Seismic evaluation of existing DOE facilities: a case study at Los Alamos National Laboratory

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Procedures for seismic evaluation

- FEMA 273/274
  - Early 1990s to 1997
  - Commercial buildings
    - 1945 to 1995
  - Provisions (273)
  - Commentary (274)
  - FEMA 356, ASCE 41-06, -13
  - Performance levels
    - CP, LS, IO, F
  - Basic performance objectives
  - Deterministic basis
Procedures for seismic evaluation

- FEMA 273/274
  - Analysis methods
    - Linear static
    - Nonlinear static
      - First mode horizontal
  - Modeling
    - Linear
    - Nonlinear
  - Acceptance criteria
    - Linear analysis
      - $m$, $F_\mu$
    - Nonlinear analysis

FEMA, 1997
Procedures for seismic evaluation

- FEMA P-58
  - Late 2012
  - Roots
  - Commercial buildings
- Losses
- Probabilistic basis
  - Distributions of loss
  - Intensity
  - Scenario
  - Time-based
- Analysis methods
  - Simplified linear
  - Nonlinear dynamic
    - Ground motion selection and scaling
  - Soil-structure-interaction
- Modeling
  - Nonlinear components
  - Best estimates
- Fragility functions
  - Families of fragility functions
  - Damage states
- Consequence functions
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Dimensions between A-H
Dimensions between O-H

Service Chase Floor
6" slab toc El 7312.71'

12" Service Chase wall beam

10" roof slab
roof beam
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Fluor, 1973
Existing DOE buildings

• Nonlinear analysis of soil-structure systems
  – Distributions of demand at \( n \) intensities
  – Ground motion selection and scaling
    • NIST GCR 11-917-15
  – Soil-structure interaction analysis important
    • Validated nonlinear soil models
    • Treatment of gapping and sliding
    • Size of soil domain, layering
    • Seismic inputs, consistent with PSHA
  – Non-ductile reinforced concrete framing
    • Rules for component modeling
      – Cyclic backbone curves
      – Reliable hysteretic models
  – Treatment of uncertainty and variability
Existing DOE buildings

- Risk calculations
  - Risk targets or performance goals
    - Smaller than the design basis hazard MAFE
    - Shaking more intense than design basis, requiring nonlinear analysis
    - Risk accrues at what (improper) fractions of DBE shaking?
      - Known after the analysis is performed
  - Fragility functions for damageable components
    - Safety-critical MEP components, including HVAC
    - Safety-critical structural components
      - Perimeter and interior shear walls
      - Roof framing
      - Columns supporting roof and laboratory floor
    - Correlated fragilities and redundancy
      - Understanding what is correlated
      - Salmon et al., Mertz
  - Systems analysis
Component modeling: shear walls

• No consensus models of low aspect ratio walls
• Developing an understanding of behavior
  – ATC-114 project
    • Data collection for walls
    • Datasets of Gulec (to 2009) and Luna (2010-2015)
    • Cyclic tests of 240 low-aspect-ratio walls
      – No monotonic data
    • Digitized *reported* cyclic test results
      – Tabulated *reported* wall and material properties
• Design variables
  – Aspect ratio, concrete strength, web reinforcement ratio, boundary elements, axial load, OOP shear, OOP moment
Component modeling: shear walls

- Cyclic backbone
  - Points to define curve
  - Cracking (A), *yielding* (B, C), post-peak (D)
Component modeling: shear walls

- Planar walls
- Drift at cracking
  - Three variables
Component modeling: shear walls

- Planar walls
- Resistance at cracking
  - Three variables
Component modeling: shear walls

- Planar walls
- Resistance at cracking
  - Three variables
Component modeling: shear walls

- Planar walls
- Peak strength
  - Empirical equations
Component modeling: shear walls

• Cyclic (hysteretic) models
  – Based on Ibarra-Krawinkler Pinching (IKP) model
    • Trilinear pre-peak, bilinear unloading responses
    • Implemented in Matlab
    • Calibrated model
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• Planar wall

Fluor, 1973
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- Risk assessment of an mission-critical building
  - Mission-critical SSCs
- Integrated LANL-led process underway
  - Systems models and paths to failure
  - Seismic hazard calculations
  - Nonlinear analysis of soil-structure models
    - $n$ intensities of ground motion
    - Nonlinear models for soil and components
    - Formal treatment of variability and uncertainty
    - Distributions of demand at each intensity
  - Fragility calculations for damageable components
    - Supported by new test data as needed
    - Conditional probabilities of failure at each intensity
  - Calculation of MAF of unacceptable performance
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