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# The US Experience in Northridge

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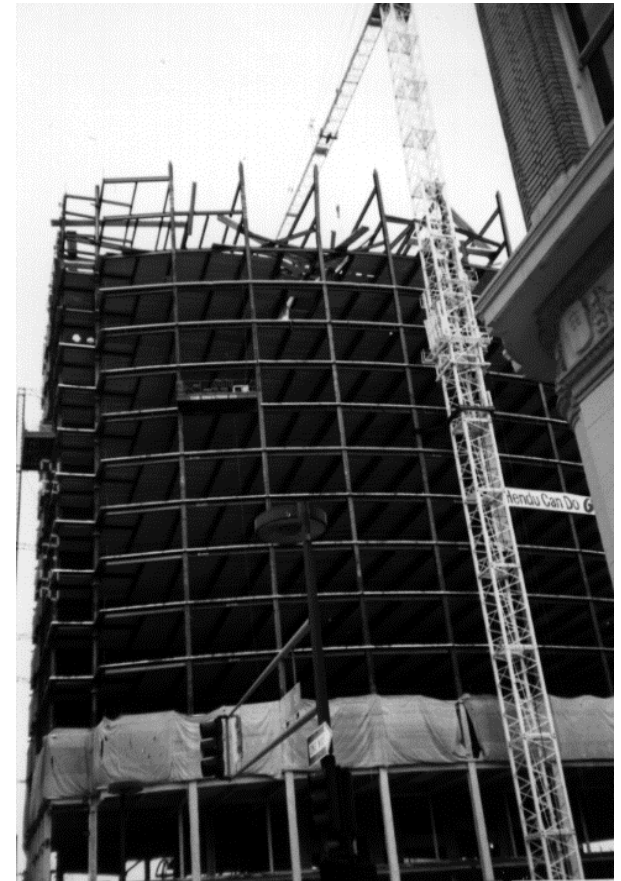


**The 1994 Northridge Earthquake:  
Impacts, Outcomes, and Next Steps**

January 16-17, 2014  
Los Angeles, CA

# 20 Years + 1 Day Ago

- Steel moment frame construction was seen as one of the best seismic performers.
- Desirable technique due to flexibility and open space.
- However, economic pressures led to the use of cost effective techniques not as thoroughly tested.
  - High deposition weld metals.



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# 20 Years Ago Today

- Northridge earthquake occurs early morning on January 17, 1994.
- Occurring early morning on a holiday greatly reducing the casualties.
- Steel moment frame buildings appear to be largely unaffected.
  - Thank you Hank.



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# And Then...

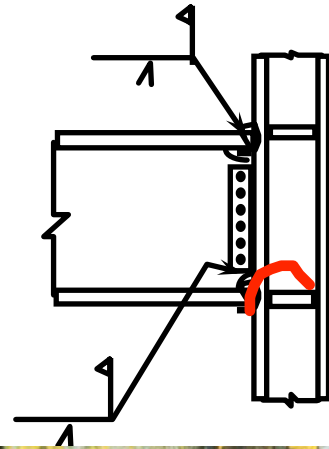
- February, 1994
  - Initial reports of fractured connections.
    - CSAA building
    - Santa Clarita City Hall
    - Borax Building
    - Getty Museum
- May, 1994
  - Wide-scale reports of damage documented, including in FEMA recovery applications.



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# The Northridge Problem

- Damage observed was brittle fractures of beam to column welded connections
- Fractures were found in welds, in the parent material, and extending into columns
- Many buildings had fractured connections:
  - new and old
  - tall and short
  - conventional and critical facilities



# The Northridge Problem

- This unexpected performance occurred in a less than design, or “elastic” event.
- While there were no collapses, there was also no observed ductile behavior.
- Damage was not visible; inspections difficult.
- Result was a loss of confidence in current code requirements.
- The level of safety and how to repair were unknown.
- This was a significant problem for owners, regulators and for FEMA, as the funder of repair/replacement of buildings owned by public and non-profit entities.



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# Overview of Development Process

- September, 1994
  - SAC Joint Venture formed.
  - FEMA contracts with the SAC Joint Venture.
  - Funding for Phase 1 was \$2 M; FEMA's share of NEHRP Northridge Congressional supplemental.
  - SAC Advisories 1 and 2 are prepared and distributed at SEAOC Convention.

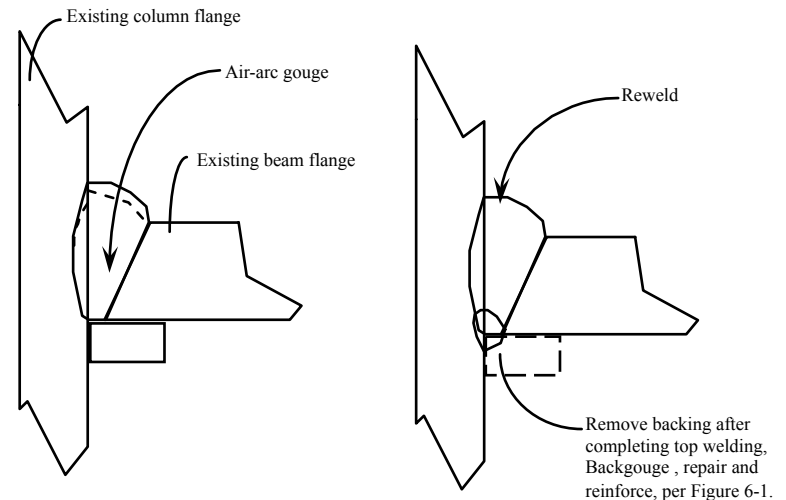


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# Overview of Development Process

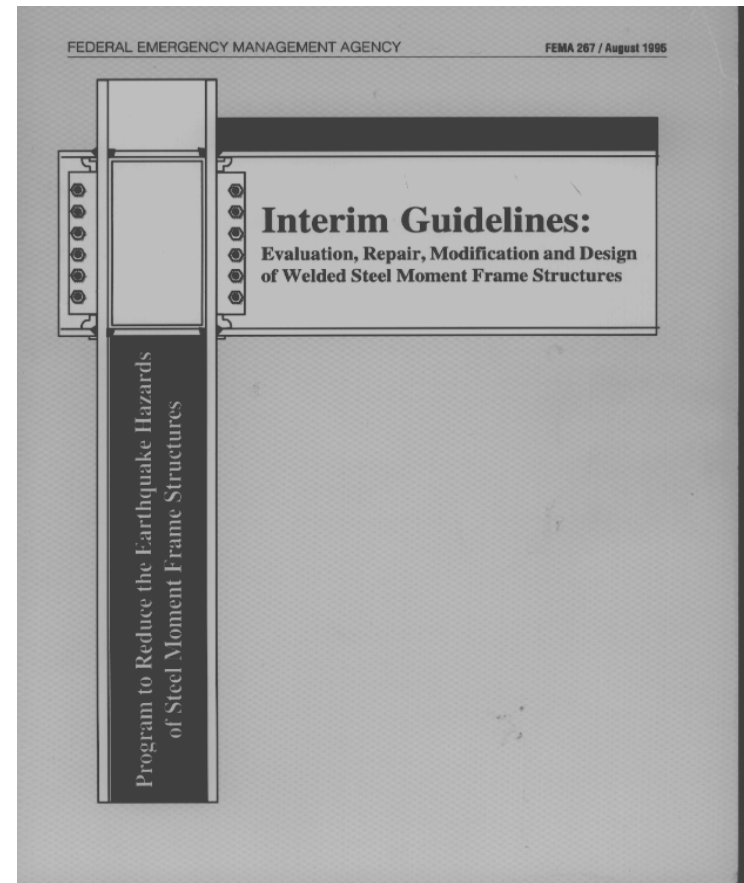
- December, 1994
  - SAC Advisory 3 is prepared and published.
  - Sees broader distribution than Advisories 1 and 2.
  - Its focus is on inspection and repair of damaged connections.





# Overview of Development Process

- August, 1995
  - FEMA-267 Interim Guidelines published.
    - inspection & repair
    - retrofit (modification)
    - design & construction of new buildings
  - Recommendations were Interim and advisory.
  - Rapidly accepted as a code.



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# Phase 2: FEMA Program to Reduce the Earthquake Hazards of Steel Moment-Frame Structures

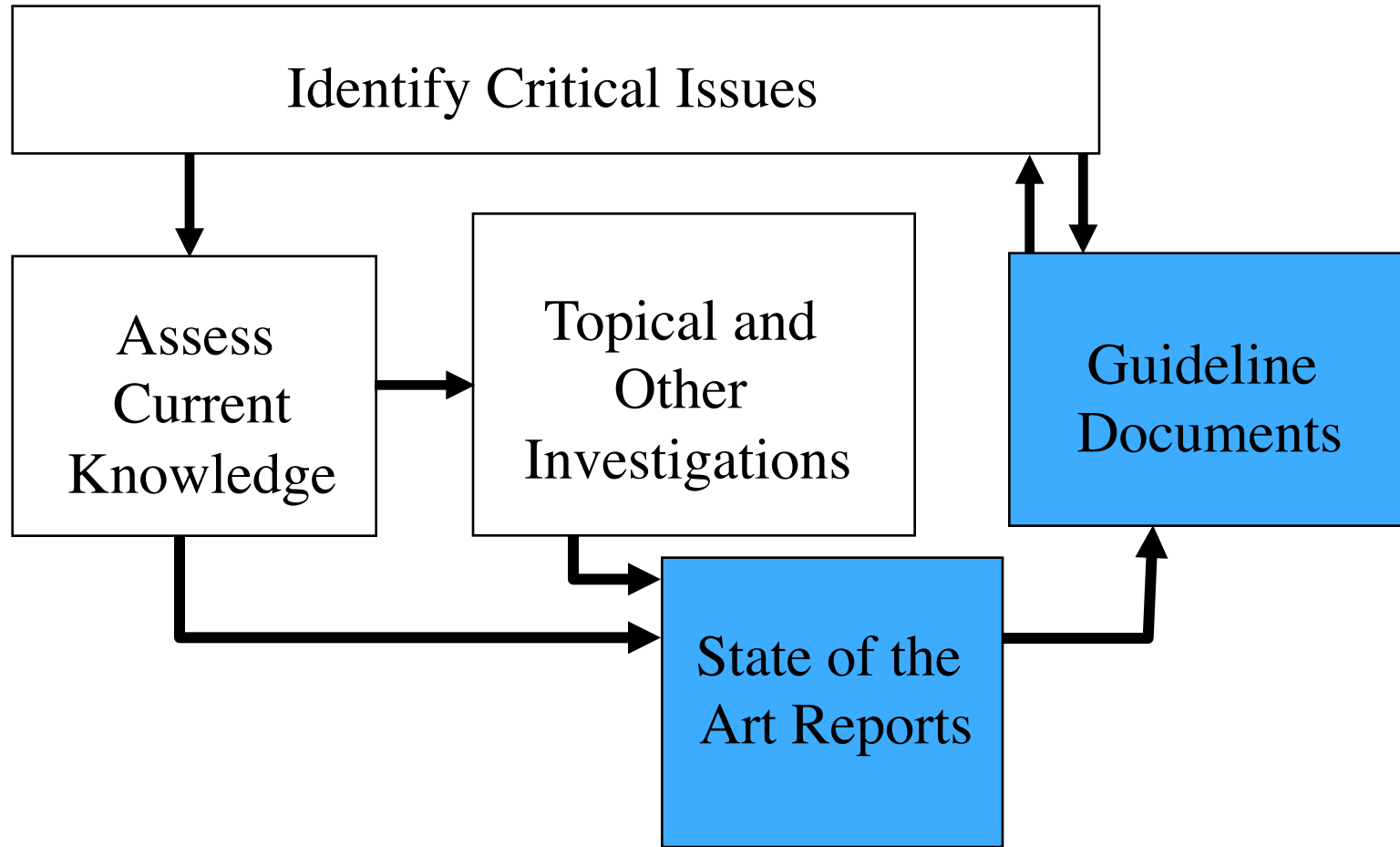
- Goal of Phase 2 was to develop reliable, practical and cost effective guidelines for:
  - the design and construction of new steel moment-frame buildings,
  - the identification, inspection, evaluation and retrofit of existing steel moment-frame buildings, and
  - the identification, evaluation, repair or upgrading of damaged buildings following earthquakes.
- Competitively contracted with the SAC Joint Venture.
- Funding was ~\$16M, half from President's Northridge Supplemental and half from FEMA NEHRP funds.



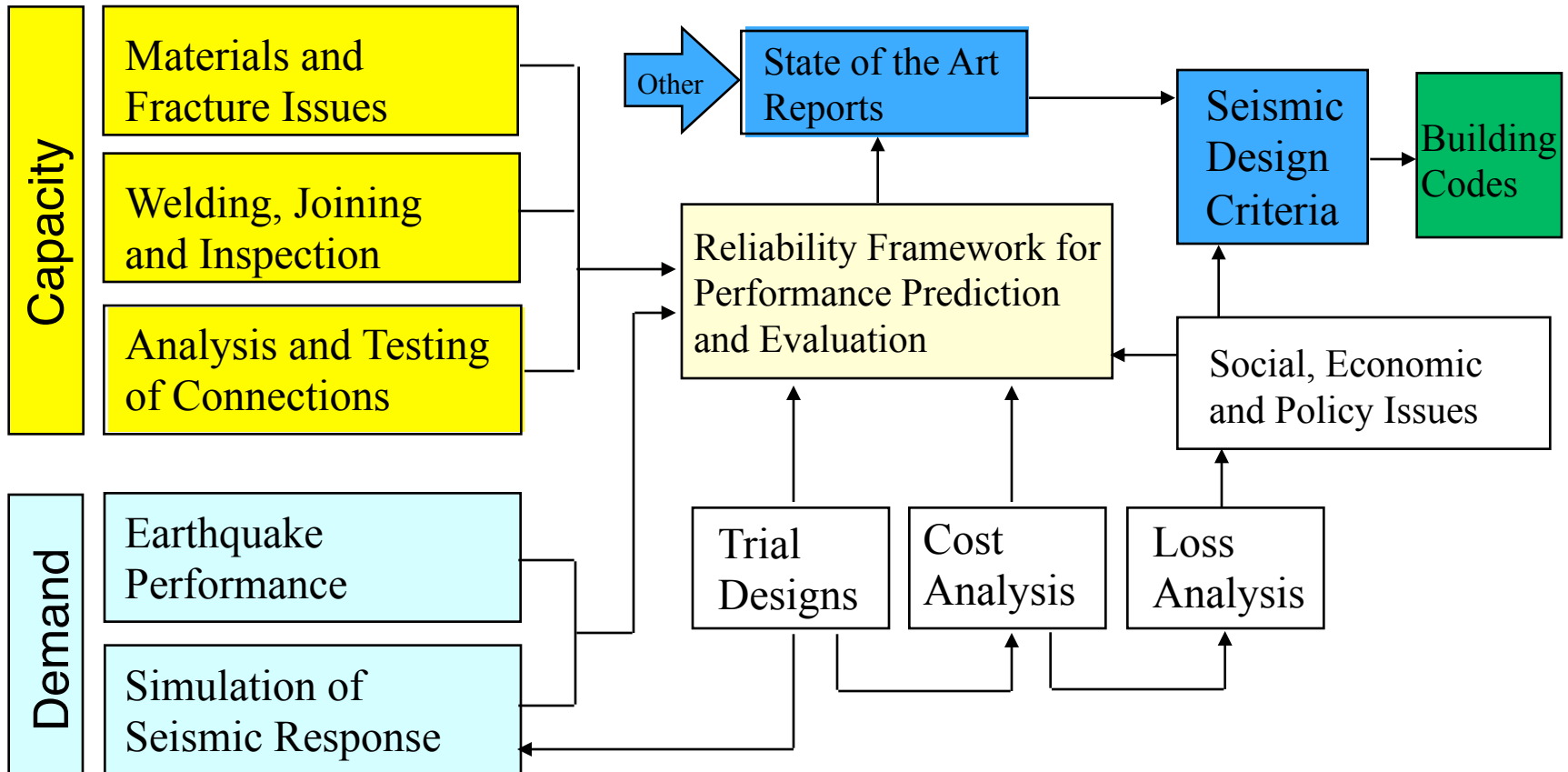
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# Overall Technical Approach



# The FEMA/SAC Steel Project



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# Initial Phase 2 Products

- *Background Reports on Metallurgy, Fracture Mechanics, Welding, Moment Connections and Frame Systems* published as FEMA 288.
- *Connection Test Summaries* (FEMA 289).
  - Superseded by *Prequalified Connections for Special and Intermediate Steel Moment Frame for Seismic Applications* - AISC 358.
- *Interim Guidelines Advisory No. 1 – Supplement to FEMA 267* published in 1996.
- Available from FEMA and [www.sacsteel.org](http://www.sacsteel.org).



# Design Provisions for New Buildings

- Final Design Guidelines were among the first to quantify performance, and provided:
  - 90% confidence of less than a 2% probability of global collapse in 50 years
  - 50% confidence of less than a 2% probability of local damage capable of resulting in partial collapse in 50 years



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# Achieved for New Buildings by:

- Use of NEHRP Provisions for structure analysis and proportioning:
  - Definition of design earthquake
  - Analysis procedures and modeling
  - Force reduction factors, redundancy factors, drift limits, etc.
  - Proportioning (strong column-weak girder, etc.)
- Welding specifications and QA/QC more clearly stated.
- Use of “prequalified” connections:
  - Explicit design calculations
  - Limits on range of materials, sizes, relative strengths, details, etc. that can be used

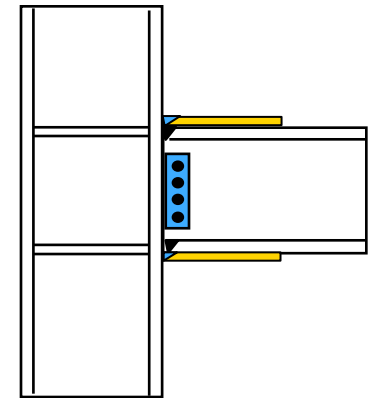
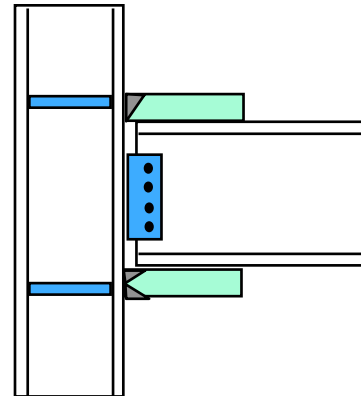
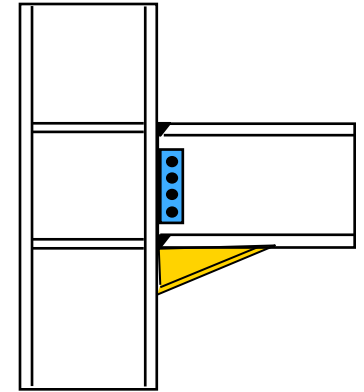
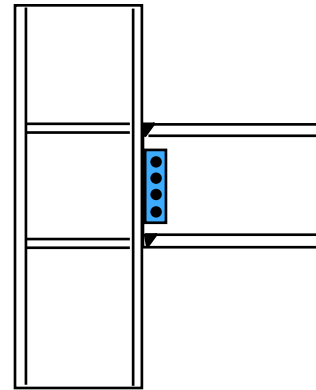
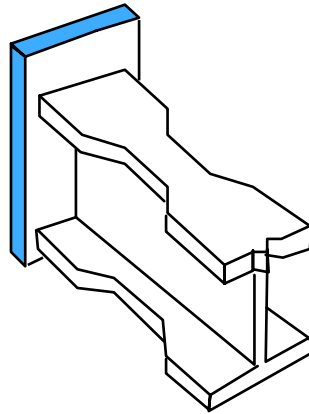


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# Welded Prequalified Connections

- “Improved” unreinforced connections.
- Reinforced connections
- Welded flange plate connections
- Reduced beam section connections



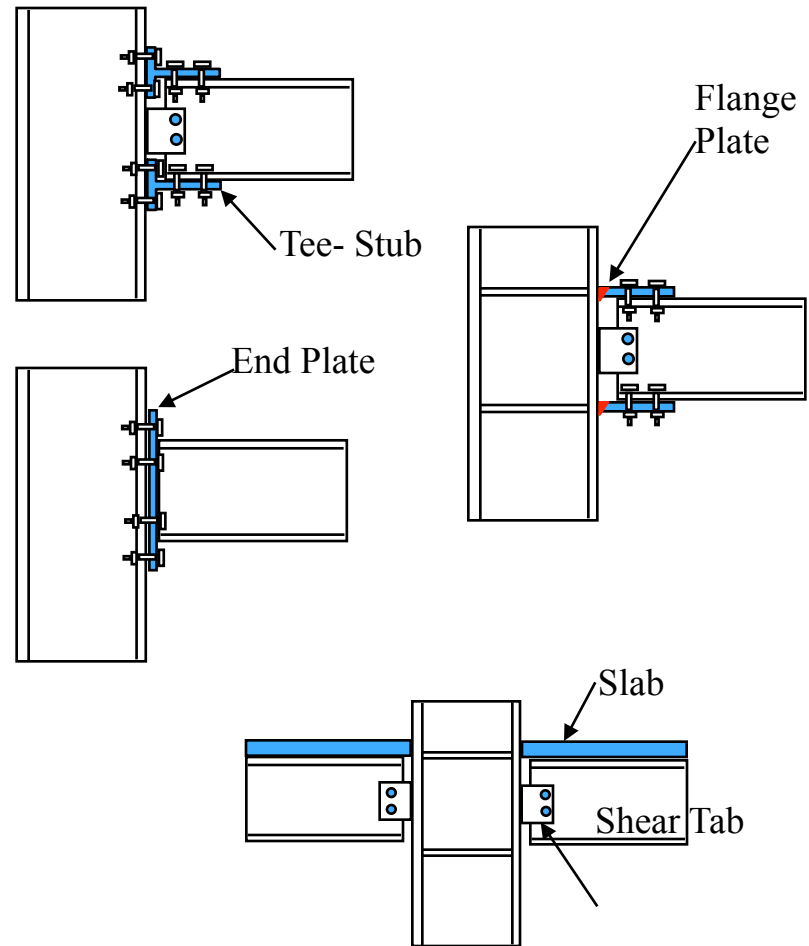
# Bolted Prequalified Connections

## Bolted Connections

- Tee-stub Connections
- Bolted flange plate connections
- End plate connections

## Gravity Connections

- Simple connections with and without slabs



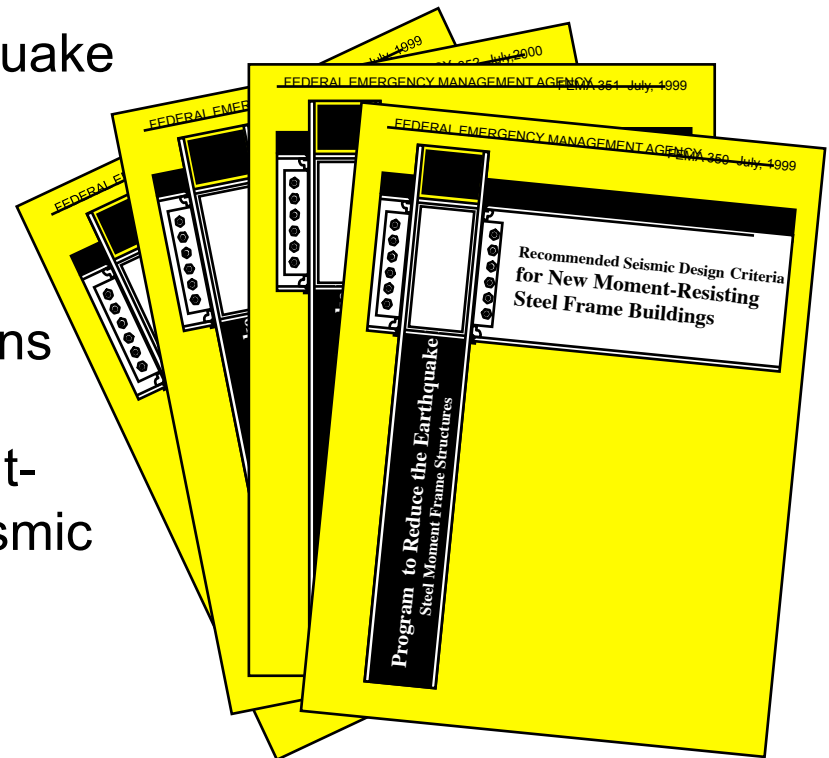
# Final FEMA/SAC Guidelines

**FEMA-350:** Recommended Seismic Design Criteria for New Steel Moment-Frame Buildings.

**FEMA-351:** Recommended Seismic Evaluation and Upgrade Criteria for Existing Welded Steel Moment-Frame Buildings.

**FEMA-352:** Recommended Post-earthquake Evaluation and Repair Criteria for Welded, Steel Moment-Frame Buildings.

**FEMA-353:** Recommended Specifications and Quality Assurance Guidelines for Steel Moment-Frame Construction for Seismic Applications.

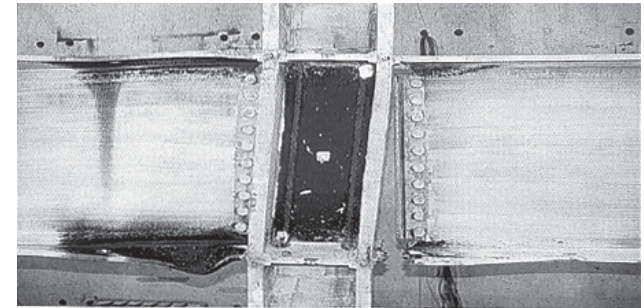


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# FEMA 355 CD

CD contains all four Guides and State of Art Reports:

- FEMA-355A: Base Metals and Fracture
- FEMA-355B: Welding and Inspection
- FEMA-355C: Systems Performance
- FEMA-355D: Connection Performance
- FEMA 355E: Past Performance of Steel Moment-Frame Buildings in Earthquakes
- FEMA-355F: Performance Prediction and Evaluation



Seismic Design Criteria for  
Steel Moment-Frame Structures: FEMA 350, 351, 352, and 353  
Policy Guide: FEMA 354  
State of the Art Reports: FEMA 355A, B, C, D, E, and F

FEMA 355



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# Status of Design Guidance Products

- FEMA 350 - 355 continue to be available free of charge from FEMA; call 1-800-480-2520
  - FEMA 350 has been incorporated into AISC 341 but is still available for reference.
  - FEMA 351-353 are still applicable and available.
- FEMA 355 CD contains all of publications and state of the art reports.
  - Also includes FEMA 354: Policy Guide for Building Owners and Community Officials
  - Moving to CD and online only.
- Related training courses conducted by AISC.



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# Summary

- This six year, \$12 million project conducted at the request of the FEMA Director and funded by both the Congress and the President.
- Goal was to research and develop criteria for:
  - design of new steel frame construction,
  - upgrading of existing buildings, and
  - inspection and repair of damaged buildings.
- This was the first FEMA effort to combine academic research with practical engineering expertise to develop technical guidance products to address a post-disaster need.



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# Conclusions / Acknowledgements

- This project done during “heyday” of NEHRP.
  - We had the funding and staff to do this.
- Could this be done again today? No.
  - FEMA Response better due to links to DHS.
  - Preparedness better due to post-Katrina funding.
  - But, NEHRP has less than ½ the funding and staff.
- Thank you to James Lee Witt.
  - Secured funding and agreed to wait five years.
- Thank you to the SAC Joint Venture.
  - Steve Mahin, Ron Hamburger, Jim Malley, Bill Hall.