Nonlinear Response-History Analysis for the Design of New Buildings: A Proposed Updated to ASCE7 Chapter 16

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Reminder of the ASCE7 Process

Proposed Substantial Change to ASCE 7

Building Seismic Safety Council (2014 NEHRP Provisions)

ASCE7 Committee (for ASCE 7-16)

Final Substantial Change to ASCE 7
**Issue Team Charge and Deliverables**

- **Issue Team Objective:** Develop recommendations to the BSSC Committee regarding proposed improvements to Chapter 16 of ASCE7.

- **Issue Team Deliverables:**
  - Chapter 16 Code language (completely revised)
  - Chapter 16 Commentary language (completely revised)
  - Earthquake Spectra sister papers – (1) Development and (2) Example Applications

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**The Issue Team Membership**

- **Industry**
  - CB Crouse, URS Corp.
  - Chung-Soo Doo, SOM
  - Andy Fry, MKA
  - Mahmoud Hachem, Degenkolb
  - Ron Hamburger, SGH
  - John Hooper, MKA
  - Afshar Jalalian, R&C
  - Charles Kircher, Kircher & Assoc.
  - Silvia Mazzoni, Degenkolb
  - Bob Pekelich, Degenkolb
  - Mark Sinclair, Degenkolb
  - Rafael Sabelli, Walter P Moore
  - Reid Zimmerman, R&C

- **Academic**
  - Curt Haselton, CSUC, Team Chair
  - Jack Baker, Stanford University
  - Finley Charney, Virginia Tech
  - Greg Deierlein, Stanford Univ.
  - Ken Elwood, Univ. of British Col.
  - Steve Mahin, UC Berkeley
  - Graham Powell, UC Berkeley Em.
  - Jon Stewart, UCLA
  - Andrew Whittaker, SUNY Buffalo
  - Robert Hanson, FEMA

- **Government**
  - Jay Harris, NIST
  - Nico Luco, USGS
  - Mike Tong, FEMA
Project Timeline and Current Status

- **2009/2010:** Issue Team topic selection.
- **October 2010:** Started the Issue Team
- **Past 2.5 years:** Worked, presented to BSSC Provisions Update Committee quarterly.
- **Current Status:** Proposal is complete and is in the BSSC committee voting process.
- **Late 2013:** Expect BSSC process to be complete.
- **2014:** Proposal goes to ASCE7.
- **ASCE7-16:** Expected new ASCE7 Chapter 16.

Literature Review

- We now have a lot to draw on (which was not the case only a few years ago)…

- *Guidelines for Performance-Based Seismic Design of Tall Buildings,* PEER Center, Tall Building Initiative (PEER, 2010).
Building Safety Goals

- Basic goals are from ASCE 7-10 Table C.1.3.1b:

<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>
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</tr>
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Chapter 16 Proposal: Overall Structure

- Section 16.1: General Requirements
- Section 16.2: Ground Motions
- Section 16.3: Modeling and Analysis
- Section 16.4: Analysis Results and Accept. Criteria
- Section 16.5: Design Review
Proposal: Section 16.1 (General)

- The basic structure of the design approach is:
  - Linear DBE-level analysis (to enforce minimum base shear, enforce basic load combinations, etc.).
  - Nonlinear MCE-level response-history analysis.

Proposal: Section 16.2 (Ground Motion)

- Ground motion level: MCE\textsubscript{R}
- Number of ground motions: 11 motions
- Selection of motions:
  - Same general language.
  - Added: "It is also desirable for ground motion spectral shapes to be comparable to the target response spectrum of Section 16.2.2."
- Scaling of motions: Scale the maximum direction Sa to the target spectrum (which is max. direction).
- Period range: 0.2T\textsubscript{1} to 2.0T\textsubscript{1}, but also 90% mass.
- Spectral matching: Each comp. must meet target.
Proposal: Section 16.2 (Ground Motion)

- Target spectrum:
  - Method 1: Typical $MCE_R$ spectrum.
  - Method 2: Multiple "scenario" spectra (typically two scenarios).
Proposal: Section 16.2 (Ground Motion)

Scenario: M=7, R=10 km
(characteristic event for many CA sites)

MCE_R target for $S_a(T_1 = 1.0s)$
(at the high-end for an MCE motion at CA sites)

Figure reference: J.W. Baker – 2006 COSMOS

Proposal: Section 16.2 (Ground Motion)

40 real records with M ≈ 7 and R ≈ 10 km

Figure reference: J.W. Baker – 2006 COSMOS
Proposal: Section 16.2 (Ground Motion)

40 real records with $M \approx 7$ and $R \approx 10$ km

Observations:
- Unique “peaked” spectral shape (Sa is not large at all periods).
- These records will tend to be less damaging as the structural period elongates past 1.0s.

Figure reference: J.W. Baker – 2006 COSMOS
Proposal: Sec. 16.3 (Modeling & Analysis)

- This section says what to do but not how to do it.
- This was intentionally not written to be a nonlinear analysis guideline.

Proposal: Section 16.4 (Accept. Criteria)

- Treatment of “collapses” and other “unacceptable responses”:
  - **Current Treatment in ASCE7-10**: Nothing but silence….
  - **Philosophical Camp #1**:
    - Outliers are statistically meaningless.
    - Acceptance criteria should be based only on mean/median.
    - If we have 5/11 (or 3/7) “collapses”, this means nothing.
  - **Philosophical Camp #2**:
    - Outliers are statistically meaningless, but are still a concern.
    - Acceptance criteria should also consider “collapses”.
    - If we have 5/11 (or 3/7) “collapses”, this is a great concern.
Proposal: Section 16.4 (Accept. Criteria)

- Results of a statistical collapse study:

| Number of Collapses | Likelihood for Various $P[C|\text{MCE}_R]$ Values |
|---------------------|---------------------------------|
| 0 of 11             | 93% 74% 51% 30% 7%               |
| 1 of 11             | 7% 23% 36% 38% 21%               |
| 2 of 11             | 0% 3% 11% 22% 29%               |
| 3 of 11             | 0% 0% 2% 8% 24%               |
| 4 of 11             | 0% 0% 0% 2% 13%               |
| 5 of 11             | 0% 0% 0% 0% 5%               |

- Conclusions of collapse study:
  - Even with 0/11 collapses, this in no way proves that the $P[C|\text{MCE}_R] \leq 10\%$. There is way too much uncertainty. We must rely on the other mean-based acceptance criteria.
  - Even if $P[C|\text{MCE}_R] = 10\%$, there is still a 26% chance of getting 1+ collapses (i.e. “false positive”). Therefore, an acceptance criterion of “no collapses allowed” would not be appropriate.
  - If $P[C|\text{MCE}_R] = 10\%$, it is highly unlikely (only a 3% chance) that we will see 2+ collapses. Therefore, an acceptance criterion that prohibits two collapses would be reasonable.
  - **Proposed Criterion:** Allow up to 1/11 “collapses” but not 2/11.
Proposal: Section 16.4 (Accept. Criteria)

- Component-level acceptance criteria are separated by:
  - Force-controlled (brittle) components
  - Deformation-controlled (ductile) components

Proposal: Section 16.4 (Accept. Criteria)

- Force-controlled (like Wallace, but no overstrength)

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Proposal: Section 16.4 (Accept. Criteria)

- Force-controlled (brittle) components:

  - Case 1 (critical): “If the failure of the component would likely to lead to a progressive global collapse of the building, ….”
  - Case 2: “If the failure of the component would lead to only a local collapse, ….”
  - Case 3 (non-critical): “If the failure of the component would not lead to any structural instability, ….”

  **Requirements (with exception for capacity-controlled):**
  
  2.0 \( \frac{I_e F L \text{Mean Demand}}{F L \text{Mean Strength}} \leq 1 \) \[ \varphi = 1.0 \]
  
  1.5 \( \frac{I_e F L \text{Mean Demand}}{F L \text{Mean Strength}} \)
  
  1.0 \( \frac{I_e F L \text{Mean Demand}}{F L \text{Mean Strength}} \)
Proposal: Section 16.4 (Accept. Criteria)

- Deformation-controlled (ductile) components:
  - Similar “cases” as force-controlled components.
  - Acceptance criteria are based on mean component deformation capacity.
  - “Pre-approved” uses of ASCE41 are also provided.

Proposal: Section 16.4 (Accept. Criteria)

- Drift limits:
  - Mean drift $\leq$ twice the 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
Proposal: Section 16.5 (Design Review)

- Typical requirements and language…
- Design review is critical!
Next Steps for this Project

- BSSC: Finish the committee/vetting process with the Building Seismic Safety Council (for the NEHRP Provisions). The next meeting is on June 4-5th.
- ASCE7: Further refine proposal through the ASCE7 process, with the goal to have a fully revised Chapter 16 in ASCE7-16.

Questions/Comments?

- Thanks you for your time!
- Questions, comments, suggestions?
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