Guidelines for Nonlinear Structural Analysis and Design of Buildings

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Presentation Outline

- Scope and background
- Organization of the Guidelines
- Part I: General Modeling Requirements (including approach to modeling cyclic damage)
- Part IIa: Steel Frame Building Modeling
- Part IIb: RC Frame Building Modeling
- Illustrative Example
• Support primarily nonlinear dynamic analyses (monotonic backbone curve and then cyclic deterioration).

• Primarily focused on new buildings with seismic detailing, but also applicable to Pre-Northridge Steel SMF and other situations

• Modeling vs. acceptance criteria:
  • ATC-114 focuses on modeling guidelines.
  • Rely on parent document (e.g., ASCE 7 Chp. 16) for the needed acceptance criteria checks and associated hazard levels.

• Adopt a reliability framework. Write the approach around the ASCE 7-16 draft Chapter 16, provide guidance on variability numbers.

• Audience: Practicing engineers with ~Master’s education
NIST Seismic Design Tech Brief 4: Nonlinear Structural Analysis for Seismic Design

- General guidance on using nonlinear analysis for design
- Focus on high-level goals and objectives
- Overview of key concepts and assumptions
- Summary of modeling capabilities and resources
- Guidance on NL static & dynamic analysis


- General Nonlinear Modeling
- Steel and RC Moment Frame Components
- Shear Walls and Slab-Column Frames
- Podium Diaphragms and Collectors
PEER Tall Building Initiative:
- 2010 (2017) guidelines
- Supporting documents - http://peer.berkeley.edu/tbi/

LA Tall Buildings Structural Design Council:
- 2011 guidelines
- Annual conference
- Special provisions for RC structures

Guideline Documents
- Performance Objectives
- Design Process and Documentation
- Seismic Input and Modeling Criteria
- Service Level Evaluation
- MCE Level Evaluation
- Documentation and Peer Review
ASCE 41-13 (17) Seismic Evaluation & Retrofit of Existing Buildings
• General performance assessment framework (IO, LS, CP)
• Requirements for assessing properties of existing buildings
• Structural component modeling parameters and acceptance criteria
• Nonlinear static (pushover) analysis procedure

ASCE 7-16 Minimum Design Loads for Buildings
• Chapter 16 – Seismic Response History Procedures
• Emphasis on nonlinear dynamic analysis
• Analyses and checks for MCE levels
• Selection and scaling ground motions (UHS or CMS)
• Risk/probabilistic basis for demand and acceptance criteria:
  - Deformation-controlled components
  - Force-controlled components
ATC 114: How it is Expected to be Used

ATC-114 provides guidelines for nonlinear modeling to support design in accordance with other standards.
ATC 114: Organization of Guidelines

Part I: General Guidelines

Part IIa: Guidelines Specific to Steel Moment Frames

Part IIb: Guidelines Specific to RC Moment Frames

Part IIc: Guidelines Specific to RC Shear Walls

Part IIId: Guidelines Specific to Steel Braced Frames

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ATC 114: Organization of Guidelines

Part I: General
1. Introduction and Scope
2. Overview of NL Modeling and Analysis Procedure
3. General Modeling Requirements
4. Nonlinear Static (Pushover)
5. Nonlinear Response-History
6. Performance Assessment and Acceptance Criteria

Appendices
A: Overview of Methods for RHA
B: Consideration of Uncertainties
C: Calibration of Nonlinear Component Models

Part II: System Specific
1. Introduction and Scope
2. Structural Behavior and Failure Modes
3. NL Modeling of Frames & Components
4. Concentrated Hinge Models
5. Fiber-Type Beam-Column Models
6. Continuum FE Component Models

Appendices
A: Non-ductile frames
B: Illustrative Examples
Types of Nonlinear Analysis Models

Figure 2-7 Range of structural model types (NIST, 2010).
Types of Nonlinear Analysis Models

Concentrated Hinge

Fiber-Type Elements
Basic Requirements

- Expected Properties
  - materials
  - model parameters
  - mass
  - gravity loads (1.0D + 0.5L)

- Geometric Nonlinear (P-Δ) Effects

- Structural Behavior and Failure Modes
  - “simulated” vs “non-simulated” effects
  - influence of non-structural components

<table>
<thead>
<tr>
<th>Table 3-1 Expected Steel Material Strengths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
</tr>
<tr>
<td>Structural Steel – Hot Rolled Structural Shapes and Bars</td>
</tr>
<tr>
<td>ASTM A36/A36M</td>
</tr>
<tr>
<td>ASTM A1043/1043M Gr. 30 (250)</td>
</tr>
<tr>
<td>ASTM A992/A992M</td>
</tr>
<tr>
<td>ASTM A572/A572M Gr. 50 (345) or 55 (380)</td>
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<tr>
<td>ASTM A913/A913M Gr. 60 (345), 80 (415), 85 (450), or 70 (485)</td>
</tr>
<tr>
<td>Structural Steel – Hollow Structural Sections (HSS)</td>
</tr>
<tr>
<td>ASTM A500/A500M Gr. B</td>
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<tr>
<td>ASTM A500/A500M Gr. C</td>
</tr>
<tr>
<td>ASTM A53/A53M</td>
</tr>
<tr>
<td>ASTM A1085/A1085M</td>
</tr>
<tr>
<td>Structural Steel – Plates, Strips, and Sheets</td>
</tr>
<tr>
<td>ASTM A36/A36M</td>
</tr>
<tr>
<td>ASTM A572/A572M Gr. 42 (290)</td>
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<tr>
<td>ASTM A572/A572M Gr. 50 (345), Gr. 55 (380)</td>
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<tr>
<td>ASTM A588/A588M</td>
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<tr>
<td>Reinforcing Steel</td>
</tr>
<tr>
<td>ASTM A615/A615M Gr. 60 (420)</td>
</tr>
<tr>
<td>ASTM A615/A615M Gr. 75 (520) and Gr. 80 (550)</td>
</tr>
<tr>
<td>ASTM A706/A706M Gr. 60 (420) and Gr. 80 (550)</td>
</tr>
</tbody>
</table>
Modeling Approach for Cyclic Loading

Typical Approach: ASCE 41 type curve that implicitly incorporates cyclic deterioration
Modeling Approach for Cyclic Loading

Nojavan et al., 2014
Modeling Approach for Cyclic Loading

Suzuki and Lignos, 2015
Modeling Approach for Cyclic Loading

\[ \Delta p^* \Delta p_{pc} \]

\[ Q \]

\[ Q_u \]

\[ Q_u^* \]

\[ Q_y \]

\[ Q_r^* K_e \]

\[ \text{response is typically between and depends on loading-history} \]

monotonic envelope

first-cycle envelope

ASCE 41

\[ \Delta or \Theta \]
ATC 114: Organization of Guidelines

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Appendices

A: Overview of Methods for RHA
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Part I: Acceptance Criteria

- So far, we have talked about doing a lot of detailed nonlinear modeling.
- **Structural responses** do not tell us about performance until to compare with the **acceptance criteria**.
- The acceptance criteria will depend on what document is being used to govern the design.
Part I: Acceptance Criteria

Will give examples from ASCE7-16 here.
Part I: Acceptance Criteria

- Big Focus of ASCE 7-16 Chapter 16 Revision: Develop acceptance criteria more clearly tied to the ASCE7 safety goals.

<table>
<thead>
<tr>
<th>Risk Category</th>
<th>Tolerable Probability of Collapse</th>
<th>Ground Motion Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>I or II</td>
<td>10%</td>
<td>MCE_R</td>
</tr>
<tr>
<td>III</td>
<td>6%</td>
<td>MCE_R</td>
</tr>
<tr>
<td>IV</td>
<td>3%</td>
<td>MCE_R</td>
</tr>
</tbody>
</table>

- Explicit Goal: Acceptable collapse probability.
- Implicit Verification Approach: Use average structural responses (with 11 motions) to show compliance.
ASCE 7-16: Uncertainties considered in specified acceptance criteria, including demand & capacity factors
Part I: Acceptance Criteria

- Force-controlled (brittle) components:

\[ \gamma I_e (Q_u - Q_{ns}) + Q_{ns} \leq Q_e \]

2.0 \( I_e F_u \leq F_e \) for “critical” (comparable to PEER-TBI-v1)
1.5 \( I_e F_u \leq F_e \) for “ordinary”
1.0 \( I_e F_u \leq F_e \) for “non-critical” (judgment)

\( F_u \) = mean demand (from 11 motions)
\( F_e \) = expected strength

Critical = failure causes immediate global collapse
Ordinary = failure causes local collapse (one bay)
Non-critical = failure does not cause collapse

Contrast: Much more stringent than the average-based approach that could be used in ASCE 41.
Part I: Acceptance Criteria

- Deformation-controlled (ductile) components:
  
  1) Limits applied to mean demands:
  
  ✓ ASCE 41 Limit: $CP / l_e$
  
  ✓ Loss in Vertical Load Carrying Capacity:
    
    $\phi_s \Delta_{LVCC}$ where $\phi_s$ is equal to
    
    0.3 / $l_e$ critical
    
    0.5 / $l_e$ ordinary
  
  2) Limits of analysis model for peak demands from individual ground motions
Part I: Acceptance Criteria

- Drift limits:
  - Mean drift ≤ 2.0*(normal limit)
  - The factor of two comes from:
    - 1.5 = MCE / DBE
    - 1.25 = Approx. ratio of R / Cd
    - 1.1 = A little extra because we trust NL RHA more
Part I: Acceptance Criteria

- Treatment of “collapses” and “unacceptable responses”:
  - **Past Treatment in ASCE7-10**: Nothing but silence….
  - **ASCE7-16 Criteria**:
    - Basic Case: Allow up to 1/11 “collapses” but not 2/11.
    - With Spectral Matching: Require 0/11 collapses.
    - For Risk Categories III-IV: Require 0/11 collapses.

- “Collapses” are more generally called “unacceptable responses” and include:
  - True dynamic instability,
  - Analytical solution fails to converge,
  - Deformation-controlled demands exceed valid modeling range,
  - Critical/ordinary force-controlled demands exceed capacity,
  - Predicted deformation demands on elements not modeled exceed the deformations at gravity load failure.
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