NORTHRIDGE 30
1994 – 2024

The Northridge Earthquake - 30 Years Later

A Catalyst for Engineering Resilient Communities

2024 Webinar Series

ASCE Infrastructure Resilience · ASCE Los Angeles Section · EERI Southern California · SEAOSC Structural Engineers Association of Southern California · Earthquake Country Alliance

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Episode 1: The January 17, 1994 Northridge Earthquake – Science and Engineering Aspects

TOPICS & SPEAKERS:

Geophysics	Ken Hudnut, Ph.D. *(Southern California Edison)*
Geotechnical Engineering	Jonathan Stewart Ph.D., P.E. (*UCLA)*
Lifeline Infrastructure Systems	Craig Davis, Ph.D., P.E., G.E. *(C A Davis Engineering)*
Structural Engineering	David Cocke, S.E. (*Structural Focus)*

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The Northridge Earthquake
30 Years Later, A Catalyst for Engineering Resilient Communities

Earth Science – Overview & Source

NORTHRIDGE 30
1994 2024

K.W. Hudnut, Ph.D.
Southern California Edison

Infrastructure Resilience Division
American Society of Civil Engineers

February 14, 2024

Southern California Edison

California is Earthquake Country

Northridge; a "Transformative" Event

- The longer story; from 23 years *before* Northridge 1994 until 30 years *after* it
  - ✓ San Andreas Fault – *transform* boundary with a *wrinkle* – The Big Bend
  - ✓ Compressional deformation along the San Andreas Fault
    - ✓ "Shots across the bow" – community had seen similar events already – Mother Nature gave us a heads up!
      - ✓ 1971 San Fernando / Sylmar earthquake was also a transformative event
      - ✓ New Idria, Coalinga, Kettleman Hills and Whittier Narrows & Sierra Madre "blind thrust" earthquakes
    - ✓ What's Next? Puente Hills Thrust and other faults beneath Los Angeles metro region and their hazards

- Earthquake engineers & earth scientists working together
  - Understanding the earthquake source relies on good data; 1971 and then 1994 earthquakes gave us that
  - Each earthquake, 1971 & 1994, caused the seismic network to have problems; this motivated improvements
  - New technologies were continuously incorporated, allowing faster and better earthquake source estimation - EEW
    - Seismic network *transformation*; analog to digital broadband
    - Geodetic network *transformation*; non-continuous (survey-mode) to GPS / GNSS continuously operating network
    - Geologic capabilities *transformation*; rapid 'drone' & airborne lidar mapping of surface ruptures; MCS data & SCEC CfM allows 3D rendering of deep fault geometries and representation of multiple working hypothesis and integration into earthquake source 'tree trunk & branch' models as used in UCERF3
  - Hanging wall – near-fault ground motions; 1971, 1994, and latest example in 2024 Noto Hanto, Japan

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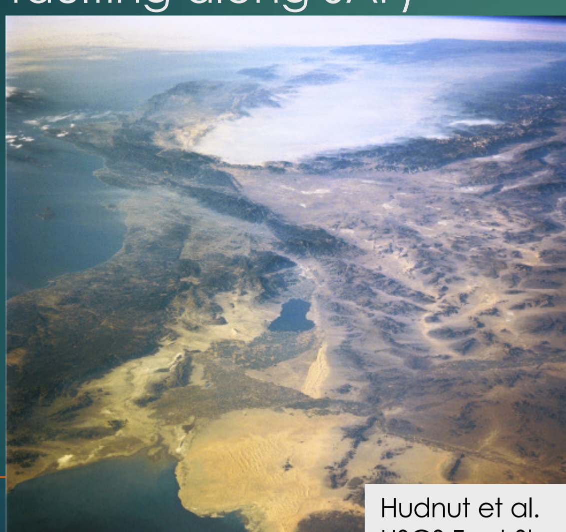
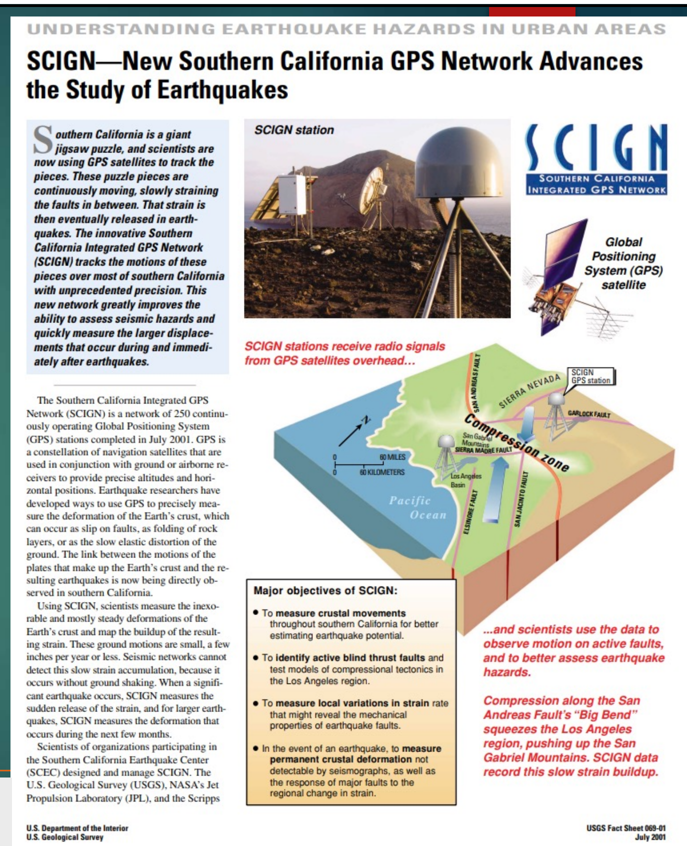
The San Andreas *Transform* … a wrinkle - The Big Bend

(compression & thrust faulting along SAF)



NASA Space Shuttle Photgraph STS103-701-39



UNDERSTANDING EARTHQUAKE HAZARDS IN URBAN AREAS

SCIGN—New Southern California GPS Network Advances the Study of Earthquakes

Southern California is a giant jigsaw puzzle, and scientists are now using GPS satellites to track the pieces. These puzzle pieces are continuously moving, slowly straining the faults in between. That strain is then eventually released in earthquakes. The innovative Southern California Integrated GPS Network (SCIGN) tracks the motions of these pieces over most of southern California with unprecedented precision. This new network greatly improves the ability to assess seismic hazards and quickly measure the larger displacements that occur during and immediately after earthquakes.

The Southern California Integrated GPS Network (SCIGN) is a network of 250 continuously operating Global Positioning System (GPS) stations completed in July 2001. GPS is a constellation of navigation satellites that are used in conjunction with ground or airborne receivers to provide precise altitudes and horizontal positions. Earthquake researchers have developed ways to use GPS to precisely measure the deformation of the Earth's crust, which can occur as slip on faults, as folding of rock layers, or as the slow elastic distortion of the ground. The link between the motions of the plates that make up the Earth's crust and the resulting earthquakes is now being directly observed in southern California.

Using SCIGN, scientists measure the inexorable and mostly steady deformations of the Earth's crust and map the buildup of the resulting strain. These ground motions are small, a few inches per year or less. Seismic networks cannot detect this slow strain accumulation, because it occurs without ground shaking. When a significant earthquake occurs, SCIGN measures the sudden release of the strain, and for larger earthquakes, SCIGN measures the deformation that occurs during the next few months.

Scientists of organizations participating in the Southern California Earthquake Center (SCEC) designed and manage SCIGN. The U.S. Geological Survey (USGS), NASA's Jet Propulsion Laboratory (JPL), and the Scripps

Major objectives of SCIGN:

- To **measure crustal movements** throughout southern California for better estimating earthquake potential.
- To **identify active blind thrust faults** and test models of compressional tectonics in the Los Angeles region.
- To **measure local variations in strain** rate that might reveal the mechanical properties of earthquake faults.
- In the event of an earthquake, to **measure permanent crustal deformation** not detectable by seismographs, as well as the response of major faults to the regional change in strain.

…and scientists use the data to observe motion on active faults, and to better assess earthquake hazards.

Compression along the San Andreas Fault's "Big Bend" squeezes the Los Angeles region, pushing up the San Gabriel Mountains. SCIGN data record this slow strain buildup.

U.S. Department of the Interior
U.S. Geological Survey

USGS Fact Sheet 069-01
July 2001

Hudnut et al.
USGS Fact Sheet 069-01

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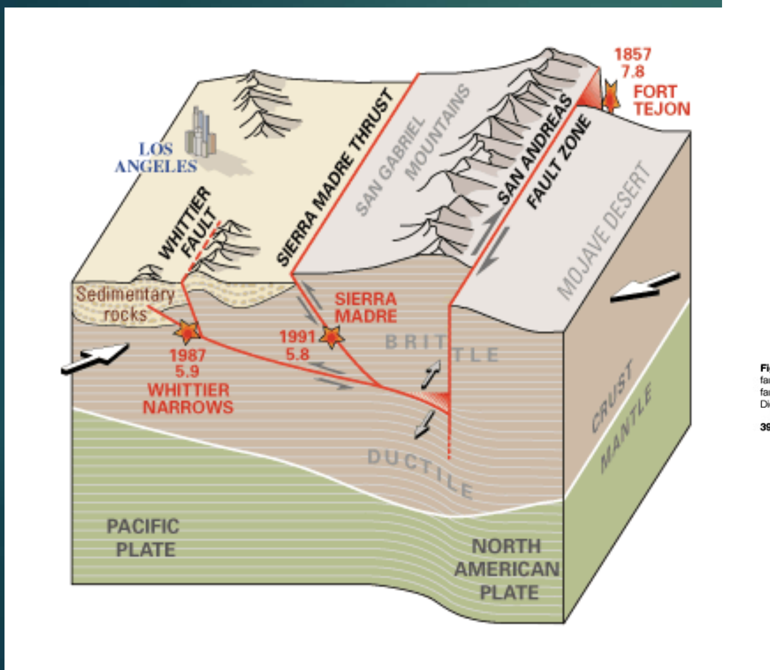
Jones et al.
Science, 1994



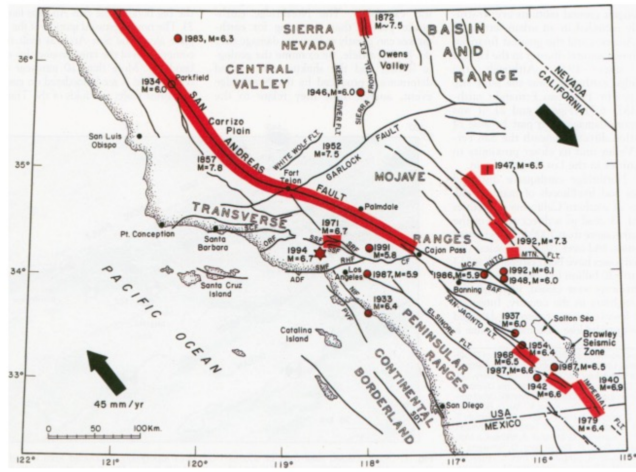


Fig. 2. Map of southern California showing the major faults and physiographic regions and the $M_L \geq 6.0$ earthquakes recorded from 1932 through 1993. Historic fault rupture is shown in red. Large arrows indicate the sense and magnitude of plate motion. Some fault names are abbreviated as follows: ADF, Anacapa Dume fault; BAF, Banning fault; CF, Cucamonga fault; MCF, Mission Creek fault; ORF, Oak Ridge fault; PVF, Palos Verdes fault; RHF, Raymond Hill fault; SDT, San Diego Trough–Soledad fault; SFF, San Fernando fault; SMF, Santa Monica fault; SRF, Sierra Madre fault; SSF, Santa Susana fault; and SCF, San Cayetano fault.

390 SCIENCE • VOL. 266 • 21 OCTOBER 1994

Fuis et al.
USGS Fact Sheet 110–99

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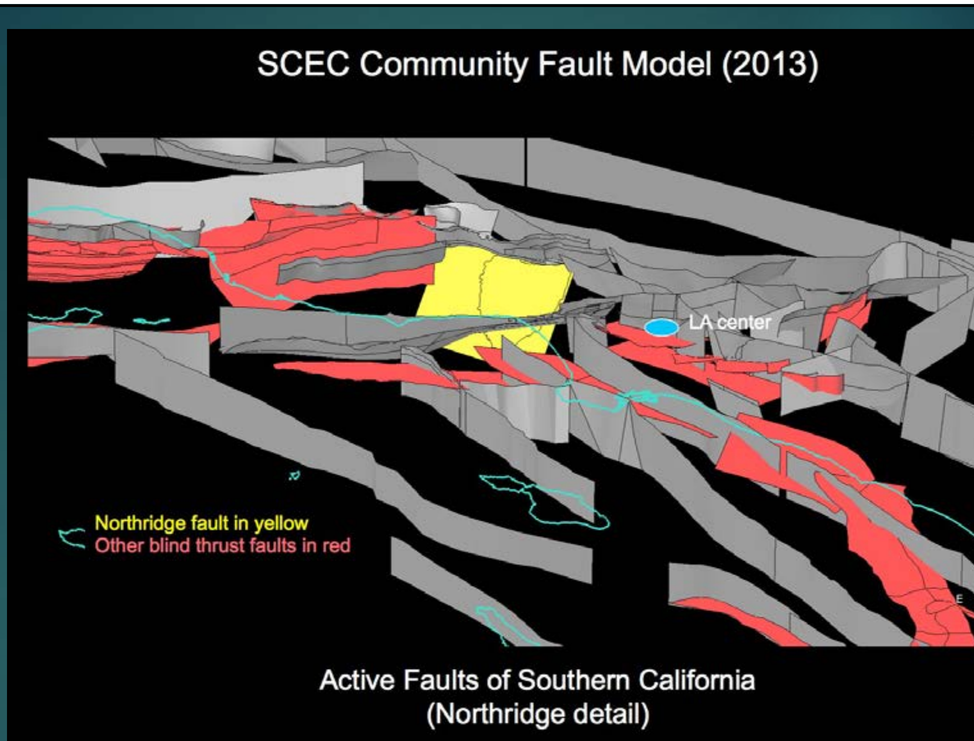

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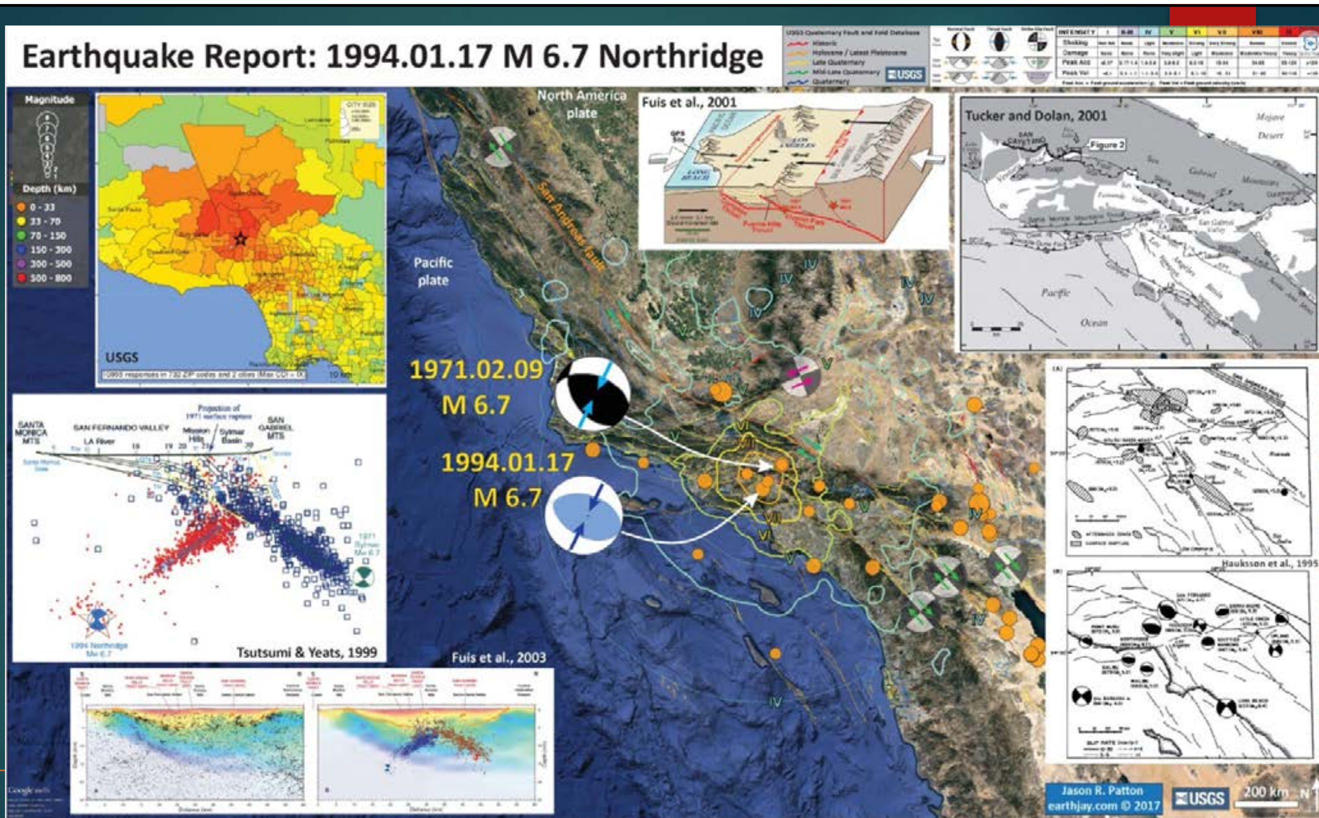

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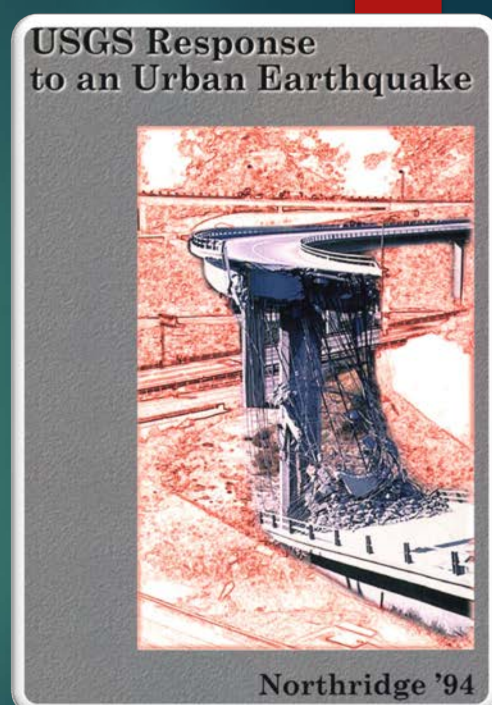
"In modern cities, where buildings, transportation corridors, and lifelines are complexly interrelated, the life, economic, and social vulnerabilities in the face of a major earthquake can be particularly acute."

U.S. Geological Survey, Open-File Report 96-263

https://pubs.usgs.gov/of/1996/0263/report.pdf



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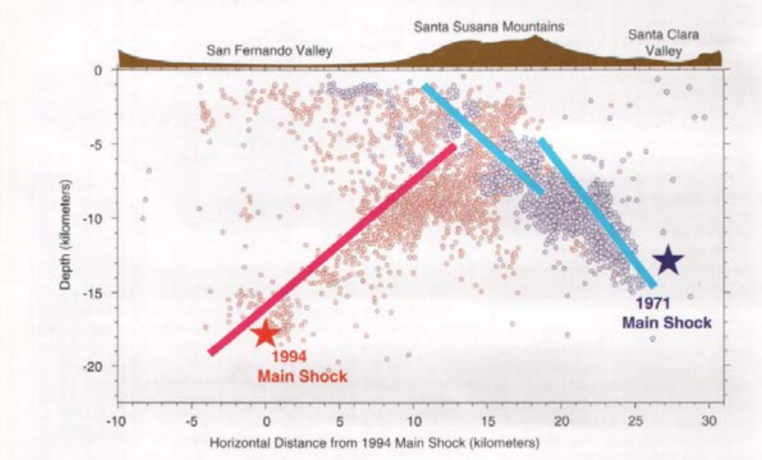
U.S. Geological Survey
Open-File Report 96-263

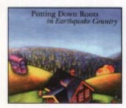
1971 and 1994 aftershocks & fault planes



Models of the fault planes of the 1994 Northridge (magenta) and 1971 San Fernando earthquakes (blue) suggest that movement on the buried thrust fault responsible for the Northridge earthquake terminated about 5 kilometers beneath the surface. This movement may have terminated against one of the faults that moved in 1971. Stars show positions of the hypocenters of the two shocks, and the arrays of red and blue dots indicate locations of aftershocks. Compare this illustration with the perspective view on page 13.

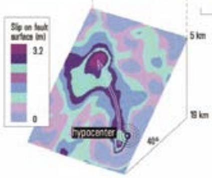






Main Shock; Source

This perspective aerial view of the Los Angeles region from the south illustrates how the Earth ruptured beneath the San Fernando Valley and shows some of the effects the resulting earthquake had on the land above.



Effects at the Land Surface ▲

Color tints on the surface show the distribution of peak ground velocities inferred from strong-motion accelerograms. The rectangle is the projected outline of the subsurface fault plane, and the star is the epicenter, the point on the land surface directly above the hypocenter. The highest values of peak ground velocities occurred about 15 kilometers north and west of the epicenter. These high values are thought to be the result of the movement of a block of earth upward and to the northwest, and to the shock being amplified in sedimentary basins.

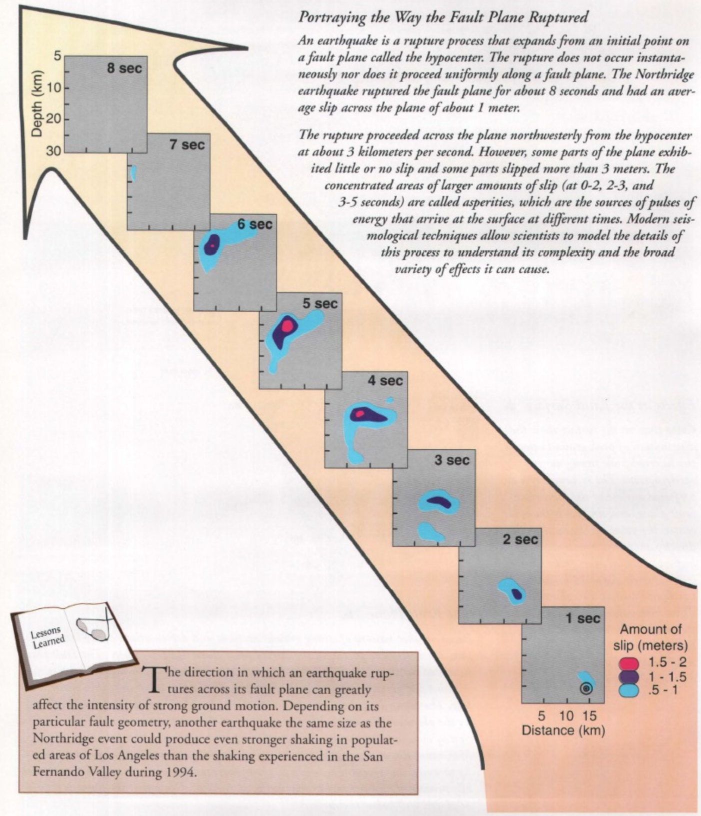
The Fault Plane ▲

Based on observations of strong ground motions and deformations of the land surface, scientists have portrayed the buried fault plane illustrated here. The fault plane is located between 5 and 19 kilometers beneath the surface. The modeled slip surface is about 430 square kilometers, although the slip did not occur over that entire surface. The plane dips about 40° to the south-southwest. The inferred amounts of slip on the plane are shown by different colors, and the color patterns suggest the progression of movement of the upper block of earth with respect to that below the plane. Maximum slip on the plane, seen in the northwest quadrant, was about 3 meters. Apparently, movement that began at the hypocenter in the southeast quadrant generally proceeded upward and to the northwest (arrow). (Note that the plane is shown displaced well below the surface.)

Portraying the Way the Fault Plane Ruptured

An earthquake is a rupture process that expands from an initial point on a fault plane called the hypocenter. The rupture does not occur instantaneously nor does it proceed uniformly along a fault plane. The Northridge earthquake ruptured the fault plane for about 8 seconds and had an average slip across the plane of about 1 meter.

The rupture proceeded across the plane northwesterly from the hypocenter at about 3 kilometers per second. However, some parts of the plane exhibited little or no slip and some parts slipped more than 3 meters. The concentrated areas of larger amounts of slip (at 0-2, 2-3, and 3-5 seconds) are called asperities, which are the sources of pulses of energy that arrive at the surface at different times. Modern seismological techniques allow scientists to model the details of this process to understand its complexity and the broad variety of effects it can cause.



The direction in which an earthquake ruptures across its fault plane can greatly affect the intensity of strong ground motion. Depending on its particular fault geometry, another earthquake the same size as the Northridge event could produce even stronger shaking in populated areas of Los Angeles than the shaking experienced in the San Fernando Valley during 1994.

Transformative changes…

After 1971 earthquake:

"Our inability to respond to that earthquake really had a strong impact on me and many of my colleagues to try to build a system that would provide information during the emergency to help emergency managers know what to do," says Tom Heaton.

USGS established office at Caltech Seismo Lab in Pasadena; seismic network improved
Analog real-time network and many more stations added from mid-1970's through 1994

After 1994 earthquake: innovation & technology application across a wide range – led to EEW

USGS & Caltech with State of California – **TriNet**; seismic network improved

SCIGN continuous GPS / GNSS array established; merged into PBO and now NOTA (EarthScope)

Funding for both TriNet and SCIGN involved numerous sources; USGS, NSF, FEMA, NASA, W. M. Keck Foundation and others

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Network of real-time sensors in 1994

Analog technology

L4C seismometer

E. Hauksson, Caltech

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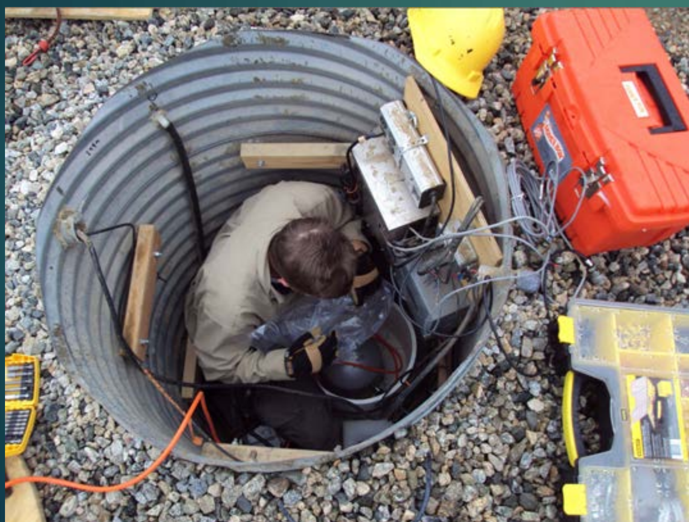
Modern SCSN Seismic Station



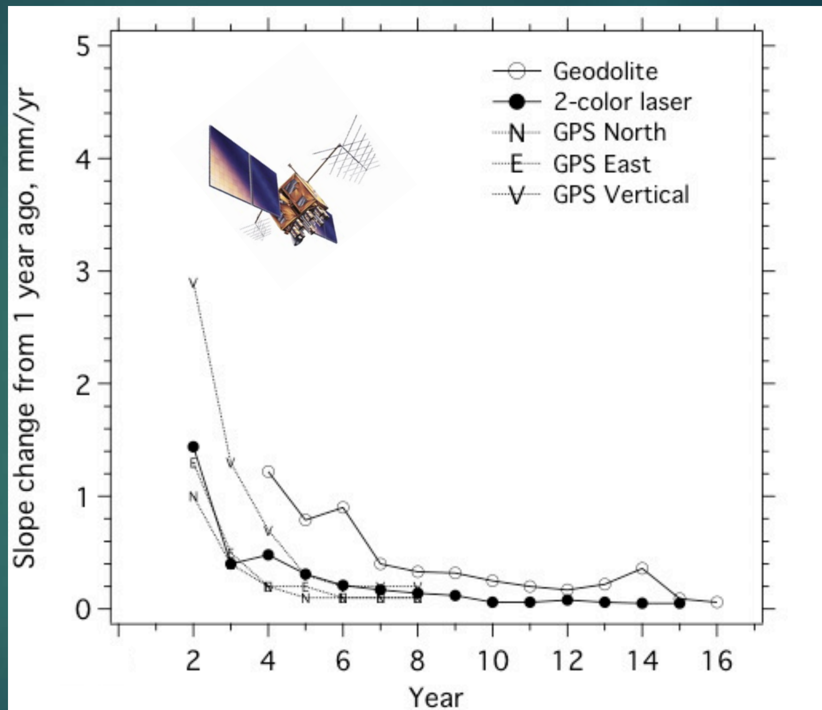
E. Hauksson, Caltech

(R)evolution of GPS Earthquake Geodesy

- The pre-GPS era; geodolite, 2-color EDM
- GPS survey-mode (set up a tripod)
- GPS continuous-mode
  - PGGA & DGGA
  - SCIGN
  - PBO
- From one week (in 1994) to
  - a few seconds (in 2014)
- GPS is ready for inclusion in EEW

In 1994, GPS was still being tested vs. previous methods

The GPS constellation had just achieved Initial Operational Capability



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Survey-mode GPS in the era of NR'94

To obtain displacements for a dozen sites took five days

- Drive to site
- Set up GPS
- Record data & wait
- Break down GPS
- Drive back to office
- Download GPS
- Process GPS data
- Repeat several days
- Modeling (hands on)

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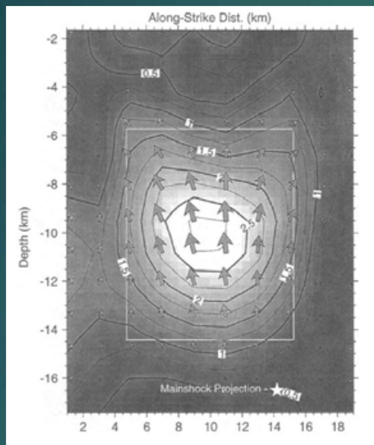
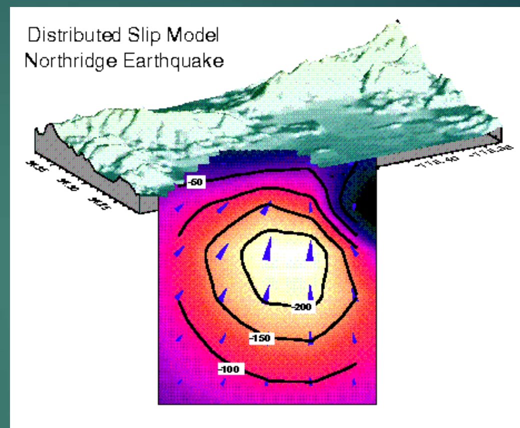
Northridge Co-Seismic Displacements





fault plane dips *south*
beneath San Fernando Valley

Hudnut et al.
BSSA, 1996

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Northridge Earthquake GPS Insights

- Initial focal mechanism – but fault rupture could have been on either plane; no surface rupture
  - 1971 dipped north, what about 1994?
  - Aftershocks of Northridge in first several days did not clearly delineate one plane or the other
- GPS displacements showed a strong preference for a deeper hypocenter and a south-dipping fault plane; NORT moved SE and up – anomalous?
  - Displacement of station NORT proved not to be the only influential station in the solutions
  - Confidence in a south-dipping plane came from geodesy

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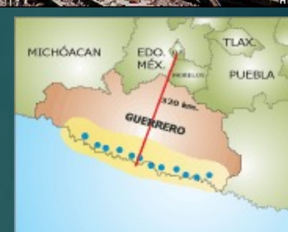
Hudnut et al.
USGS Fact Sheet 069-01

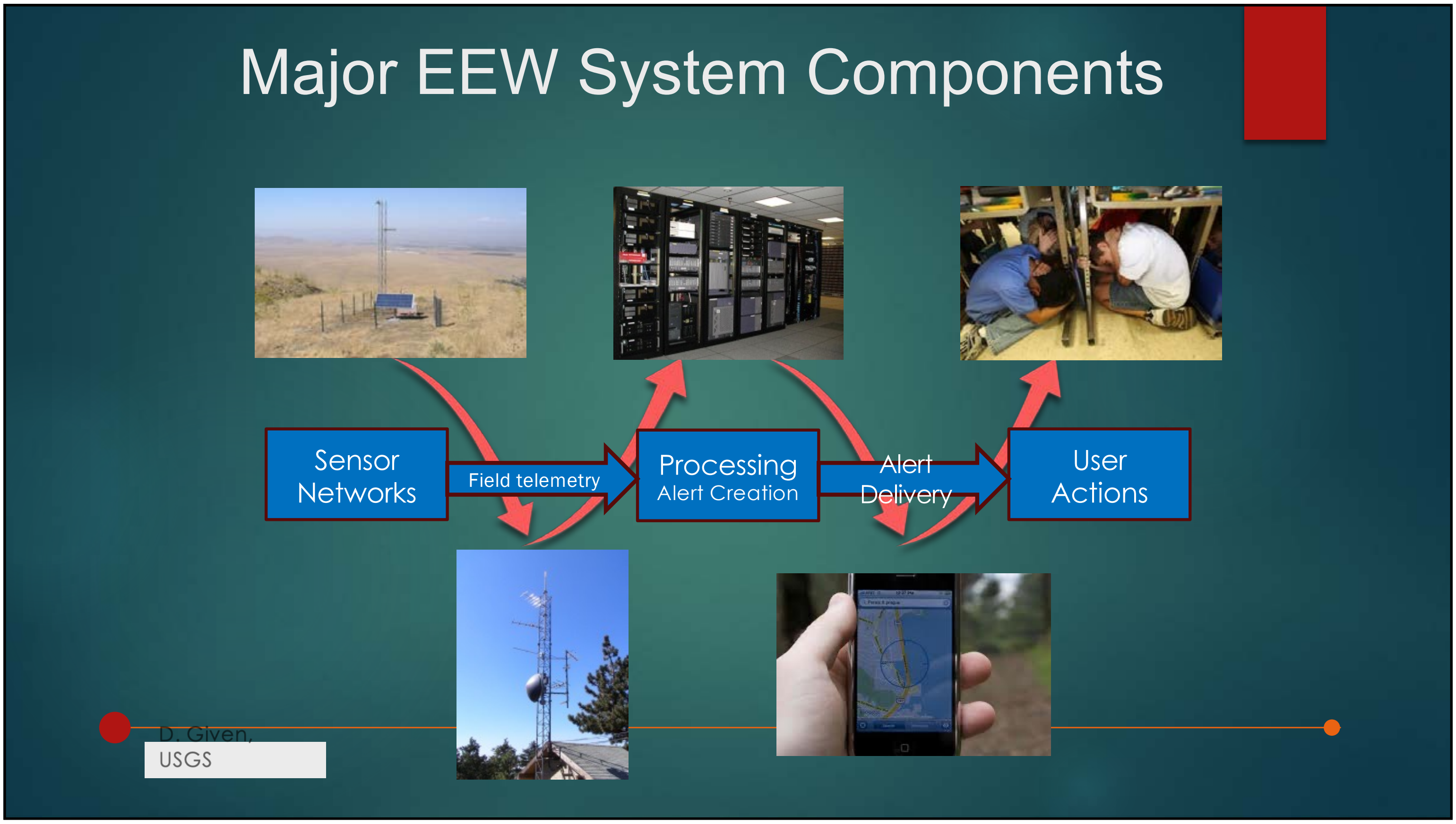
J. Galetzka, USGS

Brief History of EEW

- 1868 Hayward, M6.8 (30 killed)
  - Dr. J.D. Cooper suggests EEW system
- 1964 Japan Railroad builds Shinkansen
  - EEW for the system
- 1985 Mexico City M8.0 (~10,000 killed)
  - 1991 Mexico's EEW system goes live
- 1989 Loma Prieta M6.9 (57 killed)
  - USGS rapid-prototype EEW system
- 1995 Kobe M6.9 (6,400 killed)
  - 2007 JMA system (~$500M) goes live
- 2006 ShakeAlert development begins
  - 2012 Demonstration system live



D. Given, USGS



Major EEW System Components
Sensor Networks
Field telemetry
Processing
Alert Creation
Alert Delivery
User Actions
D. Given,
USGS

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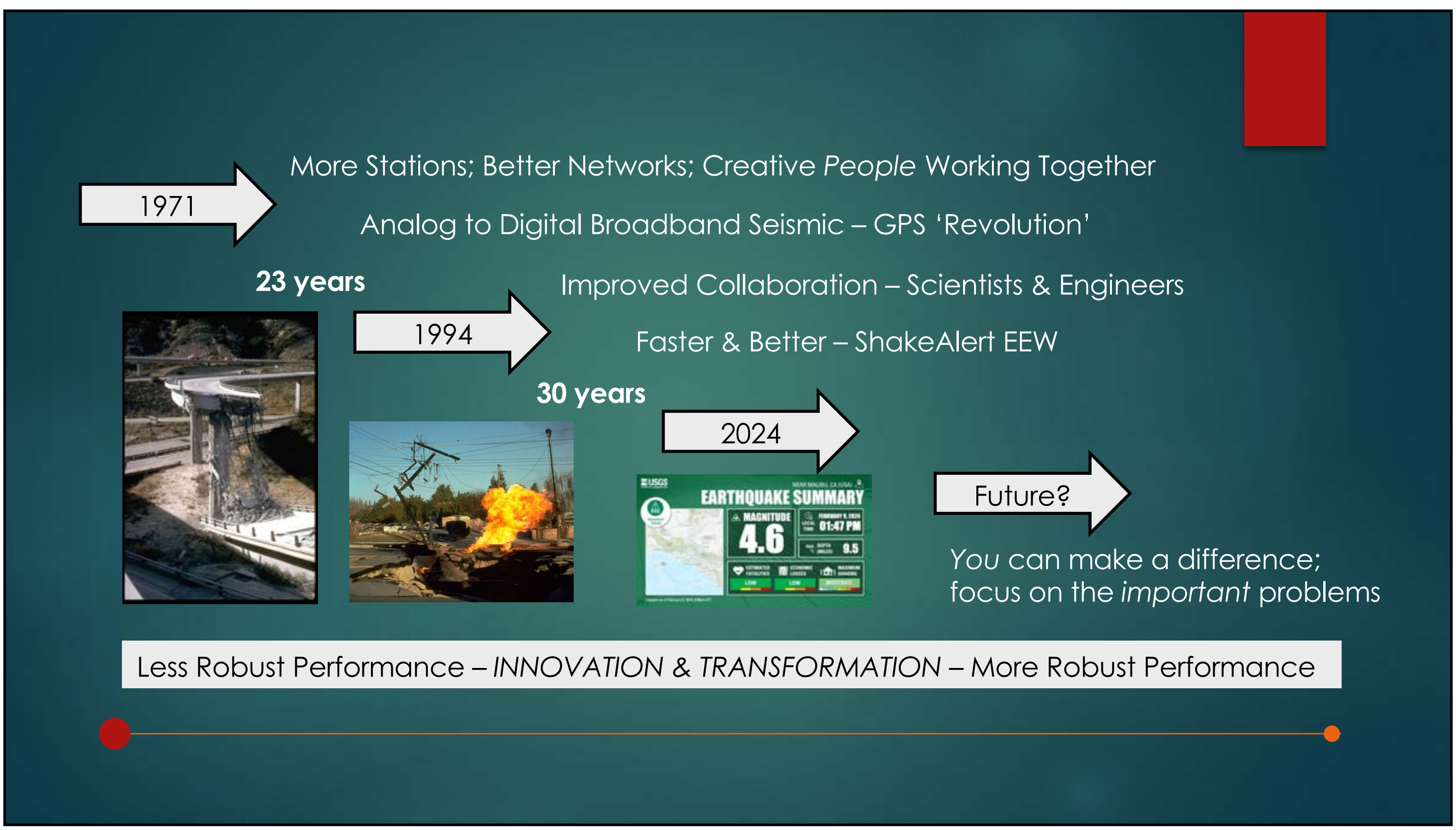

1971
More Stations; Better Networks; Creative *People* Working Together
Analog to Digital Broadband Seismic – GPS 'Revolution'
23 years
1994
Improved Collaboration – Scientists & Engineers
Faster & Better – ShakeAlert EEW
30 years
2024
EARTHQUAKE SUMMARY
MAGNITUDE
4.6
01:47 PM
9.5
Future?
You can make a difference;
focus on the *important* problems
Less Robust Performance – *INNOVATION & TRANSFORMATION* – More Robust Performance

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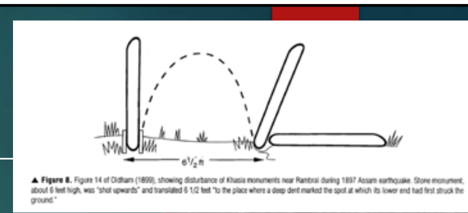
High Amplitude Near-Field Pulses

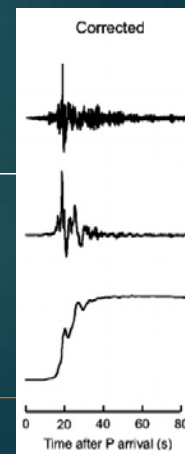


1897 Assam EQ (Oldham, 1899)

1971 San Fernando EQ (e.g., Allen, Brune, Cluff & Barrows, 1998)

1992 Landers (e.g., Sieh et al., 1993 and Iwan & Chen, 1994)

1994 Northridge EQ (e.g., Jones et al., 1994 and Wald, Heaton, Hudnut, 1996)



2002 Denali Fault EQ (e.g., Eberhart-Phillips et al., 2003 and Ellsworth et al., 2004)

… and recent examples of additional near fault seismic data

2023 Turkey EQ and 2024 Noto Hanto, Japan EQ

Important problems remain to be solved that can benefit from collaboration between earthquake scientists and engineers. You can make a difference!

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Ground Motions and Ground Failure from 1994 Northridge Earthquake

Jonathan P. Stewart, Ph.D., P.E.

Professor, UCLA

Visiting Professor, University of Canterbury, NZ

UCLA Samueli School of Engineering

EERI Southern California

ASCE Infrastructure Resilience

14 February 2024

Northridge 30 Webinar Series

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Northridge Earthquake Ground Motions

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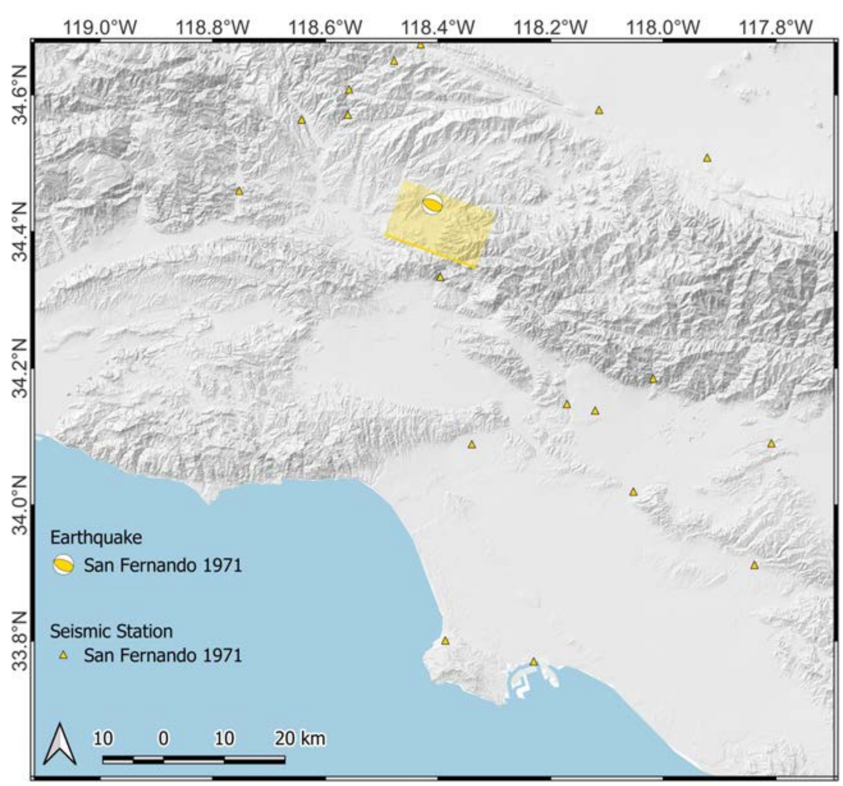
GMDB records from **1971 Sylmar Earthquake**

- CDMG and Caltech networks
- 44 recordings
- Only Pacoima Dam is near-source



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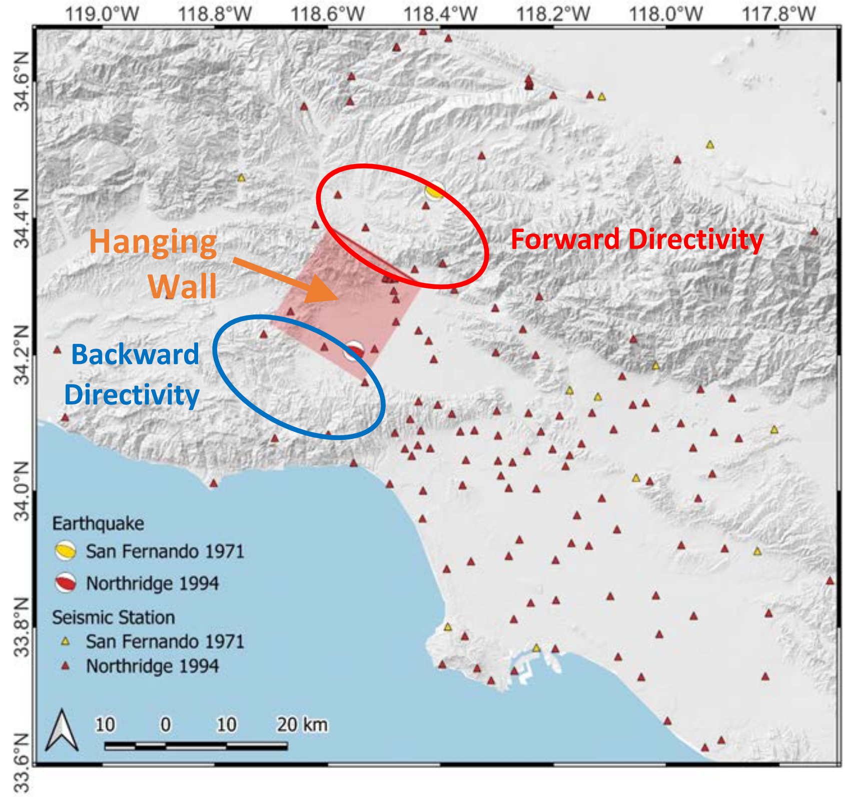
GMDB records from 1971 Sylmar Earthquake

GMDB records from **1994 Northridge Earthquake**

- CSMIP, USGS, USC, SCE, LADWP, and DWR networks
- 160 recordings
- Multiple near fault recordings

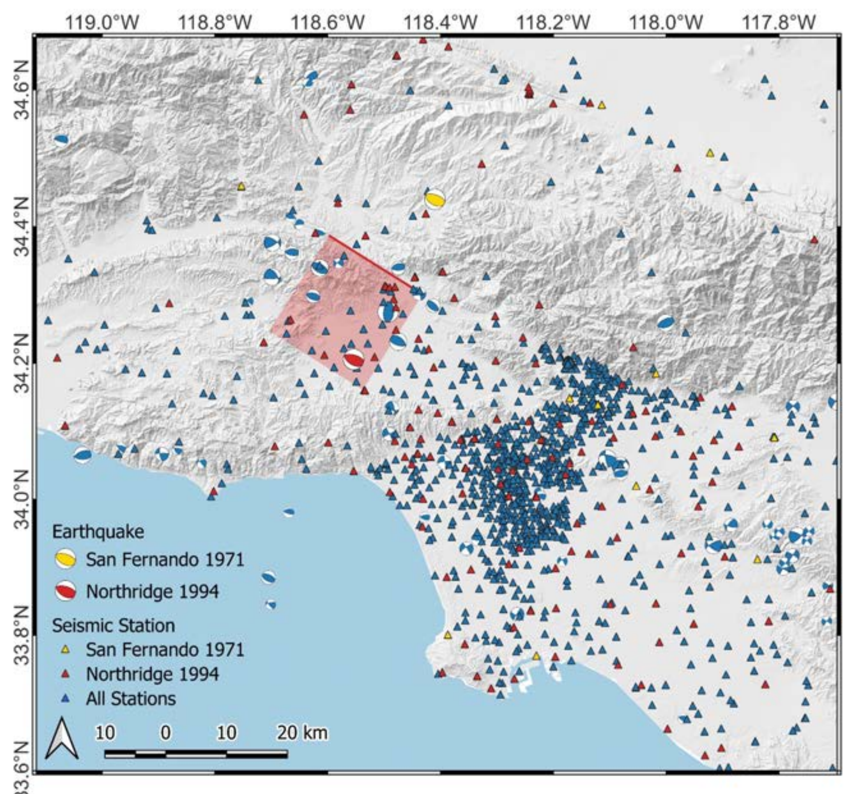


GMDB records from 1971 Sylmar Earthquake

GMDB records from 1994 Northridge Earthquake

GMDB stations now in **greater Los Angeles region**

- SCSN, CSMIP, USGS, CSN, others
- >1600 stations in figure
- Typical **M** 5 earthquake: 500-700 records

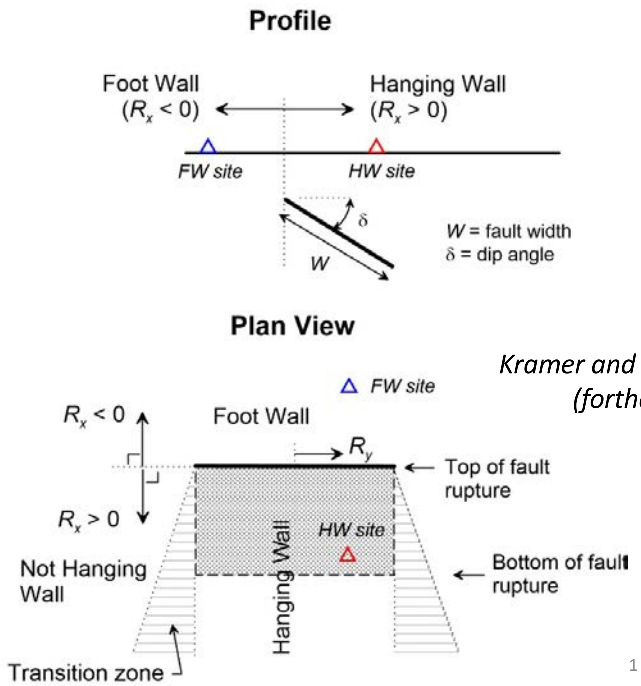


Are the Northridge ground motion recordings still important?

Yes

Valuable dataset for moderate-magnitude reverse-slip event

Example application: Hanging wall effects



Kramer and Stewart (forthcoming)

1

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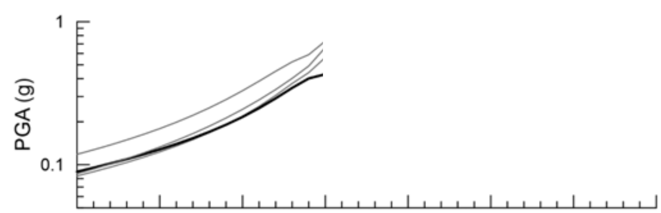
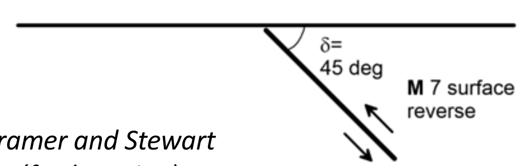
Example application: Hanging wall effects

- Footwall attenuation (reference)
- Flat / lower attenuation on hanging wall





Kramer and Stewart (forthcoming)

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- Footwall attenuation (reference)
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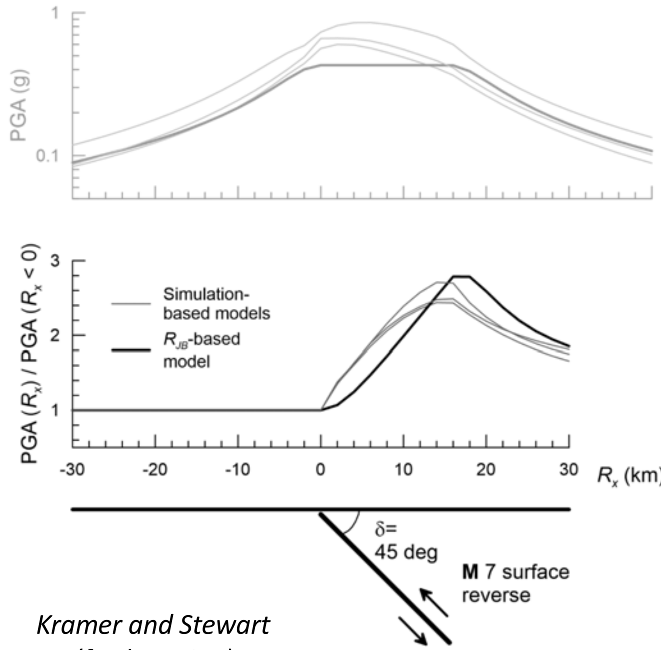
- Hanging wall amplification



Kramer and Stewart (forthcoming)

Are the Northridge ground motion recordings still important?

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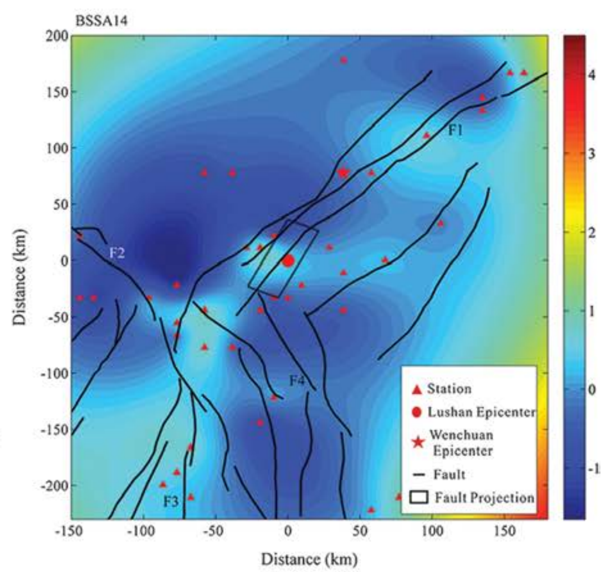
Example application: Hanging wall effects

Few other earthquakes with hanging wall motions

- **M** 6.7 2013 Luzon, China



Bai, 2013

Are the Northridge ground motion recordings still important?

Yes

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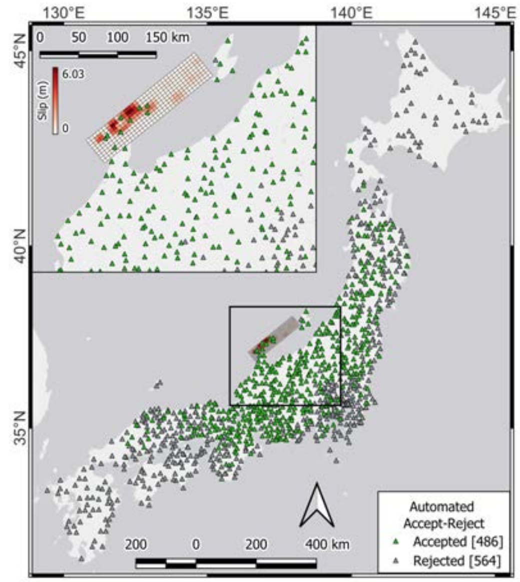
Example application: Hanging wall effects

Few other earthquakes with hanging wall motions

- **M** 6.7 2013 Luzon, China
- **M** 7.5 2024 Noru, Japan



Buckreis, 2024

Northridge Earthquake Ground Failure

"Ground Failure": permanent ground deformations caused by an earthquake

Types of Ground Failure from Northridge Earthquake

Landslides

LA Times

Tim McCrink

U.S. Air Force

Types of Ground Failure from Northridge Earthquake

Landslides

Seismic compression

Stewart et al. 2001

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Types of Ground Failure from Northridge Earthquake

Landslides

Seismic compression

Strength loss in loose, saturated soils during cyclic loading

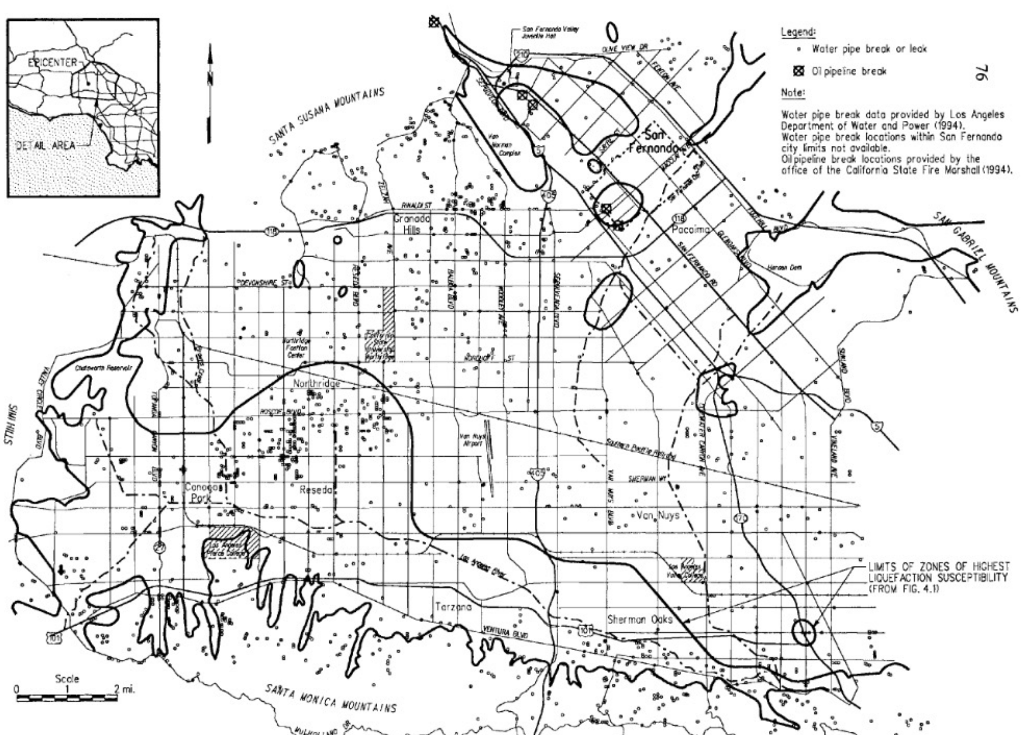
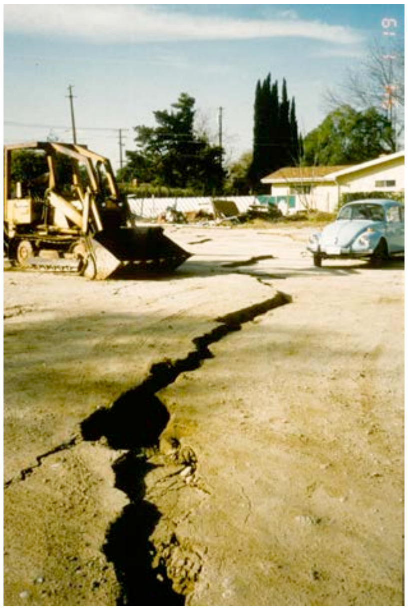


Fig. 4.5: Pipe breakage in the San Fernando Valley region

Stewart et al. 1994



Malden Street; *J. Tinsley*

Grenada Hills; *Stewart et al. 1994*

Balboa Blvd.; *LA Times*

Liquefaction analysis

Susceptibility: related to soil mineralogy – given the right saturation and loading conditions, could it liquefy?

Triggering: related to soil state, saturation, and ground motion hazard – is pore pressure generation and strength loss likely?

Effects: if triggering occurs, what will its effects be?

Liquefaction analysis

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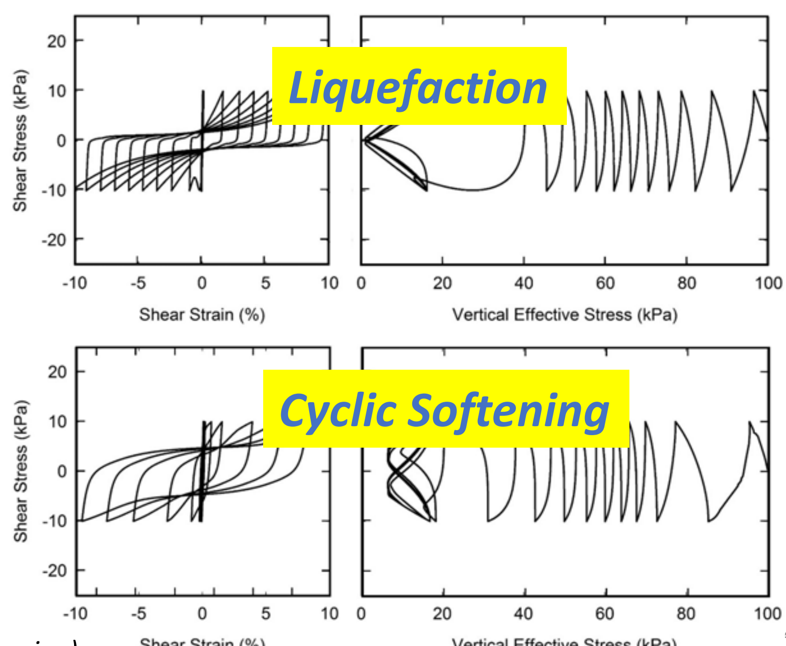
Triggering: related to soil state, saturation, and ground motion hazard – is pore pressure generation and strength loss likely?

Effects: if triggering occurs, what will its effects be?

Different types of material responses

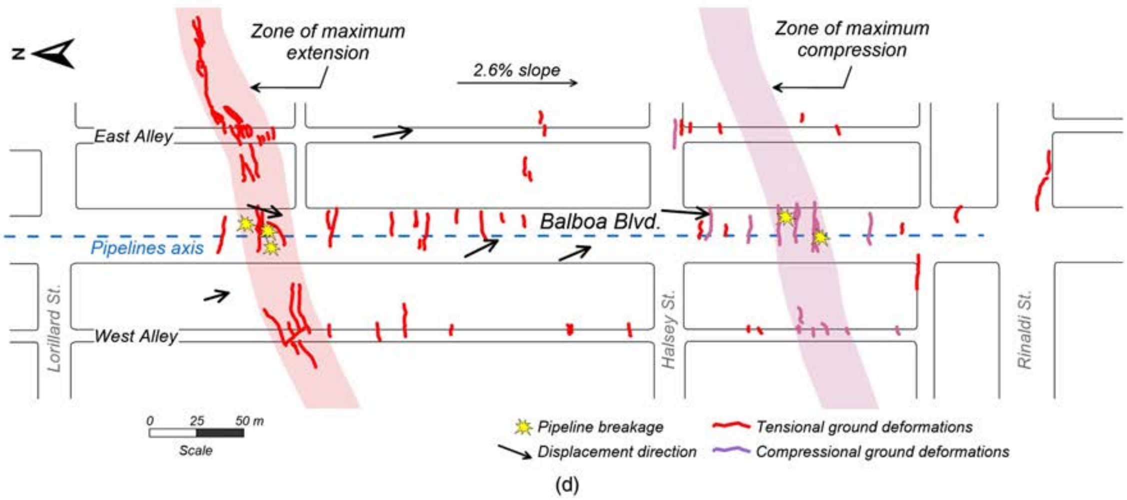
Granular soils:
- "pinched" stress-strain loops
- Near-zero effective stress
- Severe strength loss

Cohesive soils:
- Wide stress-strain loops
- Some effective stress remains
- Modest strength loss



Kramer and Stewart (forthcoming)

Balboa Blvd. Slope Movement



Pretell et al. 2021

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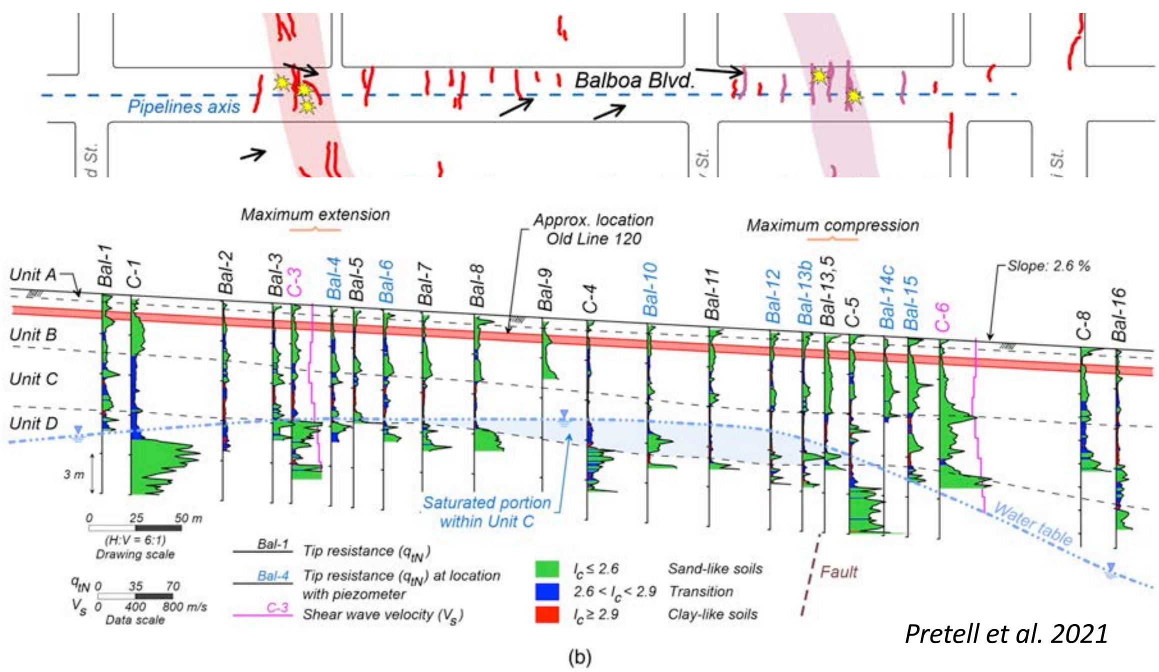
Balboa Blvd. Slope Movement



Pretell et al. 2021

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The Northridge Earthquake
30 Years Later, A Catalyst for Engineering Resilient Communities

Lifeline Infrastructure Systems

NORTHRIDGE 30
1994 2024

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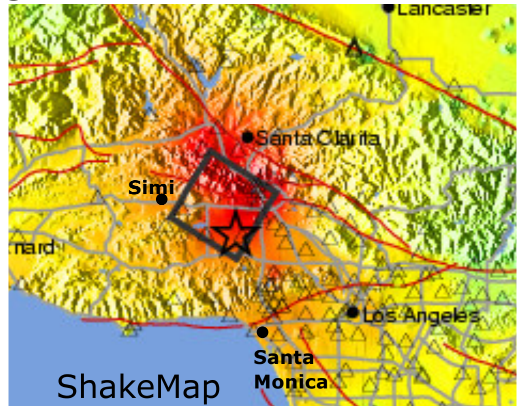
February 14, 2024

ASCE | INFRASTRUCTURE RESILIENCE
ASCE LOS ANGELES SECTION
EERI SOUTHERN CALIFORNIA
SEAOSC STRUCTURAL ENGINEERS ASSOCIATION OF SOUTHERN CALIFORNIA
Earthquake Country Alliance

Lifeline Infrastructure Systems



- Overview of:
  - Transportation
  - Water
  - Wastewater
  - Natural Gas
  - Electric Power
  - Liquid Fuels
  - Telecommunications
  - Lifeline Interdependencies and interactions
  - Fire Following Earthquake
- There are many different systems impacted in Southern California by the Northridge Earthquake
- This presentation will only summarize a few aspects and give a general overview on service disruptions to illustrate some key lessons
- Complex systems and issues are being summarized in only a few minutes

Transportation - Roadway, Highway, Rail

- Debris blocking roads
- Landslides, subsidence, and lateral spreading
- Interactions with other structures and collocated lifelines

} service disruption for days, wks, mos

- Bridge approach settlement & column/support failure
  - 237 bridges experienced damage requiring repair – service disruption
  - 7 of these bridges experienced severe damage/collapse – cut off entire communities (disrupted millions of people, goods, and services for many months)
  - Caltrans implemented innovative methods to rapidly replace bridges
- Roadway and highway damage impeded response and recovery times
- No major damage to rail, port, or other transportation systems
  - One train derailed from seismic wave movement – resulted in a toxic spill
- Commuter rail (light rail & subway) picked up displaced highway commuters (redundant transport systems)

Highway Bridges – Caltrans (courtesy M. Yashinsky)

Gavin Canyon Undercrossing

Route 14/5 Separation & Overhead

La Cienega-Venice Blvd Undercrossing

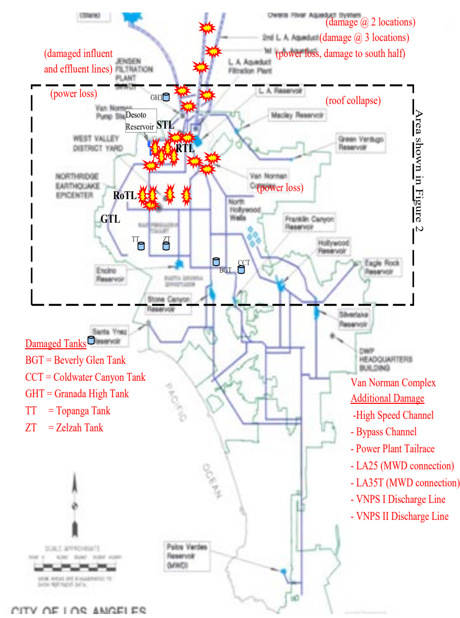
Mission Gothic Undercrossing

Telecommunications (Pac Bell, GTE, AT&T)

- Telecommunications systems performed reasonably well
- 5 switch failures removing all service to 224,000 lines for 3-13.5 hrs
  - Some from loss of power (dependency)
- 8 switches isolated from the SS7 Control Network limiting access for 386,000 lines to local dialing area for 3-8 hrs
- 2 interexchanges failed preventing 1,900,000 customers from connection to long-distance carriers for 8 hrs
- 911 worked well
- Call volume increased 4x, the surge caused delays
- 35 cell sites down, all restored within 72 hrs.

Water and Sewer Systems
(Most impacts to LA City Systems)

- Water Systems
  - Thousands of pipe repairs
  - Damage to Aqueduct and transmission lines
  - Damage to tanks, reservoirs, & treatment plants
  - Service impacts to ~1,000,000 people
  - Boil Water notices issued
  - Loss of water to fight fires
  - <u>All services restored within weeks</u>
  - System repairs completed in years
- Sewer Systems
  - Pipe and treatment plant damages
  - <u>Service outages not substantial</u>



Natural Gas (So. California Gas Company)

- Pipe damages
  - 35 transmission (old lines)
    - 3 fires
  - 154 distribution (steel)
- All newer pipes performed well
- 151,000 customers out of service (88% shut off own service)
- 51 natural gas related fires (private property)
- 172 mobile homes destroyed by fire (lack of seismic bracing)
- <u>82% of customers restored in 2-3 weeks</u>


Ground Failure, Balboa Blvd.
LADWP


https://wtop.com/national/2019/01/northridge-earthquake-shattered-los-angeles-25-years-ago/

Electric Power (LADWP and SCE most impacted)

- Damage to Transmission Towers, Converter & Receiving Stations.
- Power lost to entire City of LA for 1st time ever
- LA restored 93% customers in 1.5 days, completed within 2 days
- SCE had 825,000 customer outages, restored in 20 hours
- Power Grid impacts resulted in outages across Western USA and Canada

Liquid Fuels

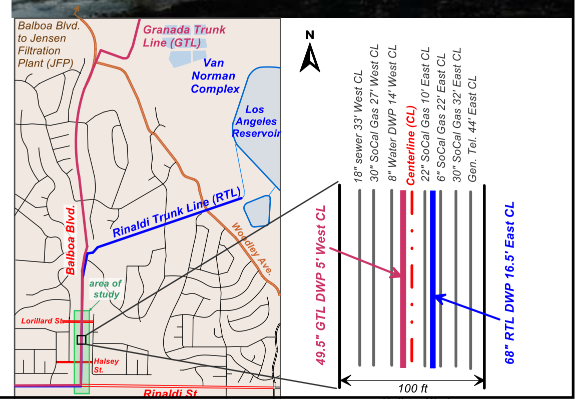
- 1 older 1925 transmission line damaged
- New pipelines were undamaged
- Several oil spills
  - 1 caught fire, damaging cars & homes
- Gas Station Outages
  - Some related to power service loss

Lifeline Service Disruption Interactions
Some examples from Northridge Earthquake

- Water break ---> Road washout, flooding
- Road/bridge closure ---> Unable to inspect & repair or deliver fuel & parts
- Tank failure ---> No water for fires, no water for residents
- Electrical failure ---> Water/sewer pumping/treatment, telecommunications, controls and SCADA, gas stations, heating, cooling, cooking
- Communication failure ---> no information, uncoordinated
- Natural gas disruption ---> No heating, cooking, industrial, power generation
- Liquid Fuels disruption ---> No delivery, repair, vehicle transport, industrial, backup power

Interdependencies Example – Balboa Blvd.

- Ground failure ~20” displacement, damaged road & water and natural gas pipelines
  - New natural gas pipelines were not damaged
- Street flooded
- Spark from truck engine ignited gas leaking from an old pipe
- Burned homes and electrical lines
- Disrupted communication cables (explosion + flood)
- Balboa Blvd. is designated as an emergency evacuation route
- Post earthquake repairs were difficult to coordinate between all collocated utilities – causing repair delays



Fire Following Earthquake

- 110 documented ignitions
- 80% structure fires
- Some nat. gas ignition - power resumed
- Water loss in ignition areas
- Alternate water needed
  - Swimming pools

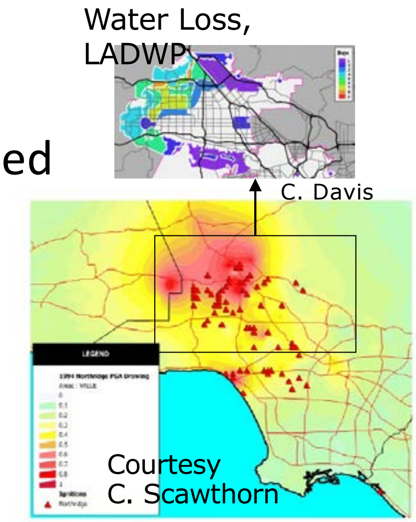


Figure 2.7 1994 Northridge earthquake ignitions overlaid on peak ground accelerations.

Key Lessons

- Mitigation works.
  - Lifelines components in all systems that were mitigated after the 1971 San Fernando earthquake, and meeting current standards, performed as expected in 1994.
    - Most were undamaged.
    - All helped keep services or restore services more rapidly
  - Those components not mitigated were damaged.
- Seismic Improvements
  - All systems made improvements after the 1994 earthquake based on vulnerabilities identified and lessons learned.
- Maintaining Preparations after the Earthquake
  - Mitigation and system improvement efforts wane over time
  - It is important to maintain improvement efforts
  - Can be accomplished with good leadership, but it is difficult with all the pressures for spending within the agencies. Multihazard mitigation efforts are important.

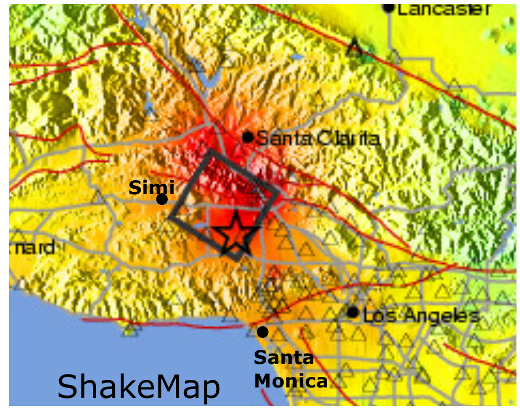
Key Lessons

- Uncertainty in the seismic hazards, their intensity, and impacts on lifelines
  - Seismic ground motion was greater than anticipated. We better understand now, but there remains high uncertainty
  - PGD could not have been predicted in all locations, & those where PGD expected had high uncertainty in the displacements.
  - The impacts on lifelines was significant
  - The uncertainty in geotechnics is not properly considered in lifeline earthquake engineering.
  - This has huge implications on design of the most critical components.

Key Lessons

- Human Aspects of Lifeline Infrastructure Systems
  - All systems utilized mutual aid & assistance to recover services
    - Internal and external to systems
  - There was difficulty in providing emergency services for workers
    - Food, housing, toilets, materials, other
    - Not readily available during a disaster
  - Lifeline services cannot be maintained nor restored without human actions
- Customers/Users adapt to disrupted services

Recap – January 17, 1994



In the earthquake near-source area:

- People were shaken awake at 4:31am
- There is no water or power
- Fires are igniting
- There are toxic spills
- Streets are flooded from broken water lines
- Phones don't work – cannot call for help, cannot call for information
- Transportation routes are interrupted – how can people evacuate or get help?

Response and recovery are hampered

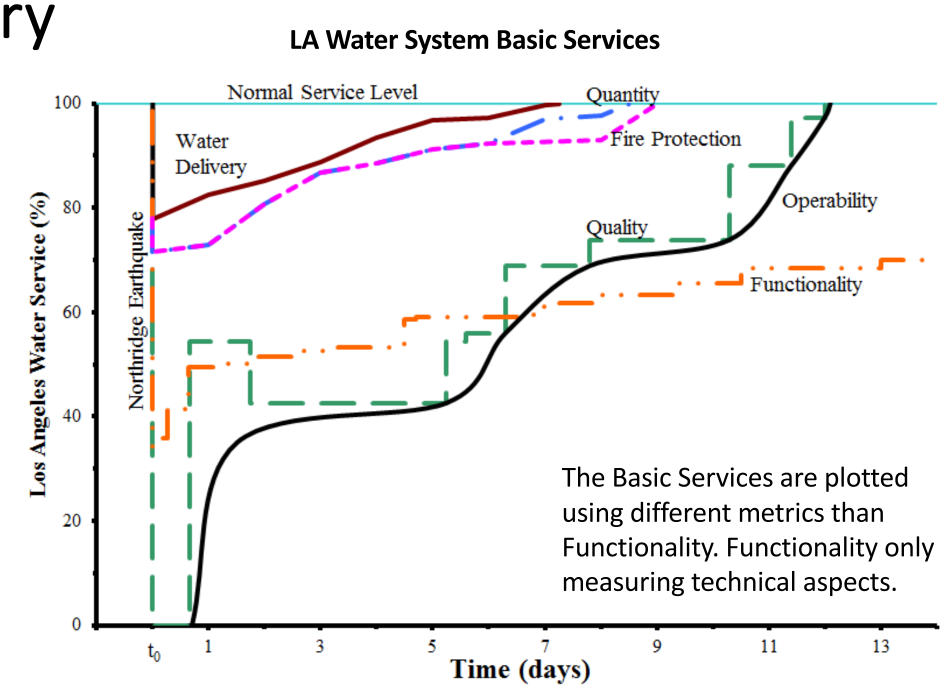
- In fact, it was difficult to even support the workers making the system repairs over the days to come
- Food, fuel, etc. are not readily available.
- Required adaptations for customers/users of most infrastructure system services
- These systems have service losses that are not supporting the community during a disaster and in fact are themselves adding to/creating the disaster.

Service Recovery

- These infrastructure systems were fairly resilient
  - Resilience is usually described in terms of a rapid recovery.
- They were able to recover their basic services to the communities experiencing the disaster in a timely manner.
- This was a result of having experienced a similar-sized earthquake-caused disaster 23 years prior in the same area.
  - Post-1971 earthquake improvements were made over the decades and paid dividends in 1994!
- **What about areas not as prepared?**
- **What about larger events?**

Service Recovery

- This earthquake revealed the importance of recovering basic services to customers
- Example from the LA Water System identifies water basic services as:
  - Delivery
  - Quantity
  - Quality, and
  - Fire Protection
- These were the targets used to restore the system after the earthquake
- Basic services can similarly be defined for other infrastructure systems



Post-Event

Lifeline Systems Focus on:

1. Life safety
2. Public health
3. Property protection
4. Containing system service losses, get control of situation
5. Make repairs & system adaptations to restore services

Addressed in:

- Items 1–3: Codes, standards, regulations and Emergency Response Plans
- Item 4: Emergency Response Plans
- Item 5: ???

There are no design procedures or response activities targeting service recovery within a defined duration.

- **What is rapid recovery and when do we achieve it (i.e., when is a system resilient and to which event size)?**
  - **Is it 1 day, 1 week, 1 month 1 year acceptable and why?**
  - **Rapid to one individual may be slow to another!**

Service Recovery

- The concept of Basic Services is now foundational knowledge for service recovery-based design
- FEMA & NIST are advancing the concept of Functional recovery
- Knowledge gained from the Northridge earthquake, and other events, forms the basis for the concept of Lifeline System Functional Recovery
- Service recovery & recovery-based design needs to account for:
  - All the concepts identified for the Northridge earthquake given in this presentation
  - Service uses by all users
  - User adaptations
  - The times when users need the services restored
- Service recovery should become a basis for how we design lifeline infrastructure systems along with safety and public health

Northridge EQ – What happened to buildings?

David W. Cocke, SE

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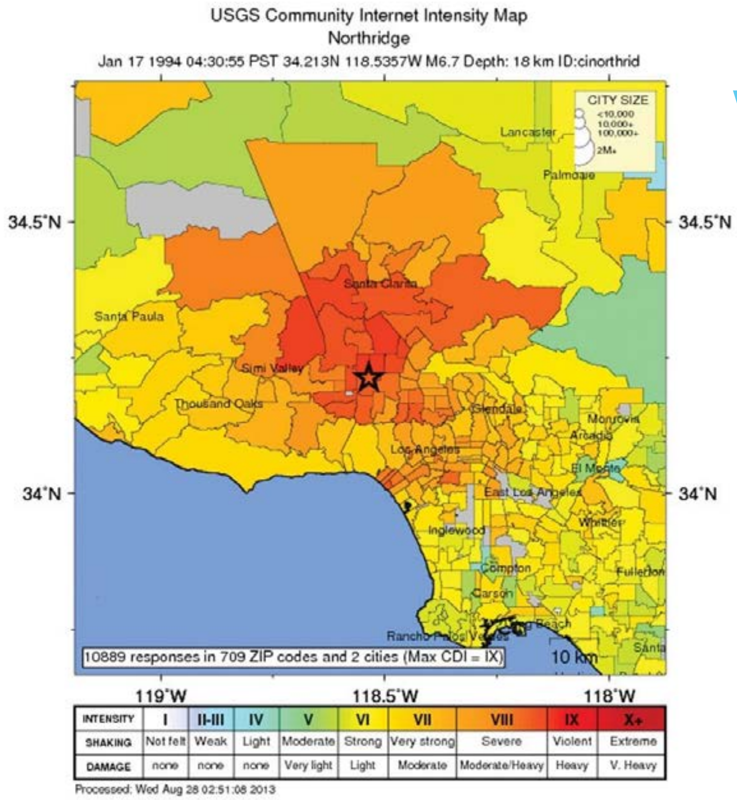

What happened?

- 6.7 magnitude at 4:30 a.m.
- Max MMI of IX
- Ground motions in much of the SF Valley near the code design levels
- The level and frequency of damage in these areas have lessons for us for buildings designed to code ground motion levels

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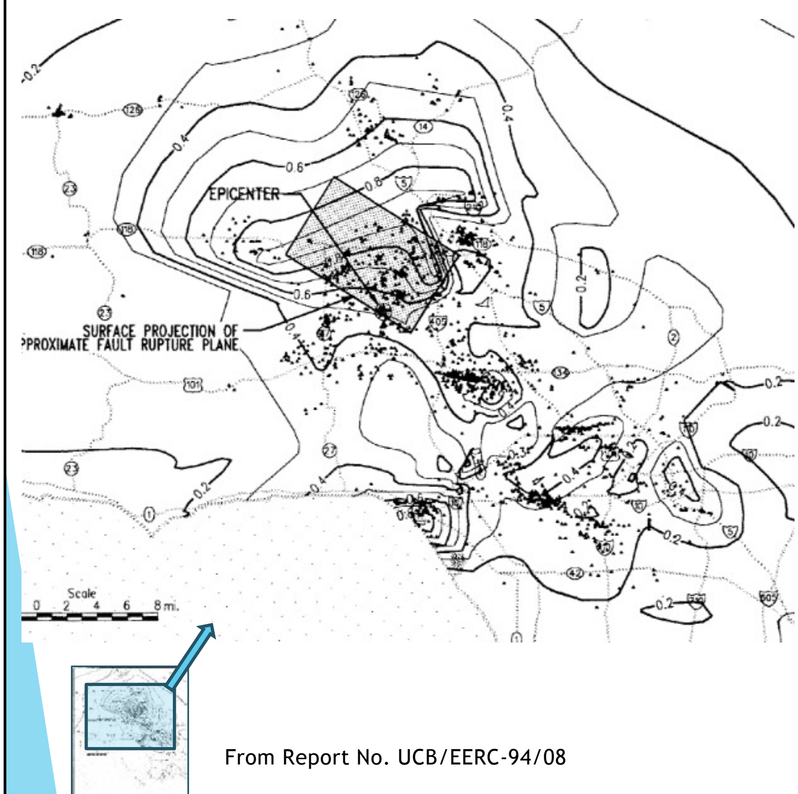

From Report No. UCB/EERC-94/08

Red-tagged Buildings

- Damaged concentrated in the valley and in Santa Monica
- Most severely damaged were
  - URM’s
  - Tilt-up’s
  - Steel moment frames
  - Concrete parking structures
  - Soft-story (mostly housing)
  - Non-ductile concrete

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Unreinforced Masonry Buildings

LA Ordinances:

DIVISION 88 - Earthquake Hazard Reduction in Existing Buildings (URM)
Ordinance 159068 Eff. 7/29/84 Oper. 1/29/1985 <u>**Mandatory**</u>

(**CA SB 547** was signed in June 1986)

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Tilt-Up Buildings

Courtesy of Doc Nghiem.

LA Ordinances:

DIVISION 91 - Earthquake Hazard Reduction in Existing Tilt-up Concrete Wall Buildings
Ordinance 169341 2/4/1994

DIVISION 96 - <u>Voluntary</u> Earthquake Hazard Reduction in Existing Reinforced Concrete and Reinforced Masonry Wall Buildings with Flexible Diaphragms
Added by Ordinance 171261 Eff. 8/30/96

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Steel Moment Frame Buildings

“best” LFRS showed surprising damage

Parking Structures

Code changes:

- Deformation compatibility
- Pre-cast concrete connections

Soft-Story Buildings

LA Ordinances:

DIVISION 92 - Voluntary Earthquake Hazard Reduction in Existing Wood-Frame Residential Buildings with Weak Cripple Walls and Unbolted Sill Plates
Ordinance 171259 Eff. 8/30/96

DIVISION 93 - Mandatory Earthquake Hazard Reduction in Existing Wood-Frame Buildings With Soft, Weak or Open-Front Walls
Amended in Entirety by Ordinance 183893 Eff. 11/22/15

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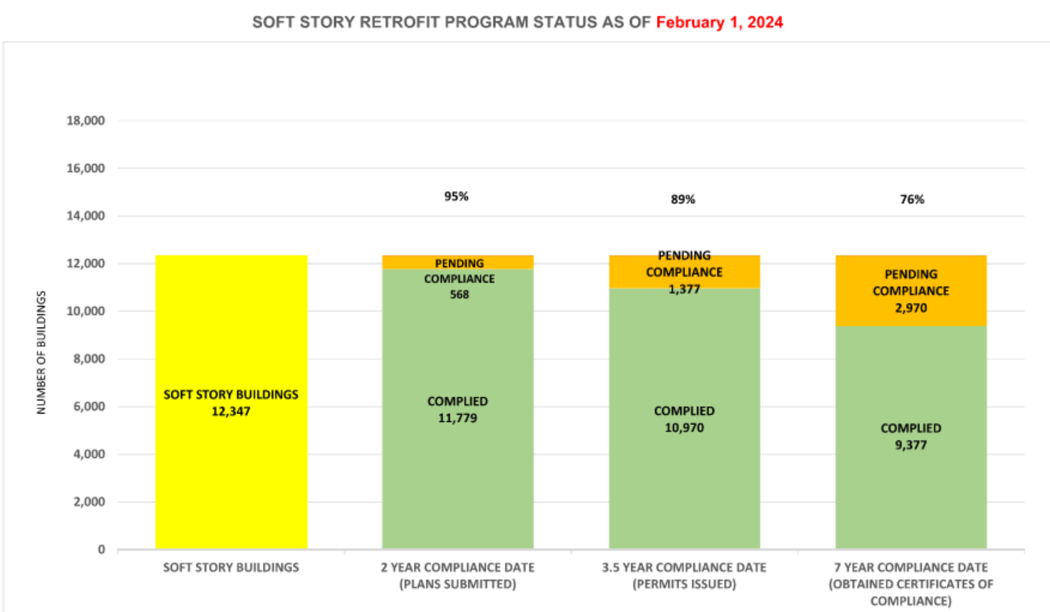

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Non-ductile Concrete Buildings

LA Ordinances:

DIVISION 95 - <u>Mandatory</u> Earthquake Hazard Reduction in Existing Non-Ductile Concrete Buildings
Amended in Entirety by Ordinance 183893 Eff. 11/22/15

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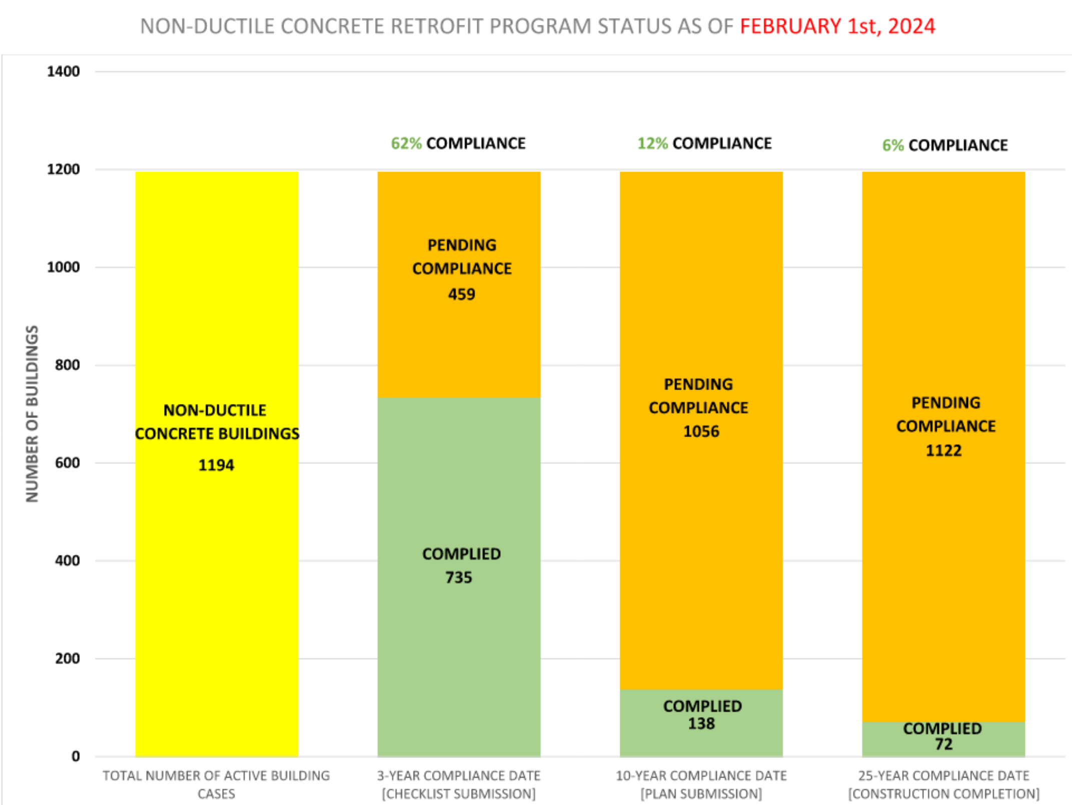

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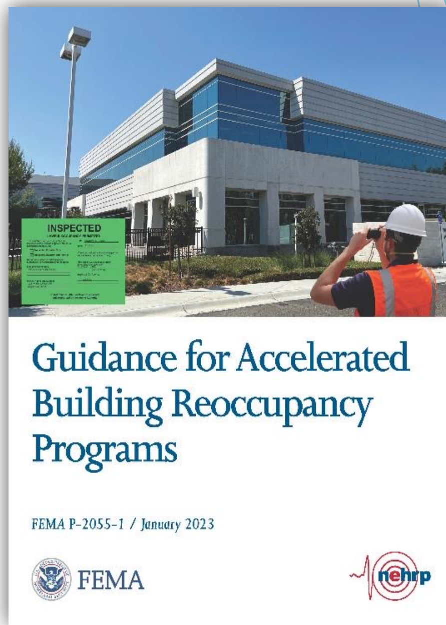
Building Safety Inspections

"After experiencing the wide-spread effects that the Northridge Earthquake had on the entire Greater L. A. Basin Region, I am convinced that a pre-established private-public partnership is the most effective path to rapid recovery of individual business institutions."

- Stuart Tom, PE, CBO, City of Glendale



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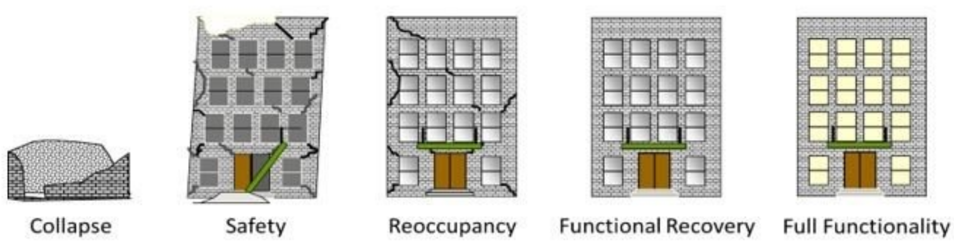
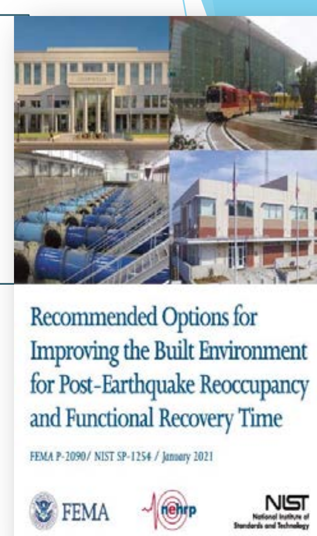
Functional Recovery





Would building inventory performance be different if we there had been a Functional Recovery standard in place?

Functional Recovery concept will be included in model codes in about 10 years - Unless we can accelerate!

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Thank you!

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