### Comparison of Major Earthquakes

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<tbody>
<tr>
<td><strong>Magnitude</strong></td>
<td>7.0</td>
<td>6.7</td>
<td>7.1</td>
<td>7.4</td>
<td>7.6</td>
<td>7.6</td>
<td>7.7</td>
<td>6.6</td>
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<tr>
<td><strong>Mitigation effort</strong></td>
<td>moderate</td>
<td>moderate</td>
<td>Low</td>
<td>v. low</td>
<td>low</td>
<td>nil</td>
<td>nil</td>
<td>nil</td>
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<tr>
<td><strong>Deaths</strong></td>
<td>63</td>
<td>57</td>
<td>5,400</td>
<td>18,000</td>
<td>2,000</td>
<td>1,200</td>
<td>20,000</td>
<td>40,000+</td>
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<tr>
<td><strong>Severely Damaged Buildings</strong></td>
<td>5,700</td>
<td>1,000</td>
<td>150,000</td>
<td>115,000</td>
<td>80,000+</td>
<td>250,000+</td>
<td>1,120,000</td>
<td>&gt;60% of structures collapsed</td>
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Failed column during the 1989 LPE and mitigation by wrapping with steel jackets
Steel Jacket

Carbon Fiber Jacket

Visual 9.3
Collapsed Murrah Building in OK City

Even moderate EQ Design Measures Benefit Other Hazards
Expenditure on mitigation involves making judgments of losses. What is the optimal balance?

What is the optimal balance?

Societal Well-being

Intolerable risks

Funds diverted from other needs

Spending on risk assessment and mitigation

Visual 9.5
Soft first-story failure of unreinforced masonry during the 1989 Loma Prieta Earthquake (garage was on first floor)
Steel bracing added to avoid soft first-story failure:
Bracing installed in the garage of a San Francisco Marina District home following the 1989 LPE
Infilling openings to avoid soft first-story failure
Photo of infilling openings to avoid soft first-story failure

Credit: NOAA (1999)
Separation joint filled with elastic material to prevent pounding
Bolting of sill plate to foundation (wooden structure)
Steel cross bracing added to increase seismic resistance (steel-framed building)
Column wrapped with carbon fiber in a reinforced concrete building
Failure of an unreinforced masonry structure during the 1989 Loma Prieta Earthquake
Wall strengthened in an unreinforced masonry (URM) structure using a fiber-reinforced sheet
Dampers added to reduce shaking of URM building during earthquake.
Dampers (four diagonal large “shock absorbers”) being installed in San Francisco
Base isolation bearing installed to support building columns

Credit: G. W. Clough
Transformer at power substation damaged during 1994 Northridge, EQ
Anchorage of transformers for increased seismic resistance
Fire in 1906 & 1989 San Francisco EQs

1906 San Francisco, EQ

1989 Loma Prieta, EQ
Broken gas line due to ground movements during 1994 Northridge Earthquake
Illustration of flexible joint being used for connection to tank
Use of High Strength Steel Pipe Improves Performance

**CAST IRON PIPE**

**STEEL PIPE**
The Alaskan oil pipeline is designed to withstand seismic forces
Tank damage (bulging at the bottom) following earthquake
Tank damage (bulging at the bottom) following earthquake
Illustration of damaged tank (left) and stiffening of tank walls (right) to mitigate earthquake shaking

Visual 9.29
Collapse of the Cypress Overpass During the 1989 Loma Prieta Earthquake
Steel jackets installed on LA highway columns
Critical areas where the presence of weak, liquefiable soil is particularly threatening to bridges.
Soil being densified to prevent liquefaction
Failure of upstream embankment of Van Norman Dam following the 1971 San Fernando Earthquake
Schematic showing berm placed down stream to increase dam stability
Special gas valve designed to automatically shut off during an earthquake
Computers strapped down to table to prevent overturning during an earthquake
Bookcases strapped to wall to prevent overturning during and earthquake