The US Experience in Northridge

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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.
20 Years Ago Today

- Occurring early morning on a holiday greatly reducing the casualties.
- Steel moment frame buildings appear to be largely unaffected.
  - Thank you Hank.
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.
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.
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.
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.
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.
Overall Technical Approach

Identify Critical Issues

Assess Current Knowledge

Topical and Other Investigations

State of the Art Reports

Guideline Documents

Northridge20 Symposium
The FEMA/SAC Steel Project

Capacity
- Materials and Fracture Issues
- Welding, Joining and Inspection
- Analysis and Testing of Connections

Demand
- Earthquake Performance
- Simulation of Seismic Response

State of the Art Reports

Reliability Framework for Performance Prediction and Evaluation

Seismic Design Criteria
- Building Codes
- Social, Economic and Policy Issues

Trial Designs
- Cost Analysis
- Loss Analysis

Northridge20 Symposium
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.
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
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
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-351**: Recommended Seismic Evaluation and Upgrade Criteria for Existing Welded Steel Moment-Frame Buildings.


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