Freeway and collapsed or damaged bridge locations

Interstate 5/State Road 14 Interchange

EERI (left); Paul Harris, Getty Images
Unbalanced bent stiffness

Short (stiff) piers attracted large lateral force crushing Pier 2 and triggering collapse of 3 spans.

Tall (flexible) piers attracted little lateral load and were undamaged.

Ian Buckle
Unexpected plastic hinge locations

Bull Creek Canyon Bridge

SR 118 Mission-Gothic Undercrossing
Good performance of jacketed columns
Building damage

Shaking of >0.4 g can collapse freeway overpasses

Buildings damaged by shaking over a wide area (red dots)

Landslides
Older existing concrete

Van Nuys Holiday Inn

Kaiser Permanente

NISEE (left); Visions of America/UIG via Getty Images (right)
Concrete gravity framing

CSU Northridge Parking Garage

Gene Corley, CTL (left); Peter Weigand, CSU-Northridge (right)
Concrete diaphragms

Northridge Fashion Center Parking Garage

AP Photo/Reed Saxon
Rigid Wall Flexible Diaphragms
Woodframe buildings

**Casualties**: 24 of the 25 fatalities in the Northridge Earthquake that were caused by building damage occurred in woodframe buildings (1)

**Property Loss**: Half or more of the $40 billion in property damage was due to damage to wood buildings; approximately. $15 billion in insured loss (2)

**Functionality**: 48,000 housing units, almost all of them in woodframe buildings, were rendered uninhabitable by the earthquake (3)

(1) EQE and Calif. OES, 1995
(2) Charles Kircher et al., 1997, and Robert Reitherman, 1998
(3) Jeanne B. Perkins, et al., 1998

Kelly Cobeen, CUREE Wood-Frame Project
Multi-family residential woodframe buildings with weak/soft stories
Hillside homes

Photo credit: City of Los Angeles Department of Building and Safety
Unbraced or unbolted cripple walls
Nonstructural/Hospitals

Olive View Hospital 1971

Olive View Hospital 1994

1973 Hospital Seismic Safety Act
Requires hospitals to be designed and constructed to withstand a major earthquake and remain operational

Maryann Phipps
Performance of all buildings at 23 hospital sites

<table>
<thead>
<tr>
<th>Type of Damage</th>
<th>Number (%) of Buildings</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Pre Act</td>
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<td>12 (24%)</td>
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Performance of all buildings at 23 hospital sites

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<td>Yellow Tagged</td>
<td>17 (33%)</td>
<td>1 (3%)</td>
<td></td>
</tr>
<tr>
<td>Green Tagged</td>
<td>22 (43%)</td>
<td>30 (97%)</td>
<td></td>
</tr>
<tr>
<td>Nonstructural Damage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Major</td>
<td>31 (61%)</td>
<td>7 (23%)</td>
<td></td>
</tr>
<tr>
<td>Minor</td>
<td>20 (39%)</td>
<td>24 (77%)</td>
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</tr>
<tr>
<td>Total Buildings</td>
<td>51</td>
<td>31</td>
<td></td>
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</table>
Increased focus on nonstructural + SB1953
Steel buildings

Quake Cracks Steel Buildings

In past earthquakes, unreinforced brick and stiffly designed concrete buildings were considered most vulnerable to collapse. Buildings made of steel were deemed safer, because they tend to bend but not break. The Northridge earthquake shattered those assumptions. Engineers have identified a dozen or more steel buildings as high as 10 stories with badly cracked welds and supporting steel columns. Although they did not collapse, they were seriously weakened.

Two types of cracks

Moment resisting frame

A steel moment resisting frame is a rectangular assembly of beams and columns. The beams are welded and bolted to the columns.

Source: Michael D. Englander, assistant professor of civil engineering at University of Texas, Austin.
Steel buildings

Beam flange

Column web

Base plate
The SAC Steel Project is funded by FEMA to solve the problem of brittle behavior of welded steel frame structures that surfaced in the January 17, 1994 Northridge, California (Los Angeles) Earthquake.
Codes for steel seismic design

- **Before Northridge – ’85 UBC**
  - Ductile Moment Frames covered in one page
  - Those were the days!

- **Steel Moment Frames in ’92 AISC Seismic**
  - 4 ½ pages total
  - Pre-qualified what came to be known as the “Pre-Northridge” Connection

- **AISC 341-10**
  - 20 pages of Moment Frame Requirements
  - AISC 341-10 is 356 pages, including Commentary
  - AISC 358-10 (Pre-qualified connections standard) is another 157 pages
  - AWS D1.8 (Seismic Supplement to D1.1) is another 111 pages

James Malley
1994 - Historic Context

PBD for Existing Buildings
- ATC 33 (ASCE 41)

PBD for New Buildings
- FEMA action plan
- SEAOC Vision 2000

SEAOC Seismology converting UBC to strength basis

AISC struggling with dual-certified steel
Major Impacts of Northridge EQ

- Scope of UBC strength conversion expanded
  - Redundancy
  - Rigid-wall flexible diaphragm wall anchorage force increase
  - Near-fault Seismic Design Categories established
  - Spectral shape and base-shear limit for long-period motion (velocity pulses)
  - Prohibition in extreme soft/weak stories, torsional irregularities

- FEMA/SAC Project
  - Revamp of AISC 341
  - Introduction of AISC 358, AWS D1.8
  - Use of reliability-based approaches to establish design criteria

- Performance-based design
  - Vision 2000
  - ATC 33 (ASCE 41)
  - FEMA P695
  - PEER focus on PBD
  - ATC-58 Project
  - TBI Guidelines
Thanks to...

- Ian Buckle: Bridges and Transportation
- SK Ghosh: Concrete Structures
- Kelly Cobeen: Woodframe Structures
- William Holmes: Existing Buildings
- James Malley: Steel Structures
- Maryann Phipps: Nonstructural/Hospitals
- Ron Hamburger: Codes and PBEE