Earthquake Hazard Information – Photos of Earthquake Damage, Modes of building Failure – Part 1 (Information for interpreting the results of building contest and shake table testing; L. Braile, 03/12/03)

In the building contest, we test model buildings on a shake table using accelerations and frequencies that are similar to those associated with actual earthquake shaking that affects buildings. Many types of building, structure or ground failure are observed in actual earthquake damage. Many of these failure modes are also visible in the shake table testing of model buildings. Others, such as poor connection to foundation, fallen objects, or ground failure can be simulated with appropriate modification of the model building and the shake table testing. Photos of some building damage form some notable earthquakes and some associated intensity maps are shown below. The examples are classified by the dominant mode of failure observed.

1. Soft first story/inadequate shear strength

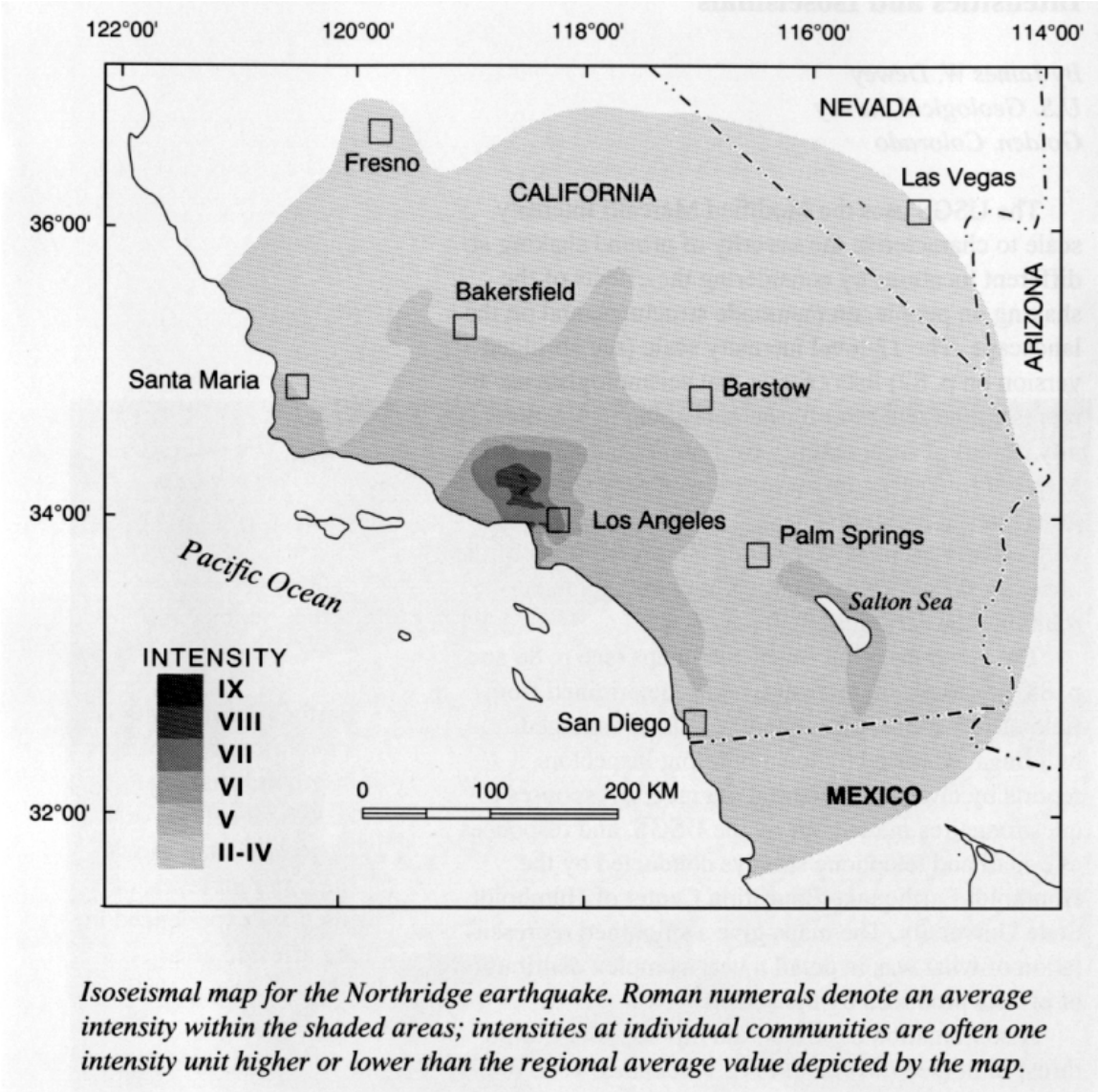
Loma Prieta earthquake damage in San Francisco. The soft first story is due to construction of garages in the first story and resultant reduction in shear strength. (Photo from: http://earthquake.usgs.gov/bytopic/photos.html)

Kobe earthquake damage. Failure of the first story caused partial collapse of upper stories. (Photo from: The January 17, 1995 Kobe Earthquake: An EQE Summary Report. April 1995, http://www.eqe.com/publications/kobe/kobe.htm)

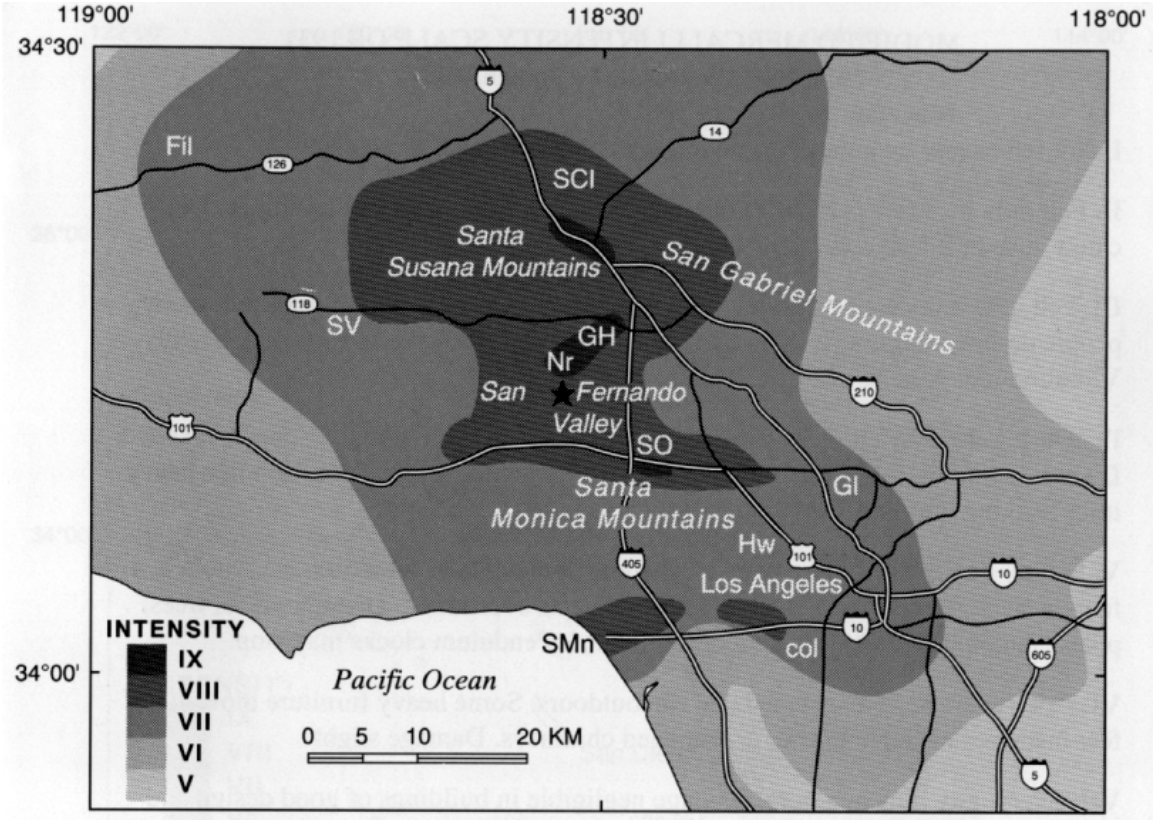
Heavily damaged apartment building, Reseda. The building has collapsed onto its structurally weak first story, partially crushing several parked cars. This type of damage was common in the epicentral region; partially open first-story levels have poor resistance to strong, horizontal ground motion. The piles of debris and the destruction on the left are the results of a fire that broke out after an aftershock. Photograph by J. W. Dewey.

Northridge earthquake soft first story (parking level) damage. (Photo from: Brown, R.D., Jr., Lessons reaffirmed, extended, or revealed, *Earthquakes and Volcanoes*, Vol. 25, No. 2, 103-106, 1994)

Northridge earthquake soft first story (parking level) damage. (Photo from: http://www.ngdc.noaa.gov/seg/hazard/slideset/earthquakes/)

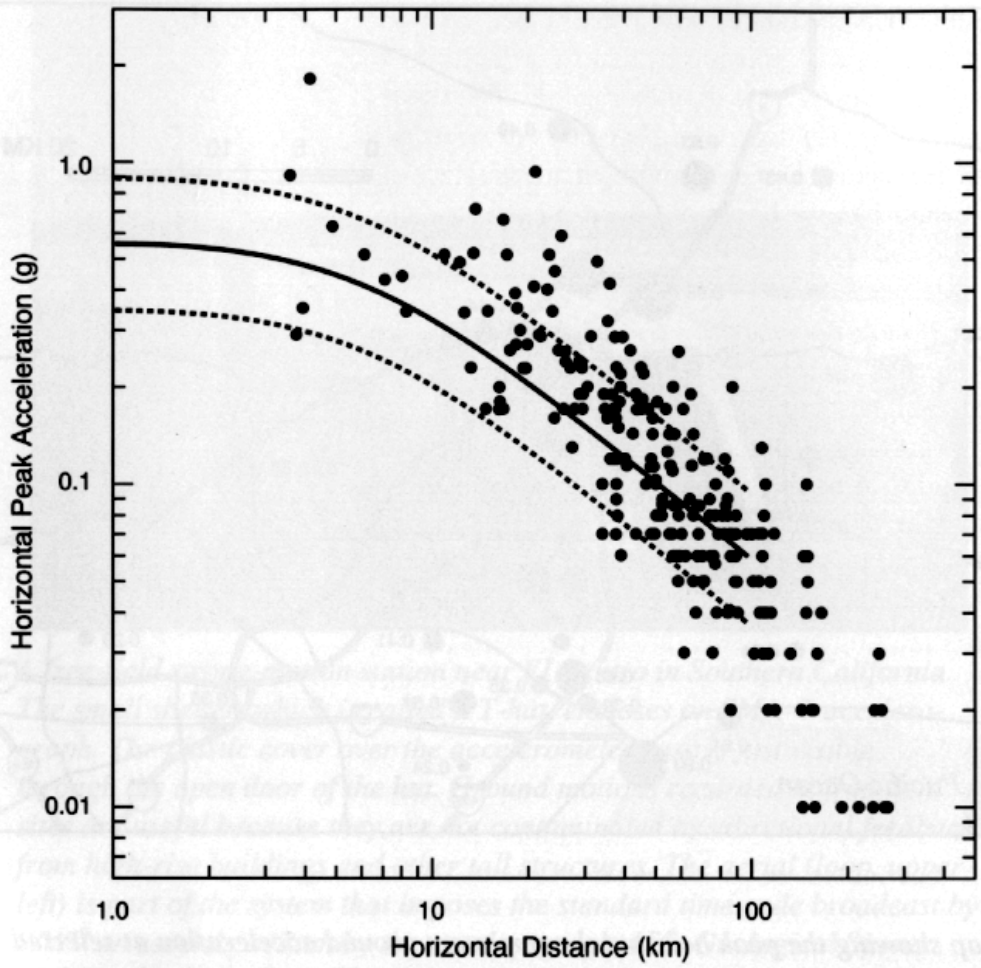


Modified Mercalli intensity map for the Northridge earthquake. (Map from: Dewey, J.W., Intensities and isoseismals, *Earthquakes and Volcanoes*, Vol. 25, No. 2, 85-93, 1994)



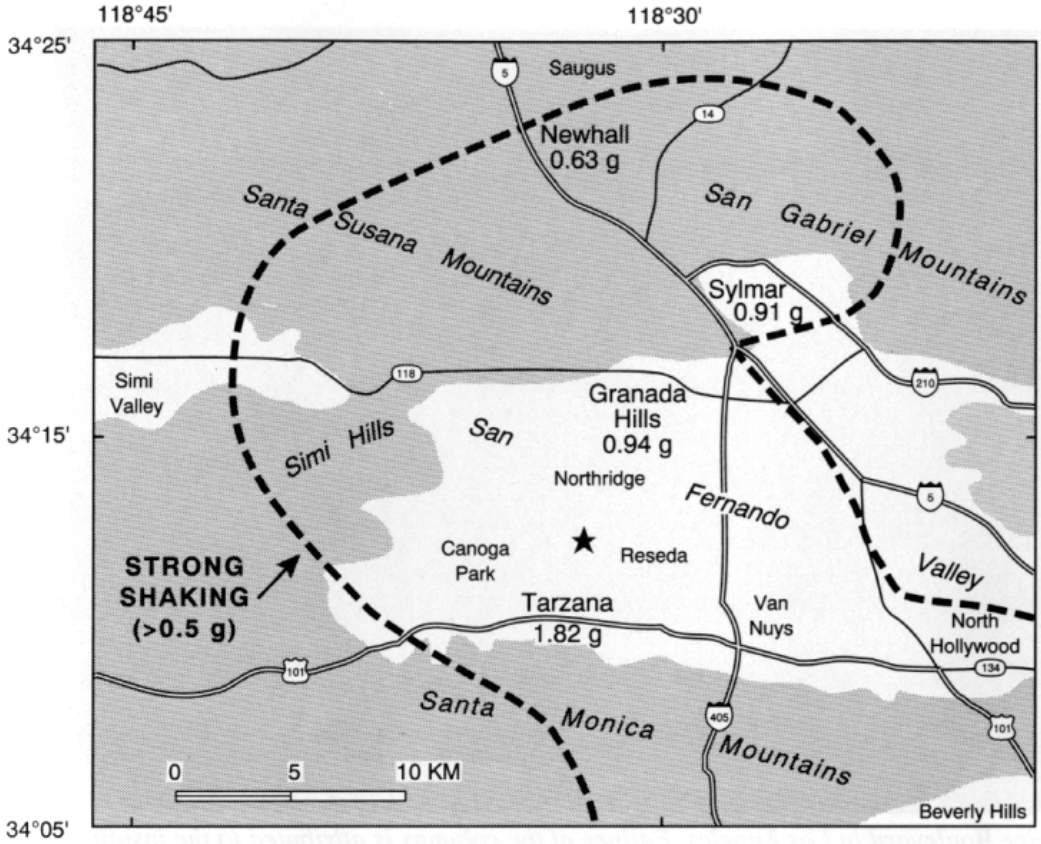
Isoseismal map depicting the region of strongest shaking. Abbreviations designate specific towns or sites: "col" – Los Angeles Coliseum; "Fil" – Fillmore; "GH" – Granada Hills; "Gl" – Glendale; "Hw" – Hollywood; "Nr" – Northridge; "SCl" – Santa Clarita; "SMn" – Santa Monica; "SO" – Sherman Oaks; "SV" – Simi Valley. The star denotes the epicenter of the earthquake.

Modified Mercalli intensity map for the Northridge earthquake – area of strongest shaking. (Map from: Dewey, J.W., Intensities and isoseismals, *Earthquakes and Volcanoes*, Vol. 25, No. 2, 85-93, 1994)



Horizontal-component peak acceleration versus distance from the earthquake fault. The solid circles represent Northridge data from free-field sites underlain by stiff soil or soft rock. The curves represent the average peak acceleration (solid line) and the corresponding ±1 standard-deviation accelerations (dashed lines) expected for a magnitude 6.7, reverse-faulting earthquake. Graph provided by David Boore.

Peak acceleration versus distance for the Northridge earthquake. (Graph from: Mueller, Charles, Ground motion, *Earthquakes and Volcanoes*, Vol. 25, No. 2, 75-84, 1994)



Northridge earthquake location map. The dashed line encloses the area of strongest shaking, where peak horizontal accelerations exceeded one-half the acceleration of gravity. Especially high accelerations are shown for Tarzana, Granada Hills, Sylmar, and Newhall. The star designates the epicenter of the Northridge earthquake, the point on the surface directly above the hypocenter, where the initial rupture on the fault occurred.

Area of strong ground shaking (>0.5g) for the Northridge earthquake. (Map from: Celebi, Mehmet, and R. D. Brown, Jr., Structural damage, *Earthquakes and Volcanoes*, Vol. 25, No. 2, 94-102, 1994)

Mid-story collapse, Kobe earthquake. (Photo from: The January 17, 1995 Kobe Earthquake: An EQE Summary Report. April 1995, http://www.eqe.com/publications/kobe/kobe.htm)

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2. Inadequate attachment of building to foundation

Wood-frame house shifted off its foundation in Fillmore. In many cases, damage to older wood-frame houses could be attributed to their not being securely bolted to their foundation or to failure of cripple-stud walls in the crawl space between the foundation and first floor. Photograph by J. W. Dewey.

House shifted off its foundation, Northridge earthquake. (Photo from: Dewey, J.W., Intensities and isoseismals, *Earthquakes and Volcanoes*, Vol. 25, No. 2, 85-93, 1994)

House shifted off its foundation, Loma Prieta earthquake. (Photo from: http://earthquake.usgs.gov/bytopic/photos.html)

3. Column failure/ broken joints/too much weight for building design or construction

Column failure, Loma Prieta earthquake. (Photo from: http://earthquake.usgs.gov/bytopic/photos.html)

Collapsed section of I–10 (Santa Monica freeway), West Los Angeles.The freeway had been built across relatively soft soils (drained wetlands), the probable reason for the structural failure. This section of freeway was repaired and made serviceable in three months time. Photograph by Kerry Sieh.

Column failure on interstate highway overpass, Northridge earthquake. (Photo from: Celebi, Mehmet, and R. D. Brown, Jr., Structural damage, *Earthquakes and Volcanoes*, Vol. 25, No. 2, 94-102, 1994)

These crushed columns formerly supported the heavy deck of the I-10 freeway at Venice Boulevard in Los Angeles. Failure of the columns is attributed to the insufficient number and spacing of the horizontal, circular ties (reinforcing bars that girdle the columns). During vigorous earthquake shaking, the ties failed to confine the concrete and the vertical reinforcing bars in the columns. This freeway was constructed before 1960; newer freeways are designed to withstand stronger earthquake forces. Photograph by Mehmet Celebi.

Column failure on interstate highway overpass, Northridge earthquake. (Photo from: Celebi, Mehmet, and R. D. Brown, Jr., Structural damage, *Earthquakes and Volcanoes*, Vol. 25, No. 2, 94-102, 1994)

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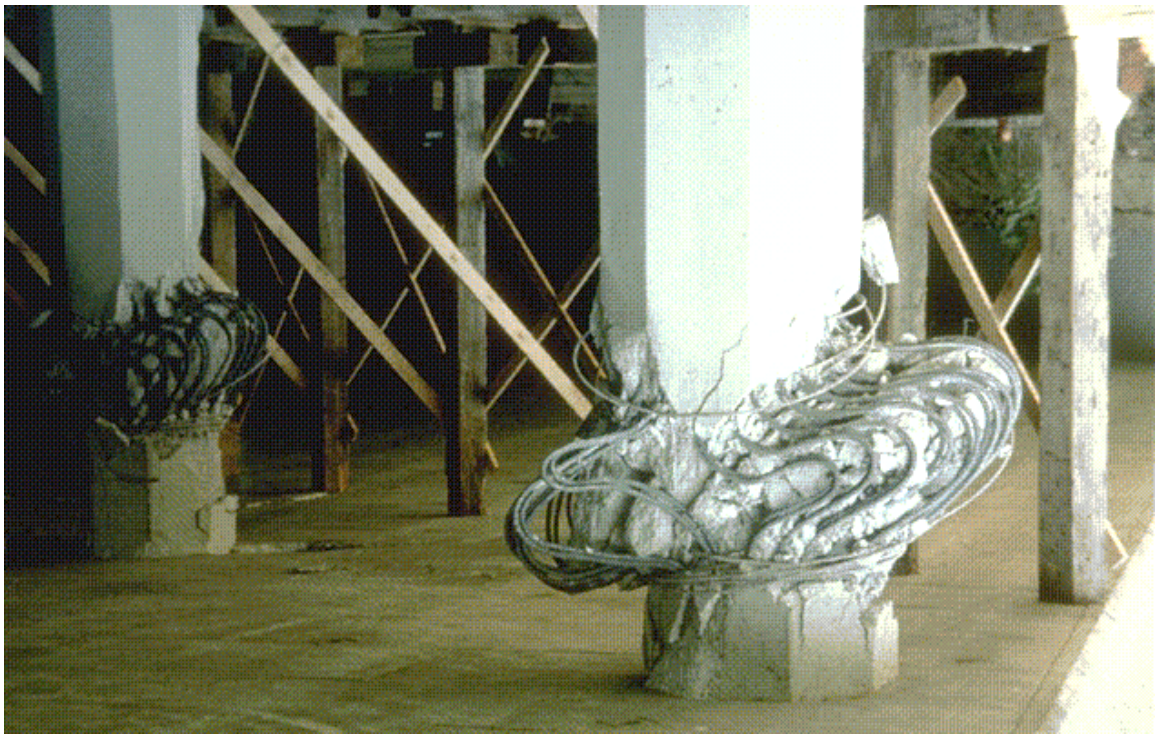

Column failure on interstate highway overpass, Northridge earthquake. (Photo from: http://earthquake.usgs.gov/bytopic/photos.html)

Column failure (inadequate connection to decking) on interstate highway overpass, Northridge earthquake. (Photo from: Cover photo, *Earthquakes and Volcanoes*, Vol. 25, No. 2, 1994)