ACI COMMITTEE 369
SEISMIC REPAIR AND REHABILITATION
ACI Fall Convention
Monday, October 25, 2010
W-Allegheny 1
3:00 p.m. to 6:00 p.m.
Pittsburgh, PA

Minutes (Draft)

**Members Present:** Ken Elwood (Chairman), Sergio Breña (Secretary), Jeff Dragovich, Adolfo Matamoros, Dominic Kelly, Thomas Kang, Ying Tian, Insung Kim, Mo Ehsani, Chris Pantelides, Jose A. Flores Ruiz, Jack Moehle, Roberto Stark, Murat Saatcioglu, Dan Palermo, Shyh-Jiann Hwang, Harry H.J. Lee, Sarah Orton, Mohammad Iqbal.

**Visitors Present:** Attila Beres, Khan Shahzada, Muhammad Fahad, James Lai, Nate Sauer, Ian Scott, Chien-Chung Chen, Ed Dean.

1. Welcome and Introductions
   The meeting was called to order at 3:04 PM.

2. Approval of meeting agenda
   Motion: To approve meeting agenda as presented with new business modifications as presented in Attachment A.
   Moved: Moehle; Second: Kelly
   Result: Passed.

3. Approval of minutes from 2010 Spring meeting
   Motion: To approve minutes as presented and distributed through the ACI committee webpage.
   Move: Ehsani; Second: Kang
   Result: Passed.

   Sponsored in collaboration with ACI 341 (K. Elwood)
   K. Elwood gave a summary report of this workshop.
   Day 1: will focus on work being done by committees from ACI and JCI on seismic rehabilitation.
   Presentations by task group representatives from ACI 369 will take place this day.
   Day 2: will consist of presentations given by invited speakers on seismic rehabilitation of bridges and buildings.
   Day 3: Trip to E-Defense to witness two 4-story RC buildings.
   The goal plan is to publish a new IPS document based on papers presented at the workshop.

   ACI 369 is co-sponsoring this special session. It has been moved to Dallas during the Spring 2012 convention.

6. Parallel efforts related to Seismic Rehabilitation
   - NIST Task Order 5 (ATC 76-5) (K. Elwood)
   K. Elwood gave a summary of the program plan contents.
   ATC 76-5 is a project intended to develop a program plan for the production of guidance documents for collapse assessment of non-ductile RC buildings. It will result in a 5-year
A research program. A report with findings from ATC 76-5 is reaching the final stages for publication. ACI 369 is identified in the ATC 76-5 report as a key participant in the process to accomplish the goals of the program plan. The result of the 5-year research effort could potentially contribute and be used for updates to ACI 369R.

ATC 78 has been started to provide information on performance indicators (a high priority of the program plan).

- **ASCE/SEI 31 and 41 (K. Elwood)**
  The *ASCE Seismic Rehabilitation Standards Committee* (SRSC) was reformed in December 2009. A new release of ASCE 41 will be published in 2013 (Poland, Chair; Pekelnicky, Secretary). The committee created a concrete issue team (Chair: K. Elwood), to provide changes to Chapter 6 of ASCE 41. Balloting for ASCE 41-13 will start in Spring 2011. K. Elwood proposed the formation of a liaison subcommittee to facilitate coordination between activities of ASCE 41 and ACI 369 committees.

  **ASCE SRSC members = ACI 369-L (ACI 369 – ASCE 41 Liaison Committee)**
  Liaison subcommittee members must be members of both ASCE SRSC and ACI 369L. The liaison subcommittee will include task group chairs from ACI 369. Breña will attend the ASCE-ACI coordination committee on Wednesday, 27 October 2010, to confirm if this approach is the best for coordination between ACI and ASCE committees.

  The first task will be the translation of ACI 369R-11 back to mandatory language for incorporation into ASCE 41-13. Future activities will be to keep track of changes (updates) to ACI 369R for incorporate into ASCE 41.

  **Note after ASCE/ACI coordination committee meeting**: formation of ACI 369L was viewed as a good approach for coordination. Activities related to incorporation of information from ACI 369 to ASCE 41 were viewed within the purview of the *ASCE Seismic Rehabilitation Standards Committee* highlighting the importance that members of ACI 369L be also members of ASCE SRSC. These members will likely be intimately involved in the coordination of these two documents.

- **NEES-GC (J. Moehle / A. Matamoros)**
  J. Moehle and A. Matamoros gave an update on this NSF-sponsored project. Corner beam-column joints (UC Berkeley) and columns (NEES-MAST) with various details have been tested to date.

  **7. Guide and Commentary for Seismic Rehabilitation of Existing Concrete Frame Buildings (K. Elwood)**
  Final ballot passed; all negatives resolved and all comments considered. The final balloted document was sent to TAC for review including ACI 369 responses to TAC comments. The ACI 369R guide was sent to ACI staff and is currently in queue for publication. The guide will likely be published as a 2011 document (ACI 369R-11).

  **8. Task Groups Reports**
  New task group was formed (Task group F) – Slab-column connections (Chair: Thomas Kang). K. Elwood has asked all task group chairs to prepare change proposals to make modifications to the ACI 369R guide. Each task group will create change proposals, come to an agreement on them, and bring to the full committee for balloting.

  K. Elwood asked whether task groups should be redefined as subcommittees now that ACI 369R will be published. **Action**: Separate meeting rooms will be booked prior to the ACI 369 main meeting if needed during the next convention (Tampa Bay, Spring 2011). K. Elwood will contact sub-committee chairs to determine if booking rooms are needed prior to the main committee meeting. It was suggested that Sunday afternoon be the time when task groups (subcommittees) meet.
Several task group chairs were unable to attend the meeting. K. Elwood gave a summary of activities from task groups A, C and D.

- TG A - Materials (H. Sezen)
- TG B - General Provisions (J. Dragovich)
- TG C - Beams and Columns (W. Ghannoum)
- TG D - Beam-Column Joints (L. Lowes)
- TG E - Rehabilitation Techniques (S. Breña)
- TG F - Slab-Column Connections (T. Kang) – new task group

9. New Business
   Brief presentation on earthquake damage of rehabilitated buildings in Chile (S. Breña)
   Brief presentation on column retrofit system (M. Ehsani)

10. Next meeting – Tampa Bay, FL
    Date: Monday, April 4, 2011
    Time: 2:00-6:00pm.

11. Adjournment
    Meeting was adjourned at 6:15pm
Attachment A
ACI COMMITTEE 369
SEISMIC REPAIR AND REHABILITATION
ACI Fall Convention
Monday, October 25, 2010
Pittsburgh, Pennsylvania

Room W-Allegheny 1
2:00 p.m. to 6:00 p.m.

Agenda

1. Welcome and Introductions
2. Approval of meeting agenda
3. Approval of minutes from 2010 Spring meeting
5. Special Session and Publication: James Jirsa's Legacy in Structural Concrete: A Time to Reflect, Fall 2011, Cincinnati (S. Alcocer)
6. Parallel efforts related to Seismic Rehabilitation
   • NIST Task Order 5 (ATC 76-5) (K. Elwood)
   • ASCE/SEI 31 and 41 (K. Elwood)
   • NEES-GC (J. Moehle / A. Matamoros)
7. Guide and Commentary for Seismic Rehabilitation of Existing Concrete Frame Buildings - Submitted to Staff for publication!!
8. Task Groups Reports
   • Materials (H. Sezen)
   • General Provisions (J. Dragovich)
   • Beams and Columns (W. Ghannoun)
   • Beam-Column Joints (L. Lowes)
   • Rehabilitation Techniques (S. Breña)
   • Slab-column connections (T. Kang)
9. New Business
   - If time permits - a brief presentation on earthquake damage in Chile by S. Brena.
10. Next meeting
11. Adjournment
Attachment B: Meeting and Task Group Presentations
Agenda

1. Welcome and Introductions

2. Approval of meeting agenda

3. Approval of minutes from 2010 Spring meeting


5. Special Session and Publication: James Jirsa's Legacy in Structural Concrete: A Time to Reflect, Fall 2011, Cincinnati

6. Parallel efforts related to Seismic Rehabilitation
   a) NIST Task Order 5 (ATC 76-5) (K. Elwood)
   b) ASCE/SEI 31 and 41 (K. Elwood)
   c) NEES-GC (J. Moehle / A. Matamoros)

7. Guide and Commentary for Seismic Rehabilitation of Existing Concrete Frame Buildings

8. Task Groups Reports
   a) Materials (H. Sezen)
   b) General Provisions (J. Dragovich)
   c) Beams and Columns (W. Ghannoum)
   d) Beam-Column Joints (L. Lowes)
   e) Rehabilitation Techniques (S. Breña)
   f) Slab-column connections (T. Kang)

9. New Business
   - If time permits - a brief presentation on earthquake damage in Chile by S. Brena.
     - a brief presentation by Mo Ehsani

10. Next meeting – Tampa Bay
ACI 369R - 11

• Final ballot passed
• All negatives resolved
• Comments not requiring reballot considered
• Sent to TAC for review of our response to TAC comments.
• Now in queue for publication.
JCI-ACI Workshop

• December 13-15, 2010
• Soukairou Hall, Roppongi, Tokyo, Japan
• Day 1
  – JCI Committee presentations on new document on Performance-oriented seismic rehabilitation of concrete bridges and buildings
  – ACI Committee presentations on ACI 369R and ACI 341 Retrofit Guide
• Day 2
  – Invited speakers on seismic rehabilitation of bridges and buildings.
• Day 3
  – Trip to E-Defence to witness test on two 4-story RC buildings
JCI-ACI Workshop

• ACI 369R Presentations
  – Task Group A – Materials (Halil Sezen)
  – Task Group B – General Provisions (Jeff Dragovich)
  – Task Group C – Columns (Wassim Ghannoum)
  – Task Group E – Rehabilitation Techniques (Insung Kim)

• International Invited speakers
  – Jim Jirsa; Jack Moehle; Sergio Alcocer; Shyh-Jiann Hwang; David Sanders; Denis Mitchell; Bill Holmes

• IPS Document expected based on papers presented.
NIST Task Order 5
ATC 76-5

Program Plan for the Development of Collapse Assessment and Mitigation Strategies for Existing Reinforced Concrete Buildings

NEHRP Consultants Joint Venture
A partnership of the Applied Technology Council and the Consortium of Universities for Research in Earthquake Engineering

NIST
National Institute of Standards and Technology
U.S. Department of Commerce
Industry needs

- Improved procedures to identify collapse vulnerable building systems, including simple tools not requiring a detailed analysis.

- Updated acceptance criteria for concrete components based on latest research results.

- Identification of cost-effective mitigation strategies to reduce collapse risk in existing concrete buildings.
### Component Deficiencies

<table>
<thead>
<tr>
<th>Deficiency</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: Shear-critical columns</td>
<td>Shear and axial failure of columns in a moment frame or gravity frame system.</td>
</tr>
<tr>
<td>B: Unconfined beam-column Joints</td>
<td>Shear and axial failure of unconfined beam-column joints, particularly corner joints.</td>
</tr>
<tr>
<td>C: Slab-column connections</td>
<td>Punching of slab-column connections under imposed lateral drifts.</td>
</tr>
<tr>
<td>D: Splice and connectivity weakness</td>
<td>Inadequate splices in plastic hinge regions and weak connectivity between members.</td>
</tr>
</tbody>
</table>

### System Deficiencies

<table>
<thead>
<tr>
<th>Deficiency</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>E: Weak-story mechanism</td>
<td>Weak-column, strong-beam moment frame or similar system prone to story collapse from failure of weak columns subjected to large lateral deformation demands.</td>
</tr>
<tr>
<td>F: Overall weak frames</td>
<td>Overall deficient system strength and stiffness, leading to inadequacy of an otherwise reasonably configured building.</td>
</tr>
<tr>
<td>G: Overturning mechanisms</td>
<td>Columns prone to crushing from overturning of discontinuous concrete or masonry infill wall.</td>
</tr>
<tr>
<td>H: Severe plan irregularity</td>
<td>Conditions (including some corner buildings) leading to large torsional-induced demands</td>
</tr>
<tr>
<td>I: Severe vertical irregularity</td>
<td>Setbacks causing concentration of damage and collapse where stiffness and strength changes. Can also be caused by change in material or seismic-force-resisting-system.</td>
</tr>
<tr>
<td>J: Pounding</td>
<td>Collapse caused by pounding of adjacent buildings with different story heights and non-coincident floors.</td>
</tr>
</tbody>
</table>
Recommended Documents

1. Assessment of Collapse Potential and Mitigation Strategies
2. Acceptance Criteria and Modelling Parameters for Concrete Components – Columns
3. Acceptance Criteria and Modelling Parameters for Concrete Components – Beam-Column Joints
4. Acceptance Criteria and Modelling Parameters for Concrete Components – Slab-Column systems
5. Acceptance Criteria and Modelling Parameters for Concrete Components – Walls
6. Acceptance Criteria and Modelling Parameters for Concrete Components – Infill Frames
7. Acceptance Criteria and Modelling Parameters for Concrete Components – Beams
8. Acceptance Criteria and Modelling Parameters for Concrete Components – Rehabilitation Components
Assessment of Collapse Potential and Mitigation Strategies

Goals

• Improved procedures to identify collapse vulnerable building systems and how to retrofit such systems.
  – Including simple assessment tools not requiring detailed analysis
  – Focus on system performance

• Identify parameters (*collapse indicators*) that are correlated with “elevated” collapse potential (probability)

→ High Priority!
<table>
<thead>
<tr>
<th>Type of Collapse Indicator</th>
<th>Global</th>
<th>Local</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA-G1:</td>
<td>Maximum ratio of column-to-floor area ratios for two adjacent stories (Deficiency A-B,F)</td>
<td>Average minimum column transverse reinforcement ratio for each story (Deficiency B)</td>
</tr>
<tr>
<td></td>
<td>Maximum ratio of horizontal dimension of the SFRS in adjacent stories (Deficiency A-B, I)</td>
<td>Minimum column aspect ratio (Deficiency C)</td>
</tr>
<tr>
<td></td>
<td>Maximum ratio of in-plane offset of SFRS from one story to the next to the in-plane dimension of the SFRS (Deficiency I)</td>
<td>Misalignment of stories in adjacent buildings (Deficiency J)</td>
</tr>
<tr>
<td></td>
<td>Plan configuration (L or T shape versus rectangular) (Deficiency H)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Minimum ratio of column area to wall area at each story**</td>
<td></td>
</tr>
<tr>
<td>EC-G1:</td>
<td>Maximum ratio of story stiffness for two adjacent stories (Deficiency A-B)</td>
<td>Maximum ratio of plastic shear capacity (2M_p/L) to column shear strength, V_p/V_n (Deficiency B and C)</td>
</tr>
<tr>
<td></td>
<td>Maximum ratio of story shear strength for two adjacent stories (Deficiency A-B)</td>
<td>Maximum axial load ratio for columns with V_p/V_n &gt; 0.7 (Deficiency B and C)</td>
</tr>
<tr>
<td></td>
<td>Maximum ratio of eccentricity (distance from center of mass to center of rigidity or center of strength) to the dimension of the building perpendicular to the direction of motion (Deficiency H)</td>
<td>Maximum ratio of axial load to strength of transverse reinforcement (45 deg truss model) (Deficiency B-C)</td>
</tr>
<tr>
<td></td>
<td>Portion of story gravity loads supported by columns with ratio of plastic shear demand to shear capacity &gt; 0.7 (Deficiency B and C)</td>
<td>Maximum ratio of joint shear demand (from column bar force at yield) to joint shear capacity for exterior joints (Deficiency D)</td>
</tr>
<tr>
<td></td>
<td>Maximum gravity shear ratio on slab-column connections (Deficiency G)</td>
<td>Maximum gravity shear ratio on slab-column connections (Deficiency G)</td>
</tr>
<tr>
<td>BA-G1:</td>
<td>Maximum degradation in base or story shear resistance (Deficiency A-F,H-I)</td>
<td>Maximum drift ratio (Deficiency A-B, D-E, G-I)</td>
</tr>
<tr>
<td></td>
<td>Maximum fraction of columns at a story experiencing shear failures (Deficiency B-C, H-I)</td>
<td>Maximum ratio of deformation demands to ASCE/SEI 41 limits for columns, joints, slab-column connections and walls (Deficiency A-I)</td>
</tr>
<tr>
<td></td>
<td>Maximum fraction of columns at a storey experiencing axial failures (Deficiency B-C, H-I)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Minimum strength ratio (as defined in ASCE/SEI 41) (Deficiency A)</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>Weak soils likely to result in overturning or large deformation demands in the building.</td>
<td></td>
</tr>
</tbody>
</table>
### Table 6.1: Type of Collapse Indicator

<table>
<thead>
<tr>
<th>Global</th>
<th>Local</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RA-G1.</strong></td>
<td>Maximum ratio of column-to-floor area ratios for two adjacent stories (Deficiency A-B, E)</td>
</tr>
<tr>
<td>RA-G3.</td>
<td>Maximum ratio of in-plane offset of SFRS from one story to the next to the in-plane dimension of the SFRS (Deficiency I).</td>
</tr>
<tr>
<td>RA-G4.</td>
<td>Plan configuration (L or T shape versus rectangular) (Deficiency H).</td>
</tr>
<tr>
<td>RA-G5.</td>
<td>Minimum ratio of column area to wall area at each story**</td>
</tr>
</tbody>
</table>

| EC-G1. | Maximum ratio of story stiffness for two adjacent stories (Deficiency A-B) |
| EC-G2. | Maximum ratio of story shear strength for two adjacent stories (Deficiency A-B) |
| EC-G3. | Maximum ratio of eccentricity (distance from center of mass to center of rigidity or center of strength) to the dimension of the building perpendicular to the direction of motion (Deficiency H). |
| EC-G4. | Portion of story gravity loads supported by columns with ratio of plastic shear demand to shear capacity > 0.7 (Deficiency B and C) |

| BA-G1. | Maximum degradation in base or story shear resistance (Deficiency A-B, H-I). |
| BA-G4. | Minimum strength ratio (as defined in ASCE/SEI 41) (Deficiency A). |

**Other**

- Weak soils likely to result in overturning or large deformation demands in the building.
Evaluate Collapse Indicators

**Methodology**
- Determine collapse fragility for a prototype building
- Develop collapse fragilities for range of selected collapse indicator
- Seek trends in $P_{col}$ for changes in collapse indicator
- Repeat for “several” building prototypes

\[
IM_{mce} \quad IM \quad IM_{limit} \quad IM
\]

\[
P_{col} = 0.0005 \quad P_{col} = 0.0025
\]
Selection of Acceptance Criteria and Modeling Parameters

- Methodology proposed by ACI 369:
ATC 76-5

• Next step?
  – NIST and others considering funding options
  – ACI 369 identified as a key participant in the process
  – Would be a 5+ year effort with several deliverables that would contribute to updates in ACI 369R.
ASCE/SEI 31/41

• ASCE Standards Committee for Seismic Rehabilitation
  – Reformed December 2009
  – Issue teams formed for each chapter
    • Chair of ACI 369 → Issue team leader for Concrete
  – Quarterly meetings
    • Next meeting this Friday
  – Schedule:
    • ASCE 41-13 → balloting begins Spring 2011
    • ASCE 41-20 (in cycle with ASCE 7)
ACI 369 → ASCE 41

- ASCE 41 Concrete Issue Team
  = ACI 369-L (ACI 369 – ASCE 41 Liaison Committee)
  - All members of ACI 369 & ASCE 41
  - Includes TG Chairs from ACI 369
  - Will get confirmation from ASCE-ACI Coordination Committee

- First task
  - Translate ACI 369R-11 back into mandatory language (under ASCE 41 umbrella)

- Future tasks
  - Keep track of changes in ACI 369R to move over to ASCE 41
NEES-GC

1. Exposure
   - Seismic Hazard Analysis
   - Ground Motions
   - Inventory
   - Prototype Buildings

2. Component and System Performance
   - Columns and Beam-Column Joints
   - Soil-Structure-Foundation Interaction
   - Floor System Membrane Action
   - Shaking Table Tests
   - Component Models and Simulation Tools

3. Building and Regional Simulation
   - Progressive Collapse Analysis of Older Concrete Building Prototypes
   - Regional Loss Studies

4. Mitigation Strategy
Task Groups

• New Task Group F – Slab-Column Connections
  – T. Kang, Task group chair
• Task Groups to prepare Change Proposals for full committee.
  – Follow ACI 318 format
• Change to Subcommittees?
  – Meet for 2 hours before full committee meeting?
Task Group A - Materials

- Minimum number of tests – focus on cores

![Graph showing the number of tests vs. COV](image)
Task Group A - Materials

• Minimum number of tests – outliers (ASTM 178-8)
Task Group C - Columns

• Re-evaluate beam and column provisions based on new methodology for selection of modeling parameters and acceptance criteria.

• Provisions for circular columns.
Circular Columns

Fragility plot - PRR \( \left( \frac{\theta_a}{\theta_{a,\text{table}}} \right)^{0.7} V_{\text{max}} \) - condition i

Old values:
Mean-rect = 1.3939
SD-rect = 0.8576
Mean-circ = 2.1516
SD-circ = 1.0153

New values:
Mean-rect = 1.2052
SD-rect = 0.7499
Mean-circ = 1.1173
SD-circ = 0.6010
Task Group D - Joints

• 3.5 – Strength of straight deformed bars anchored in beam-column joints
  – The working group will need to investigate to determine if this can be improved.

• 4.2.2.1 – Stiffness for analysis using linear static and dynamic procedures
  – The working group will need to
    1) review the results of research by Birely et al. that recommends different offset lengths using data from planar interior subassemblages, and
    2) develop revised recommendations for other configurations using available experimental data.
Task Group D - Joints

• Table 4.1 - Modeling parameters and numerical acceptance criteria for nonlinear procedures – RC beams
  – Subassemblies can be used to assess beam criteria
  – May need to link beam (column?) criteria with joint evaluation.
Task Group D - Joints

• Table 4.3 - Modeling parameters and numerical acceptance criteria for nonlinear procedures – RC beam-column joints.

  – The working group will need to review recent research results to determine a preferred approach for:

    a) determining when frame strength is controlled by the joint,

    b) in the event that frame strength is determined by beams or columns, simulating the impact of joint flexibility on initial stiffness and the deformation capacity of beams and columns

    c) in the event that frame strength is determined by the joint, simulating the nonlinear response of the joint including initial stiffness, joint demand (load or deformation) at which lateral strength is lost, and joint demand (load and/or deformation) at which axial load carrying capacity is lost.
Task Group D - Joints

• 4.2.3.2 – Strength of beam-column joints
  – Gamma values in Table 4.4 likely to change based on proposals by task group members.
Task Group B (General Provisions)

• Future Changes / Direction

  1. Effective Stiffness (long term)
     • Review/update effective stiffness factors for all components.

  2. Strength Degradation for NDP (long term)
     • Recommendations for rate of degradation, and material models for concrete and steel for more detailed analysis applications.
3. Flexure and Axial Load (short term)

- Current interaction equation 1:

\[
\left( \frac{M_{UDx}}{m_x \kappa M_{CEx}} \right)^2 + \left( \frac{M_{UDy}}{m_y \kappa M_{CEy}} \right)^2 \leq 1
\]

- ASCE 41 steel provision use AISC design equations with an additional interaction for high axial load. Thus, it appears to be intended as an interaction equation for forces.

- Equation 1 works ok for only the simplest shapes.
- Closed-form interaction equations are available, but perhaps should be in the commentary.
3. Axial Load Used (cond.)

- One of many (Hsu, ACI Structural, 1988):

\[
\left( \frac{P_n - P_{nb}}{P_o - P_{nb}} \right) + \left( \frac{M_{nx}}{M_{nbx}} \right)^{1.5} + \left( \frac{M_{ny}}{M_{nby}} \right)^{1.5} = 1.0
\]
Results

- Actual capacity maybe 70% higher than value obtained using a circular interaction surface. “Overly” conservative.
- Slightly un-conservative
4. Development Length (Medium Term)

- Four development length categories:

1. \( f_s = 1.25 \left( \frac{L_b}{L_d} \right)^{2/3} \times F_y < F_y \)  \hspace{1cm} \text{(eq 2)}

2. \( f_s = 2500 \left( \frac{L_e}{d_b} \right) < F_y \)  \hspace{1cm} \text{(eq 3)}
4. Development Length (Medium Term)

- Four development length categories (cond.):

3. \( L_d = 2 \times (ACI \, 318 \, L_d) \) for plain reinforcement
   » Excessive lengths...

4. Square bars.
   » Verify equivalency between circular and square areas.
4. Connections to existing concrete (long term)
   - Revisit Appendix D in ACI 318, and develop acceptance criteria based on more “aggressive” statistics.

5. Rehabilitation (short term)
   - The section is out-of-place.
   - Merge with the introductory material in the chapter.
Summary

• Change proposals prior to Spring 2011
  – Flexure and Axial load (Interaction eqn)
  – Development length updates (as a whole?)
  – Rehabilitation section re-organization.

• If you would like to assist and/or review, please contact jeff.dragovich@nist.gov
Task Group E
Rehabilitation Techniques
Jacketed Columns

Example: Modeling Recommendations for Concrete Columns Retrofitted With Steel Jackets
Column Deficiencies

• Low shear strength

• Preemptive lap splice failure

• Poor concrete confinement
Types of Steel Jackets

- Circular
- Rectangular
- Elliptical
- Steel Straps
- Others:
  - Shape Memory Alloys (SMA)
  - Angles
  - Tubes

Fig. 3. Schematic illustrating the concept of using prestrained SMA hoops to apply external confining pressure on RC bridge columns.

Fig. 4. Details of retrofitted specimens: (a) RC-2R; (b) RC-3R; (c) RC-3R; and (d) RC-4R.
Typical Jacketing Configurations

- Fully
- Partial Bottom Only
- Partial
Modeling Variables

• Steel Jacket
  – Thickness
  – Gap between original column and steel jacket
  – Yield stress of the steel jacket

• Reinforced Concrete Column
  – Existing longitudinal reinforcement properties
  – Compressive strength concrete
  – Column geometry
Results

Circular Column (30in Diameter) 10’ high with Circular Jacket. Modeled with equivalent hoop size #3 and spacing 0.935in. (SC2)
Results

Rectangular Column (24x16) 8’ high with Elliptical Jacket.
Modeled with equivalent hoop size #3 and spacing 1.596in. (R4R)
Equivalent Confinement

Calculate the confinement given by the steel jacket.

Give a Hoop Size and Spacing to give an equal amount of confinement.

Similar method for Rectangular Jackets; effective confinement calculation based on Mander et al. model.
# Results for Circular Jackets

<table>
<thead>
<tr>
<th>Specimen</th>
<th>(\frac{(\Delta/H)<em>y}{(\Delta/H)</em>{ny}})</th>
<th>(\frac{(\Delta/H)<em>p}{(\Delta/H)</em>{np}})</th>
<th>(\frac{(\Delta/H)<em>m}{(\Delta/H)</em>{nm}})</th>
<th>(V_y/V_{ny})</th>
<th>(V_{res}/V_{nres})</th>
<th>(V_{exp}/V_n)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.74</td>
<td>0.73</td>
<td>0.61</td>
<td>0.81</td>
<td>-</td>
<td>1.02</td>
<td>Full Retrofit</td>
</tr>
<tr>
<td>5</td>
<td>0.31</td>
<td>0.13</td>
<td>0.57</td>
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# Results for Rectangular Jackets

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ASCE 41

• Provisions of Chapter 6
  – 6.4.2.2.2 Nonlinear Static Procedures
  – Depend on:
    • Shear Capacity for Flexural Response
    • Moment of Inertia
    • Axial Load Ratio
    • Shear Reinforcement Ratio
    • Yielding Stress of the Column
    • Ultimate Strength of the Column
EI for initial slope of backbone curve

Flexural Stiffness (EI) of Jacketed Columns:

How is I calculated for partial height jackets?
Results

Circular Column (30in Diameter) 10’ high with Circular Jacket. Modeled with equivalent hoop size #3 and spacing 0.935in. (SC2)

Circular Column (24in Diameter) 8’ high with Circular Jacket. Modeled with equivalent hoop size #3 and spacing 0.602in. (C4R)
Results

Rectangular Column (24x16) 8’ high with Elliptical Jacket. Modeled with equivalent hoop size #3 and spacing 1.596in. (R4R)

Rectangular Column (10”x10”) 40” high with Rectangular Jacket. Modeled with equivalent hoop size #3 and spacing 1.271in. (RC-3R)
Partial Jackets

Rectangular Column (36”x18”) 12’ high with a Partial Rectangular Jacket. Modeled with equivalent hoop size #3 and spacing 2.190in. (FC-9)

Circular Column (24in Diameter) 12’ high with Circular Jacket. Modeled with equivalent hoop size #3 and spacing 0.602in. (Chai 5)