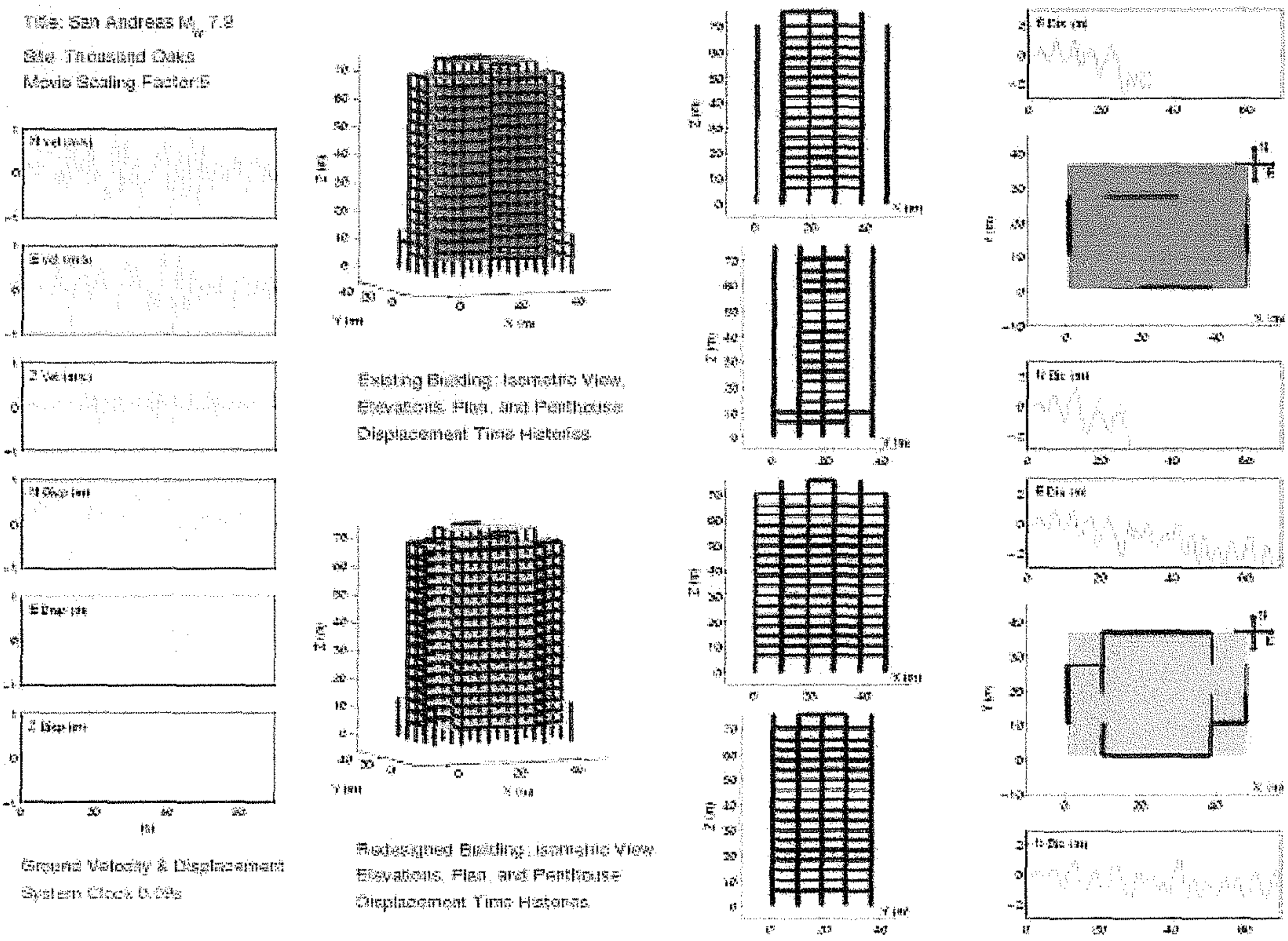

2. Building At Start of 7.9 Quake at Parkfield, CA (NW of Bakersfield)

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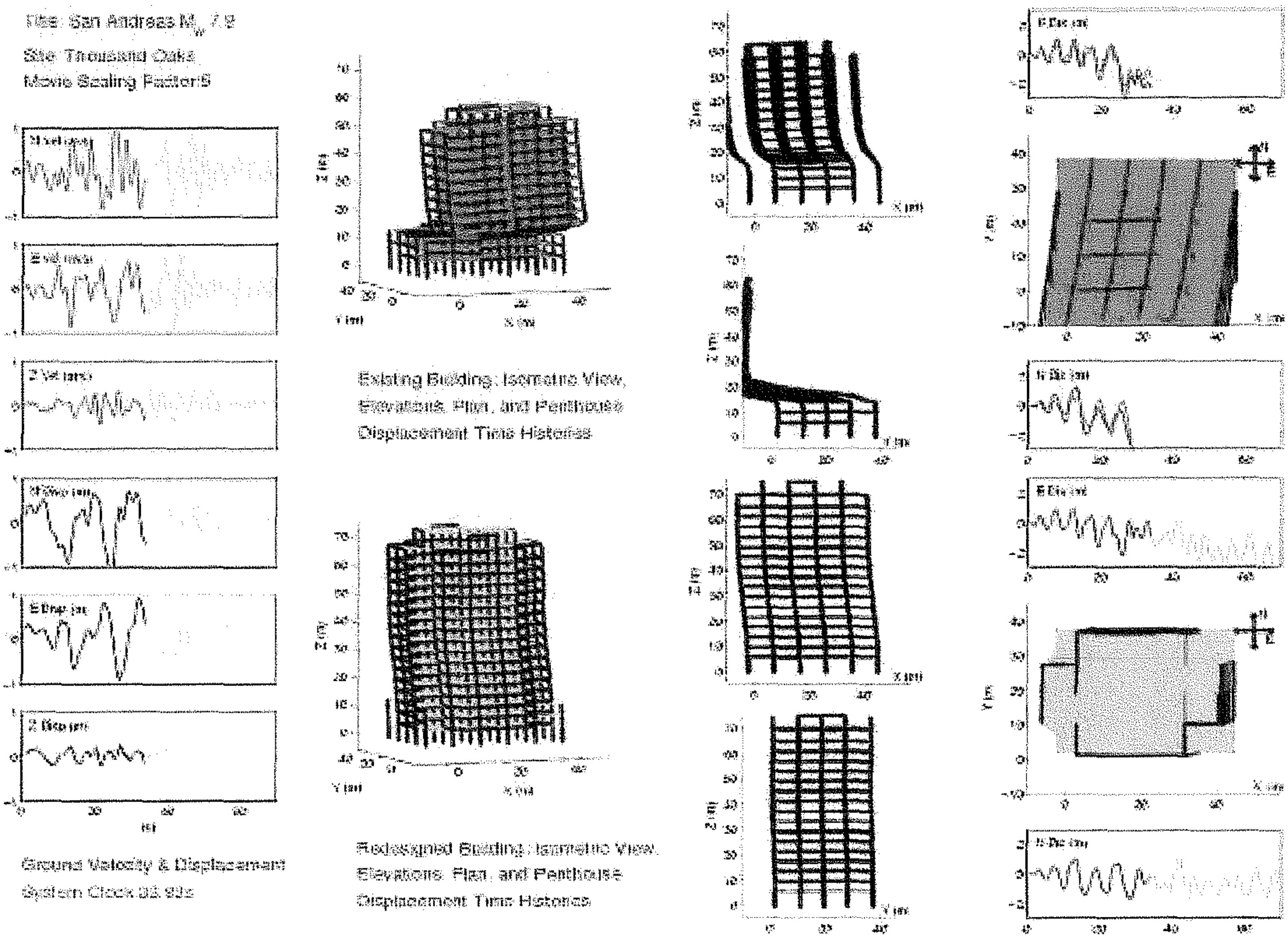

3. Existing Building Collapses during 7.9 Quake at Parkfield, CA (NW of Bakersfield)

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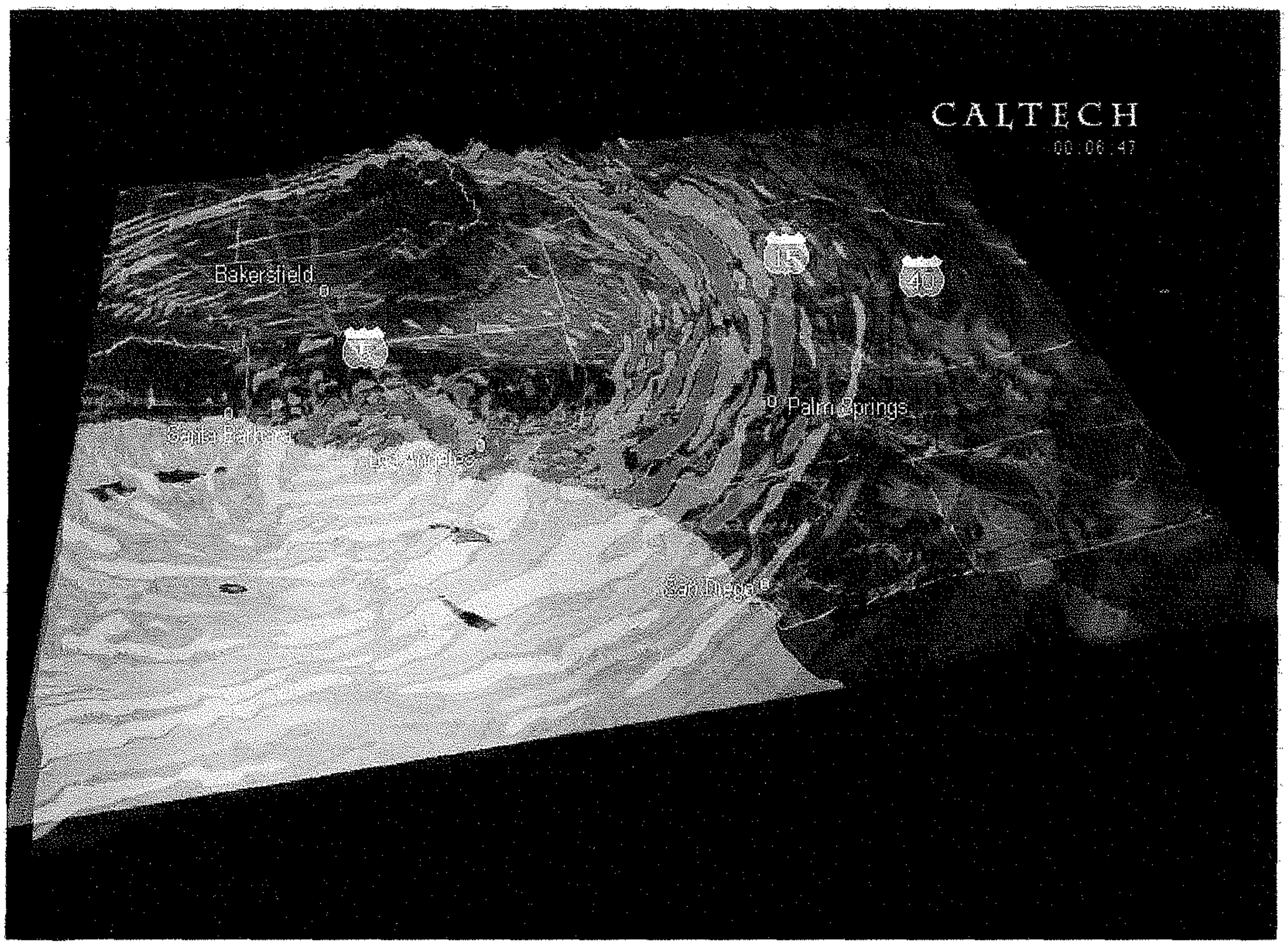

4. Distortions in Ground Waves during 7.9 Quake at Parkfield, CA (NW of Bakersfield)

CASE STUDY ILLUSTRATIONS

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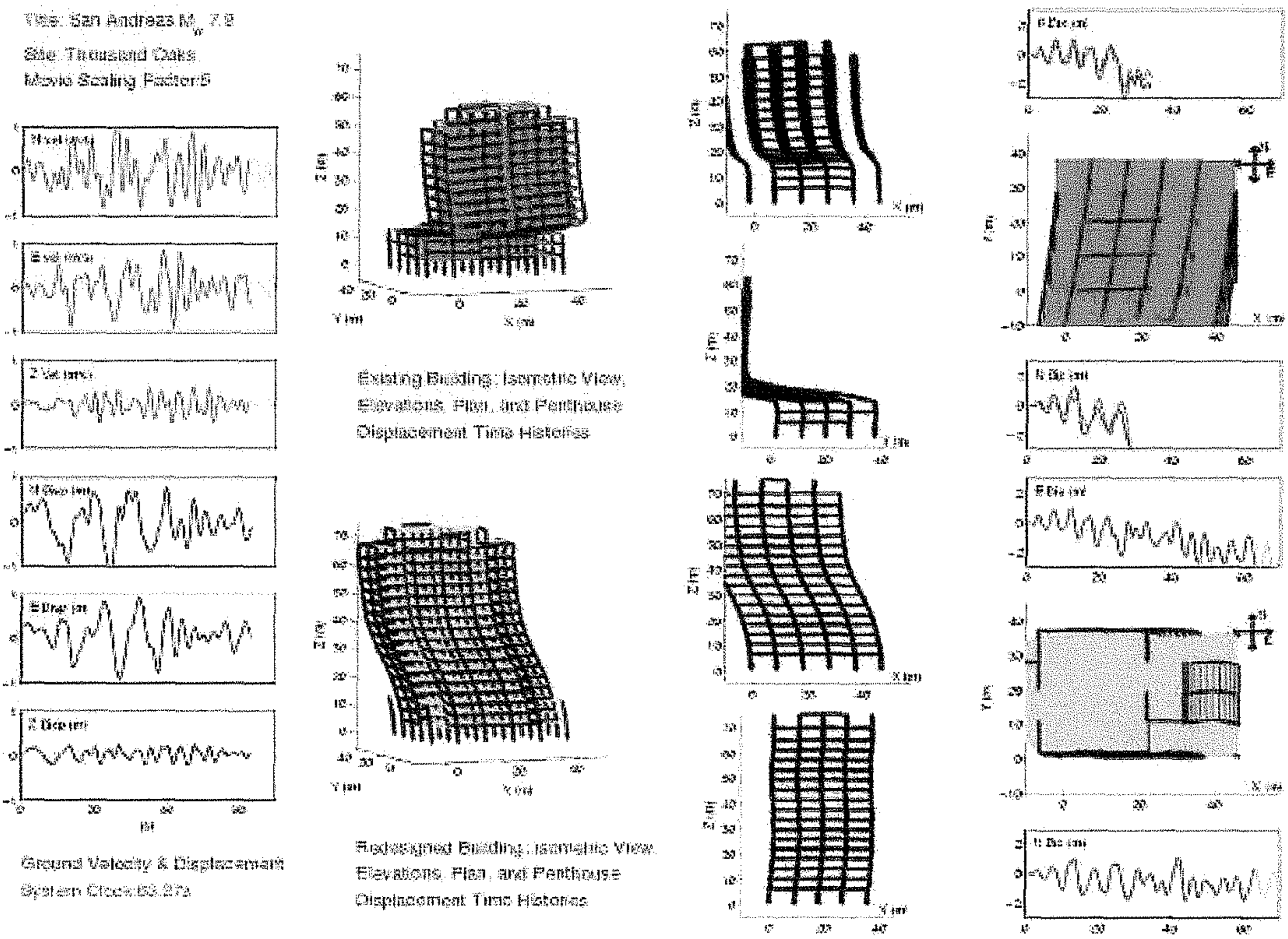

5. Code-updated Building Fails during 7.9 Quake at Parkfield, CA (NW of Bakersfield)

CASE STUDY ILLUSTRATIONS
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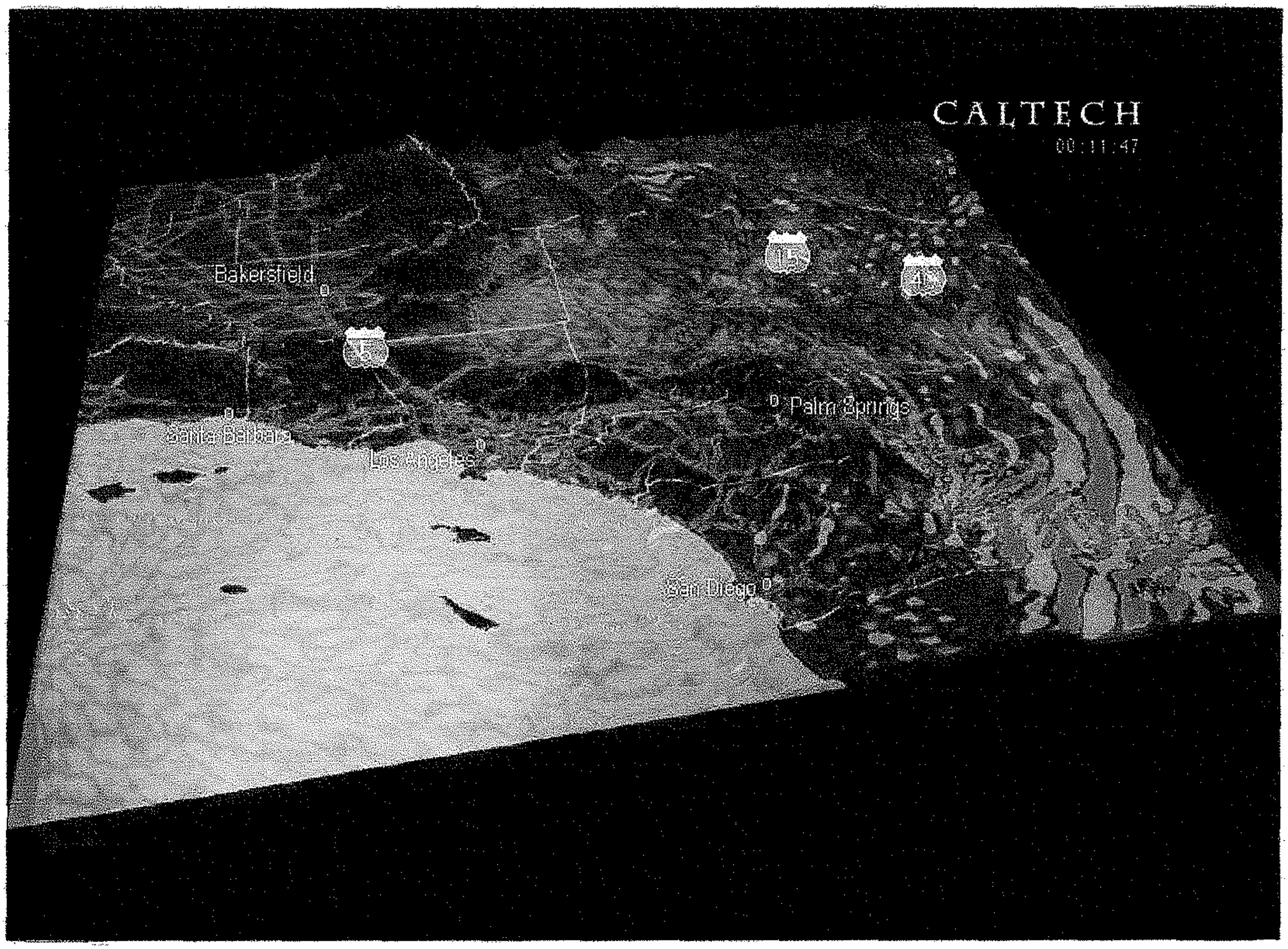
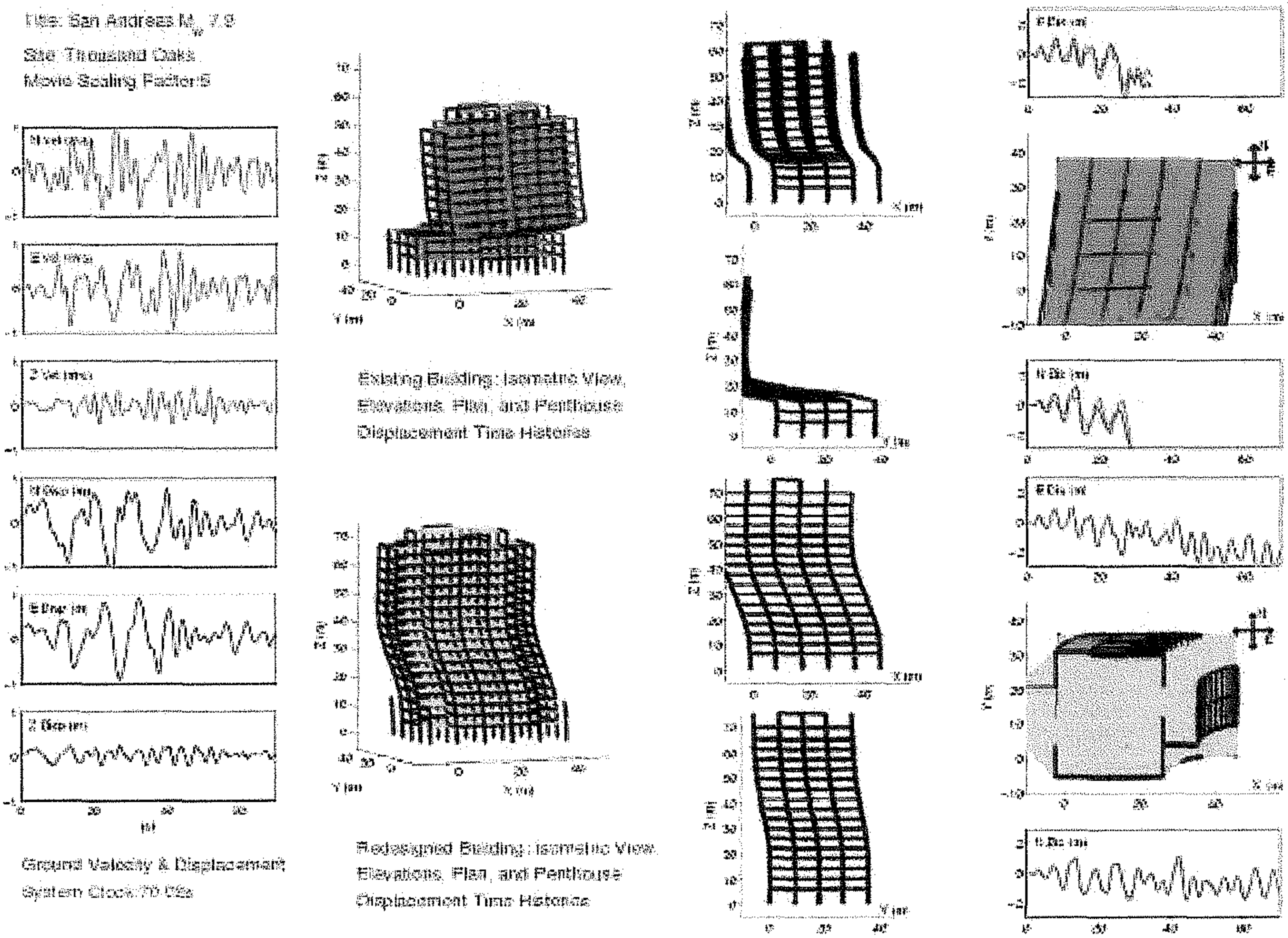


6. Seismic Waves Recede in City during 7.9 Quake at Parkfield, CA (NW of Bakersfield)

CASE STUDY ILLUSTRATIONS

These are stopped-motion pictures of Seismic Responses

See Krishnan: Case Studies of Tall Steel Moment-Frame Buildings in So. Calif.



7. Collapsed or Condemned Building after 7.9 Quake at Parkfield, CA (NW of Bakersfield)

A NEW FORECAST OF CALIFORNIA EARTHQUAKES

The 2007 Working Group on California Earthquake Probabilities (WGCEP 2007), a multi-disciplinary collaboration of scientists and engineers, has released the **Uniform California Earthquake Rupture Forecast** (UCERF) — the first comprehensive framework for comparing earthquake likelihoods throughout all of California. It provides important new information for improving seismic safety engineering, revising building codes, setting insurance rates, and helping communities prepare for inevitable future earthquakes.

In developing the UCERF, the 2007 Working Group revised earlier forecasts for Southern California (WGCEP 1995) and the San Francisco Bay Area (WGCEP 2003) by incorporating new data on active faults and animproved scientific understanding of how faults rupture to produce large earthquakes. It extended the forecast across the entire state using a uniform methodology, allowing for the first time meaningful comparisons of earthquake probabilities in urbanized areas such as Los Angeles and San Francisco Bay Area, as well as comparisons among the large faults in different parts of the state.

The study was organized by the Southern California Earthquake Center, the U.S. Geological Survey, and the California Geological Survey, and it received major support from the California Earthquake Authority, which is responsible for setting earthquake insurance rates statewide. During the three-year study, advice and comment was sought from the broader community of earthquake scientists and engineers through open meetings and workshops. Where experts disagreed on aspects of the forecast, alternative options were accounted for in calculations to reflect these uncertainties. The final forecast is a sophisticated integration of scientific data and expert opinion.

UCERF Earthquake Probabilities

According to the new forecast, **California has 99.7% chance of having a magnitude 6.7 or larger earthquake during the next 30 years.**

The likelihood of **an even more powerful quake of magnitude 7.5 or greater in the next 30 years is 46%. Such a quake is more likely to occur in the southern half of the state (37% chance In 30 years)** than in the northern half (15% chance in 30 years).

The **probability of a magnitude 6.7 or larger earthquake over the next 30 years striking the greater Los Angeles area is 67%.**

For the entire California region, the fault with the highest probability of generating at least one magnitude 6.7 quake or larger is the southern San Andreas (59% in the next 30 years).

Earthquake probabilities for many parts of the state are similar to those in previous studies, but probabilities calculated for the Elsinore and San Jacinto faults in southern California are about half those previously determined.

For the northwestern part of the State, a major source of earthquakes is the offshore 750-mile-long Cascadia Subduction Zone, the southern part of which extends about 150 miles into California. For the next 30 years there is a 10% probability of a magnitude 8 to 9 quake somewhere along that zone.

The UCERF model includes the concept that **earthquake likelihoods change with time.** A fault that has ruptured in a recent **large earthquake** is less likely to produce another quake in the near future, because tectonic stress has not had time to build back up. Likewise, a fault that last ruptured a **long time ago** is more likely to produce an earthquake, because the stress on the fault has had time to re-accumulate. The faults with elevated probabilities for an earthquake include the southern San Andreas and Hayward-Rogers Creek Faults.

Earthquake Forecasting, Hazard, and Risk

Californians know their State is subject to frequent — and sometimes very destruclive — earthquakes. Accurate forecasts of the likelihood of earthquakes can help people prepare for these inevitable events. Because **scientists cannot yet make precise predictions of the date, time, and place of future quakes**, forecasts must be in the form of the probabilities of quakes of certain sizes occurring during specified periods of time.

Earthquake probabilities derived by scientists can help people plan and prepare fur future quakes. When an earthquake occurs, two things happen. The first is a fault rupture— a crack in the Earth's crust— gives way and slips under tectonic stress. The second is the radiation of seismic waves caused by this sudden fault motion, which spread out like ripples from a pebble tossed into a pond. The **ground shaking that occurs as these seismic waves pass by causes most of the damage.** The strength of the waves at a particular site depends on the earthquake's magn itude, which measures the size of the fault rupture, the distance of the site from the rupture, and the **local geological conditions** at the site.

The UCERF study has determined the **probabilities that different parts of California will experience earthquake ruptures of various magnitudes ("earthquake rupture forecast") but not the likelihood of shaking that will be caused by these quakes ("seismic hazard").** This is an important distinction, because even **areas with a low probability of fault rupture can experience shaking and damage from distant, powerful quakes.**

The U.S. Geological Survey is incorporating the UCERF into its **official estimate of California's seismic hazard, which in turn will be used to update building codes.** Other subsequent studies will add information on the **vulnerability of manmade structures to estimate expected losses, which is called "seismic risk."** In these ways, UCERF will help to increase public safety and community resilience to earthquake hazards.

The results of the UCERF study serve as a reminder that **all Californians live in earthquake county and should therefore be prepared** (*see Putting Down Roots in Earthquake Country*) Although earthquakes cannot be prevented, the damage they do can be greatly reduced through prudent planning and preparedness. The ongoing work of the Southern California Earthquake Center, U.S. Geological Survey, California Geological Survey, and other scientists m evaluating eanhquake probabthties is part of the National Earthquake Hazard Reduction Program's efforts to **safeguard lives and property from the future quakes that are certain to strike in California** and elsewhere in the United States.

Regional Report

SUMMARY 11-02 June 2011 U.S. BUREAU OF LABOR STATISTICS

Labor market risks of a magnitude 7.8 earthquake in southern California

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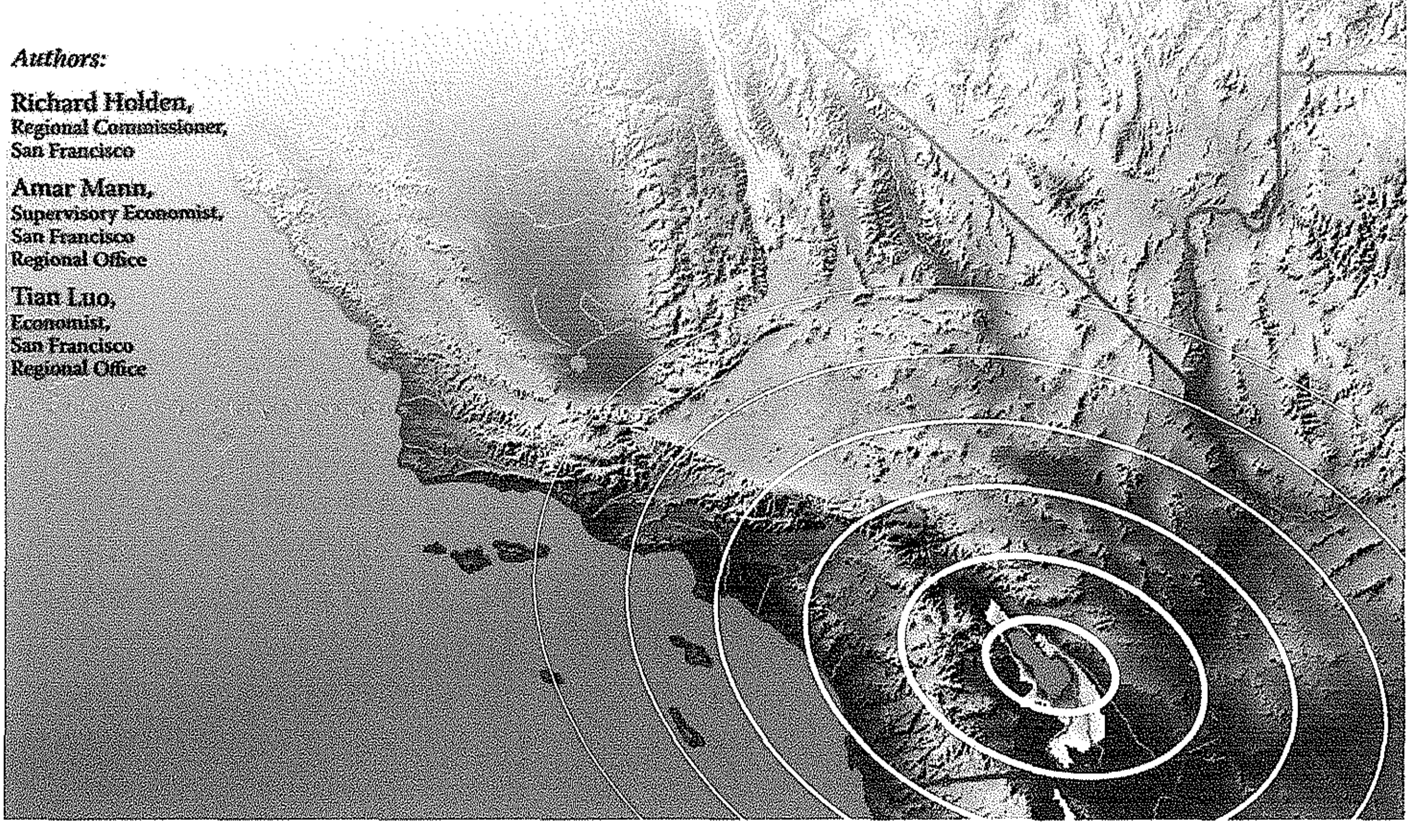


The ShakeOut Scenario is a program developed by the U.S. Geological Survey (USGS) to examine the implications of a magnitude 7.8 earthquake in southern California and to help people and organizations become better prepared before the next big earthquake. According to USGS, the most likely source of a large earthquake in California is the southern segment of the San Andreas Fault, which runs through the heavily populated counties of Los Angeles, Riverside, and San Bernardino.[1] The southern section of the San Andreas Fault has not ruptured for more than 300 years, although evidence indicates that a large earthquake has occurred on the fault every 150 years, on average. The ShakeOut Scenario simulated a magnitude 7.8 earthquake on the southern San Andreas Fault, and the program's scientists determined this hypothetical earthquake would create very strong to severe shaking and cause moderate to heavy damage across seven southern California counties.

The 7 southern California counties that would be most affected by the earthquake are home to 621,000 business establishments, 6.3 million employees, and an annual payroll of $303.3 billion, according to data from the Quarterly Census of Employment and Wages (QCEW) published by the U.S. Bureau of Labor Statistics (BLS). The inset of map 1 delineates the shaking intensities that could occur as the result of a magnitude 7.8 earthquake on the southern San Andreas Fault, as measured by the Modified Mercalli Intensity

(MMI) scale. When employment and wages data from the QCEW are spatially integrated with the shaking intensity zones provided by the ShakeOut Scenario, we are able to tabulate the potential business and labor market risks from a major earthquake, as shown in the larger part of map 1. Our analysis includes both the exposure across the seven southern California counties and the impact on industry groupings.[2]

In this report, we analyze and map QCEW data to assess the potential business and economic losses if a 7.8 magnitude earthquake were to occur in southern California. This report may be used to inform individuals, schools, businesses, organizations, communities, and governments about the effects of a major earthquake in their communities.

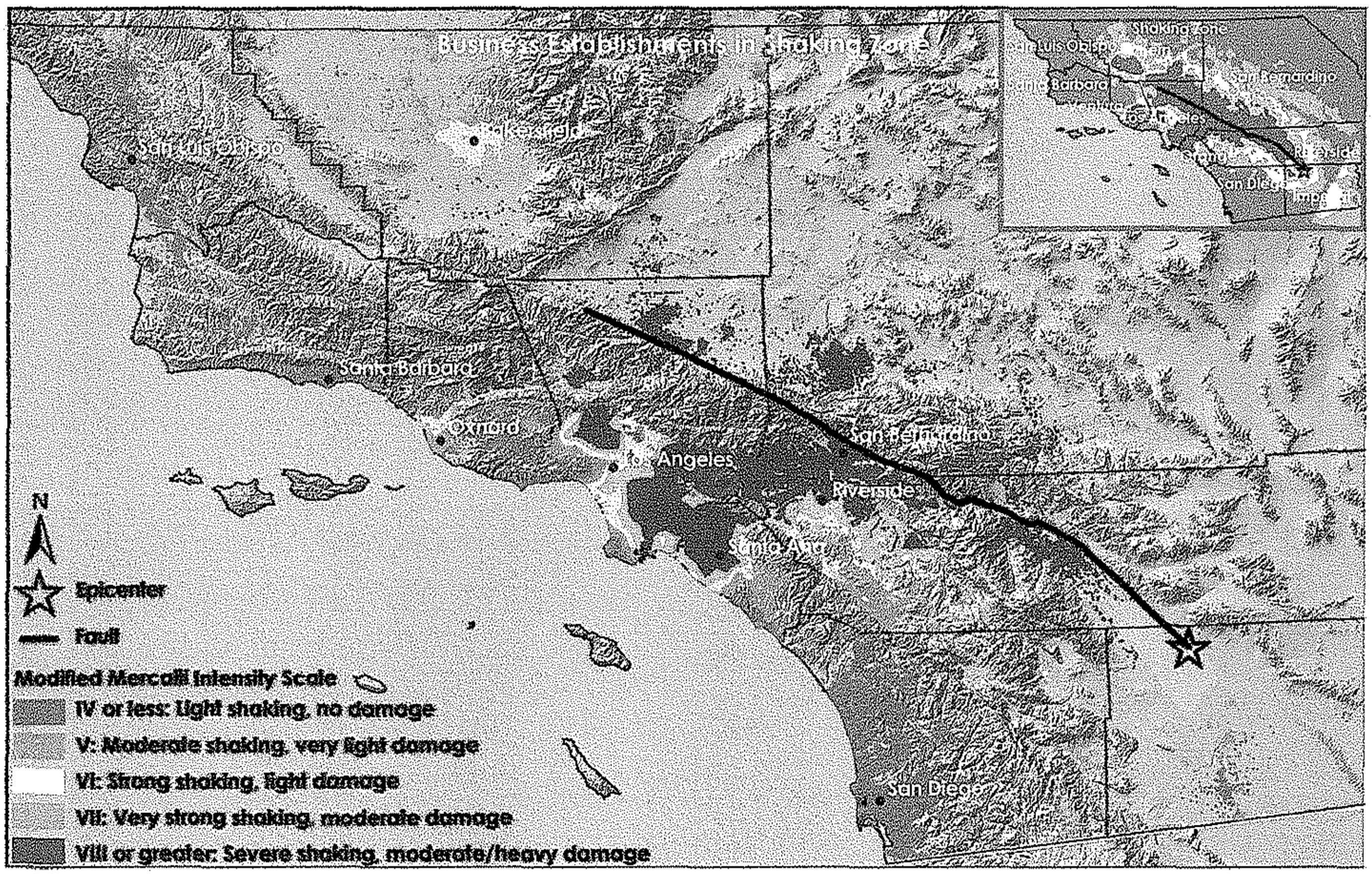
About the Modified Mercalli Intensity Scale

Seismic intensity is a measure of the effects of an earthquake at different sites. Intensity differs from magnitude in that the effects of any one earthquake vary greatly from place to place, so there may be many intensity values measured from one earthquake. Each earthquake, on the other hand, should have just one magnitude (often measured by the moment magnitude scale or by the Richter scale). The Modified Mercalli Intensity (MMI) scale is commonly used to gauge the severity of earthquake effects. Intensity ratings are expressed as Roman numerals between I at the least destructive and XII at the most destructive. At MMI-VII, while damage may be slight in specially designed structures, there is often considerable damage and partial collapse even in substantial ordinary buildings.

Methodology

Two datasets were merged to prepare for the analysis: a geographic

Map1: **Employers in Shaking Intensity Zones for a hypothetical magnitude 7.8 Earthquake on the southern San Andreas Fault**



Note: The cluster of all colors on the main map denote density of establishments; the colors of the clusters denote intensity of shaking zone.

Source: U.S. Bureau of Labor Statistics, Quarterly Census of Earnings and Wages (QCEW) program geocoded data file with shaking intensities from the USGS and an establishment-level micro dataset containing employment and wages from QCEW. The geographic file of intensities, which uses MMI scale measurements, gauges the effects of an earthquake at various distances from the fault rupture. The MMI scale ranges from I (not felt) to XII (total damage).[3] The analysis in this report will focus on those areas with estimated shaking intensities of VII and higher on the MMI scale, that is, areas of very strong shaking and moderate damage to areas with severe shaking and moderate to heavy damage.

The QCEW microdata contain geocoded establishment data, including the employment and wages associated with individual business firms as of the first quarter of 2010. Approximately 92 percent of all businesses, employment, and wages in the microdata were geographically coded and used in this report, therefore the results of the presented analysis understate the actual labor market risks. This dataset is then overlaid by the USGS shaking intensity file to tabulate the exposures to establishments and the employment and wages attributed to those firms.

Limitations of the analysis

Our analysis of business exposures that are attributable to earthquakes has certain limitations. The MMI values describe damage levels ranging from predominately light damage to widespread heavy damage. Even in the most damaged areas, not all businesses will sustain damage that will soon curtail their activities and some businesses that lose capability will return to normal operations. Thus, gauging economic impact by projected MMI levels may overstate the business interruption or losses that will occur.

However, direct damage to a region's businesses understates the interactional effects on customers or suppliers inside and outside the damaged areas. Some businesses cluster in regions to be near their customers and suppliers. If this relationship is interrupted by an earthquake, both customers and suppliers could be severely affected or even put out of business. The expected loss of life and damage to infrastructure and utilities may also interrupt the flow of goods and services in southern California and the United States as a whole because the area is a vital transportation hub for shipments by air, water, rail, and truck.

The earthquake in the ShakeOut Scenario would have broad impacts beyond the labor market, creating greater losses inside and outside the region than can be estimated using only MMI scales and damage zones. USGS has estimated the economic losses of the ShakeOut Scenario earthquake to be approximately $213 billion,[4] when accounting for the direct and indirect earthquake impacts.[5] In addition, as mentioned earlier, businesses that were not geocoded in the QCEW database were excluded from this analysis, so the results presented here represent a lower bound estimate of the at-risk labor market.

Analysis

The southern segment of the San Andreas Fault runs directly through the heavily populated Los Angeles, Riverside, and San Bernardino counties. These are 3 of the 4 most exposed counties in the region in terms of potential damage from earthquakes occurring on the fault. These counties comprise a population of 17 million inhabitants over a 32,000 square mile area, with most of the population and businesses located in Los Angeles and Orange Counties and the western parts of San Bernardino and Riverside Counties. (See table 1.)

Total exposures in the 7 counties in southern California that are in the very strong shaking zone (MMI VII) and destructive shaking zone (MMI VIII or higher) include 434,000 employers, over 4.5 million jobs, and annual wages of $206.5 billion. In the wide area circumscribed by both zones, the business, employment, and earnings exposures would fall primarily upon the counties of Los Angeles, Orange, San Bernardino, and Riverside, with Los Angeles County having the most exposures and Riverside County having the least. These four counties account for more than 99 percent of all exposures in the shaking zones. More than half of the employment and earnings exposure in the destructive shaking zone (MMI VIII or higher) would fall in Los Angeles County alone. Approximately 3 of every 5 businesses affected in the destructive shaking zone are also in Los Angeles County.

As shown in table 2, the percentage of each county's economic base that is considered to be at risk during an earthquake varies greatly. Although about 70 percent of all businesses, employment, and wages across the 7-county area are exposed, 4 of the 7 counties in the scenario are estimated to have business and labor-market

Table 1. Potential exposure from a magnitude 7.8 earthquake along the southern San Andreas Fault, 7 southern California counties, first quarter of 2010

County	Located in very strong shaking zone (MMI VII)			Located in destructive shaking zone (MMI VIII+)			Proportion of Total Affected Employment
	Business establishments	Employment	Annual wages (in millions)	Business establishments	Employment	Annual wages (in millions)	
Imperial	230	1,200	$40	140	800	$20	0.0
Kern	900	14,300	510	480	7,000	290	.5
Los Angeles	98,290	922,000	53,420	188,750	1,692,700	69,670	57.6
Orange	13,600	153,100	8,230	54,570	812,300	39,340	21.3
Riverside	9,050	106,700	4,020	23,570	299,000	11,280	8.9
San Bernardino	560	5,100	220	42,620	507,300	19,030	11.3
Ventura	970	11,000	350	360	3,900	120	.3
TOTAL	**123,600**	**1,213,400**	**66,780**	**310,480**	**3,323,100**	**139,760**	

Note: May not sum to total due to rounding. Due to unavailability of geocoded fields for approximately 8 percent of the dataset, figures presented in this table for establishment, employment, and wages are a lower bound for potential exposures from a MMI-VII+ shaking.

Source: U.S. Bureau of Labor Statistics, Quarterly Census of Earnings and Wages (QCEW) program.

exposures of 72 percent or more. The county with the greatest exposure as a percent of its total businesses, employment, and wages is San Bernardino, with 96 percent of its businesses, employees, and wages located in the very strong or severe shaking zones in the modeled earthquake. Riverside County is at risk for the next greatest exposure, with 75 percent of all businesses in the very strong or severe shaking zones. Los Angeles and Orange counties both have 73 percent of their businesses, employees, and wages located in the very strong to severe shaking zones. Imperial County overlies a portion of the southern San Andreas Fault, but has relatively little exposure in the scenario analyzed here, as the earthquake's waves are expected to radiate towards the northwest, away from Imperial County.

Just as the exposure to various counties ranges widely, the exposures for southern California industries vary across the board. The earthquake would affect a large number of jobs in health care (522,000), retail trade (504,000), manufacturing (480,000), and educational services (409,000). (See table 3.) After a disaster, functioning hospitals and medical facilities will be critical. The shaking zone map tabulations show that 72 percent of health care workers are located in the shaking zones that are expected to experience the most damage. In addition to this geographic hazard, a recent study found structural weaknesses in many hospitals in California, particularly in the southern part of the state.[6] With the exception of the agriculture and mining industries, every industry within the seven-county area could have more than half of their total employment located in the very strong to severe shaking zones. The potential economic consequences to employers and workers in southern California are widespread and are likely to have an effect on the state economy and, in turn, the national economy because of the far-reaching economic ties between firms and industries in California and beyond. This strong relationship between the southern California economy and the rest of the world is demonstrated by the large percentage of international shipments that come through the Los Angeles and Long Beach

Table 2. Percent of total businesses, employment, and wages exposed to a destructive shaking zone (MMI-VII+), first quarter of 2010

County	Business establishments	Employment	Wages
Imperial	6	4	4
Kern	8	9	9
Los Angeles	73	74	69
Orange	73	77	74
Riverside	75	79	79
San Bernardino	96	96	97
Ventura	6	6	4
TOTAL	**70**	**71**	**68**

Source: U.S. Bureau of Labor Statistics, Quarterly Census of Earnings and Wages (QCEW) program.

Industry	Business establishments	Employment	Annual wages (in millions)	Percent of total exposed employment	Percent of industry employment
Health care and social assistance	29,000	521,900	23,740	12	72
Retail trade	32,120	503,700	14,060	11	71
Manufacturing	18,150	479,600	23,560	11	77
Educational services	6,960	408,600	20,120	9	71
Accommodation and food services	21,210	370,100	6,480	8	66
Administrative and waste services	12,630	306,500	9,100	7	76
Wholesale trade	23,280	257,800	13,550	6	79
Other services, except public administration	179,400	255,300	6,120	6	72
Professional and technical services	29,380	233,400	16,480	5	61
Public Administration	1,230	201,200	13,160	4	83
Transportation and warehousing	6,840	190,500	8,420	4	74
Construction	19,200	177,000	8,740	4	75
Finance and insurance	12,860	155,700	12,850	3	68
Information	5,540	152,600	12,760	3	68
Arts, entertainment, and recreation	5,560	102,800	3,940	2	74
Real estate and rental and leasing	12,120	77,600	3,400	2	64
Management of companies and enterprises	1,220	63,600	5,020	1	76
Utilities	460	36,000	3,570	1	81
Agriculture, forestry, fishing and hunting	1,040	23,100	530	1	27
Unclassified	15,750	16,300	560	0	68
Mining, quarrying, and oil and gas extraction	150	3,400	380	0	23
TOTAL	**434,080**	**4,536,500**	**206,540**	**100**	**71**

Table 3. Potential industry exposure to destructive shaking (MMI-VII+), first quarter of 2010

Note: Figures may not sum to total due to rounding. Due to unavailability of geocoded fields for approximately 8 percent of the dataset, figures presented in this table for establishment, employment, and wages are a lower bound for potential exposures from a MMI-VII+ shaking.

Source: U.S. Bureau of Labor Statistics, Quarterly Census of Earnings and Wages (QCEW) program.

ports—more than 23 percent of the total U.S. value of goods passed through them in 2009, making it the largest U.S. port district.[7]

Conclusion

With this report, we do not claim to make a specific earthquake prediction of expected losses. However, we are able to estimate the exposure to the labor market in the event of a "highly probable" earthquake scenario in which the southern segment of the San Andreas Fault ruptures, generating a magnitude 7.8 earthquake.[8] By using geocoded employment data and shape files generated by earthquake shake modeling, this analysis concludes that a magnitude 7.8 earthquake on the southern San Andreas Fault could have wide-ranging effects on businesses, jobs, and payrolls in the southern California area.

The earthquake scenario used to estimate the exposures modeled here may never happen. Major and devastating earthquakes on the San Andreas Fault are widely believed to be inevitable and, by geologic standards, extremely common, but they may not occur as projected in the ShakeOut Scenario. Evidence suggests that the next damaging earthquake could easily be on one of the many other faults that riddle the Los Angeles basin, permanently changing the lives and livelihoods of residents and local businesses. The results of this regional report should serve as a reminder to public officials, employers, and residents of the vital importance of taking preventive actions to mitigate the potential losses from an earthquake, and to prepare for the potential disruption to businesses and employees.

Data presented here are for all workers covered by state and federal unemployment insurance programs. For additional information, contact Richard Holden, Regional Commissioner, U.S. Bureau of Labor Statistics. Email: holden.richard@bls.gov. Telephone: 415-625-2245.

Coauthors of this report were Amar Mann, Supervisory Economist, U.S. Bureau of Labor Statistics, and Tian Luo, Economist, U.S. Bureau of Labor Statistics. Information in this report will be made available to sensory-impaired individuals upon request. Voice phone: (202) 691-5200; Federal Relay Service: 1-800-877-8339.

Notes

[1] An earlier Regional Report presented data on the labor market risks of a hypothetical earthquake along the Hayward Fault in Alameda County California. See "Labor market risks of a magnitude 6.9 earthquake in Alameda County," **http://www.bls.gov/opub/regional_reports/200709_alameda.pdf**.

[2] Exposure refers to potential labor-market losses and risks. Exposure is how much of the area's employment and earnings base is in the severe shaking zone.

[3] United States Geological Survey, "Magnitude/Intensity Comparison," **http://earthquake.usgs.gov/learn/topics/mag_vs_int.php**.

[4] Lucile M. Jones, et al., "The ShakeOut Scenario," USGS Open File Report 2008-115 (U.S. Department of the Interior, U.S. Geological Survey, 2008), pg. 10, **http:/pubs.usgs.gov/of/2008/1150/of2008-1150.pdf.**

[5] Although USGS did estimate economic losses (along with casualties and injuries), they did not estimate the labor market risks in terms of jobs and wages as this study has done.

[6] According to a recent report, state and hospital officials have found significant structural weaknesses in more than 20 hospital buildings throughout California. More than a dozen of the seismic targets are located in southern California. See Erin Richard, "California Hospitals Deemed Seismically Unstable," NBC Los Angeles, Nov. 5, 2010, **http://www.nbclosangeles.com/news/local-beat/California-Hopsitals-Deemed-Seismically-Unstable-106795938.html?wwparam=1290126554**.

[7] Ronald D. White, "Ports of L.A. and Long Beach post 18% growth in container traffic," Los Angeles Times, November 16, 2010, **http://articles.latimes.com/2010/nov/16/business/la-fi-ports-20101116**.

See also "U.S. Waterborne Foreign Trade by U.S. Customs Districts," (U.S. Department of Transportation, Maritime Administration, August 20, 2010), **http://www.marad.dot.gov/library_landing_page/data_and_statistics/Data_and_Statistics.htm**.

[8] Suzanne Perry, et al., "The ShakeOut Earthquake Scenario—A Story That Southern Californians Are Writing," Circular 1324, (U.S. Department of the Interior, U.S. Geological Survey, 2008), p. 2, **http://pubs.usgs.gov/circ/1324/c1324.pdf**.

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