Emerging ABC Connection Details for High Seismic Areas - Performance and Design of Mechanical Splices (Couplers)

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Why high seismic zone matters?

• ABC relies on precast members that are connected in the field.
Seismic Performance Requirements for Bridges
(*cast-in-place or precast*)

- No collapse under strong earthquakes
- Plastic hinging of columns - structural fuse
- Capacity-protected cap beams and footings

*ABC connections must ensure*
- Column plastic hinging
- No damage to cap beams and footings

Connecting Precast Members w/ Couplers
Current US Code Provisions on Couplers in High Seismic Zones, SDC C and D

<table>
<thead>
<tr>
<th>Code</th>
<th>Coupler Type</th>
<th>Plastic Hinge</th>
</tr>
</thead>
<tbody>
<tr>
<td>AASHTO</td>
<td>Full Mech. Connection</td>
<td>No</td>
</tr>
<tr>
<td>Caltrans</td>
<td>Service</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Ultimate</td>
<td>No</td>
</tr>
<tr>
<td>ACI</td>
<td>Type 1</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Type 2</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Objective

- Utilize existing test data to develop preliminary seismic design guidelines for prefabricated column-footing and column-cap beam connections with couplers
Tasks

1. Literature search
2. Synthesis of literature to determine trends in seismic behavior of couplers and columns w/ couplers.
3. Constructability evaluation
4. Parametric study to determine coupler effect on column ductility
5. Preliminary design guideline development
6. Design examples

STATUS
Tasks 1-5– Complete
Task 6– Under internal review
Next Step: Review by ABC-UTC-UNR seismic steering committee

Bar Coupler Connections

Development and Considerations:

- Originally developed to shorten bar splice length, reduce congestion, and reduce overall cost.

- Many types of couplers available; but not all are appropriate for seismic application.

- Size and location of couplers can affect the plastic hinge zone seismic performance.
**Major Coupler Types**

**Mechanical Bar Couplers**

- **Headed Bar Coupler**
  - [hrc-usa.com](http://hrc-usa.com)

- **Threaded Bar Coupler**
  - [eric.com](http://eric.com)

- **Grouted Sleeve Coupler**
  - [splicesleeve.com](http://splicesleeve.com)

- **Bar Grip (Swaged) Coupler**
  - [barsplice.com](http://barsplice.com)

- **Shear Screw Coupler**
  - [daytonsuperior.com](http://daytonsuperior.com)

**Coupler Connections**

Connections with couplers are possible but seismic performance test data is very limited

- **Column to Cap Beam Connections**

- **Column to Footing Connections**
**Literature Search- Sample: Grouted Sleeves**

(one table for each type)

<table>
<thead>
<tr>
<th>Study</th>
<th>Bar Size</th>
<th>Bar Type</th>
<th>Mode of Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noureddine (1996)</td>
<td>No. 18 (Ø57 mm)</td>
<td>ASTM A615 Grade 60, ASTM A705 Grade 60</td>
<td>Bar fractured in three tests, coupler failed in one test</td>
</tr>
<tr>
<td>Jansson (2008)</td>
<td>No. 6 (Ø19 mm), No. 11 (Ø36 mm)</td>
<td>Grade 60</td>
<td>Bar fracture, GC fracture, shear failure of threads</td>
</tr>
<tr>
<td>Rowell et al. (2009)</td>
<td>No. 10 (Ø32 mm)</td>
<td>ASTM A615 Grade 60</td>
<td>Bar pullout, bar fracture, GC fracture</td>
</tr>
<tr>
<td>Haber et al. (2013)</td>
<td>No. 8 (Ø25 mm)</td>
<td>ASTM A615 Grade 60</td>
<td>Bar fracture</td>
</tr>
<tr>
<td>Ameli et al. (2015)</td>
<td>No. 8 (Ø25 mm)</td>
<td>Grade 60</td>
<td>Bar pullout</td>
</tr>
</tbody>
</table>

**Previous Column Studies- A sample**

Precast/CIP Columns with Coupler Connections

**New Construction**

1. Haber/Saiidi/Sanders (2013)
2. Tazarv and Saiidi (2014)
3. Pantelides et al. (2014)

**Column Repair**

4. Lehman et al. (2001)
5. Huaco and Jirsa (2012)
Previous Column Studies - Threaded Couplers

Bar Connections:

Threaded Coupler

Sample Results from Column Tests

Precast Columns with Headed Bar Couplers

Columns:

HCNP: Headed Bar Couplers w/o No Pedestal
HCPP: Headed Bar Couplers w/ Partial Pedestal
HCS: Headed Bars Couplers w/ SMA Bars
CIP: reference Cast-in-Place
Sample Results (Cont’d)

Precast Columns with Grouted Bar Couplers

Columns:
- GCNP: Grouted Couplers w/o No Pedestal
- GCPP: Grouted Couplers w/ Partial Pedestal
- GCDP: Grouted Couplers w/ Debonded Bars in Pedestal
- CIP: reference Cast-in-Place

Sample Results (Cont’d)

Precast Columns w/ Grouted Sleeve Couplers (Utah, Pantelides)

25% lower ductility than CIP
## Summary Seismic Performance of Couplers

**One table for each type— e.g. Grouted Sleeve Coupler**

<table>
<thead>
<tr>
<th>Study</th>
<th>Mode of Failure</th>
<th>Visual Evaluation</th>
<th>Quantitative Evaluation</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noureddine (1996)</td>
<td>Bar fractured in three tests, coupler failed in one test</td>
<td>Passed</td>
<td>Passed (strain more than 11%)</td>
<td>Recommended</td>
</tr>
<tr>
<td>Jansson (2008)</td>
<td>NMB: Bar fracture (1 sample), GC fracture (2 samples), bar pullout (3 samples)</td>
<td>NMB: Failed</td>
<td>N/A</td>
<td>Not recommended</td>
</tr>
<tr>
<td></td>
<td>Lenton Interlok: Failure of threads in all tests</td>
<td>Lenton: Failed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rowell et al. (2009)</td>
<td>Bar pullout (22% of samples), bar fracture (33% of samples), GC fracture (33% of samples) [9 samples in total]</td>
<td>Failed</td>
<td>Failed (strain lower than needed for ASTM A615)</td>
<td>Not recommended</td>
</tr>
<tr>
<td>Haber et al. (2013)</td>
<td>Bar fracture</td>
<td>Passed</td>
<td>Passed (strain more than 13%)</td>
<td>Recommended</td>
</tr>
</tbody>
</table>

## Summary Seismic Performance of Columns

**One table for each type— e.g. Shear screw couplers**

<table>
<thead>
<tr>
<th>Reference</th>
<th>Coupler Length</th>
<th>Coupler Location</th>
<th>Evaluation Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cruz and Saiidi (2012)</td>
<td>14d₀: used at two levels</td>
<td>Bottom couplers embedded 12d₀ into the footing on center, top couplers were 22 in. (1.83D) away from the bottom couplers on center</td>
<td>N/A (the transverse displacement demand of SMA bent was 30% lower than that of Bent 3 tested by Nelson et al. (2007) at Run 6. Test was stopped due to fracture of bars in other bents)</td>
</tr>
<tr>
<td>Huaco (2013)</td>
<td>Short (6.9d₀): used either at two levels or one level; Long (10d₀): used at one level</td>
<td>For one column, short couplers were installed at two levels, the bottom couplers were immediately above the footing, the top couplers were 1.33D away from the bottom couplers on center</td>
<td>Passed (short couplers at two levels)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>For two columns, couplers were used at one level at the column base immediately above the footing</td>
<td>Failed (short couplers at one level)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Passed (long couplers at one level)</td>
<td>Passed (long couplers at one level)</td>
</tr>
<tr>
<td>Yang et al. (2014)</td>
<td>10d₀: used at two levels</td>
<td>Bottom end of the bottom couplers was embedded 5d₀ into the footing, top couplers were 36 in. (1.0D) away from the bottom couplers on center</td>
<td>Passed (4% higher displacement ductility and 20% higher base shear capacity compared to the original test model)</td>
</tr>
</tbody>
</table>
### Evaluate Constructability

#### Constructability of Mechanical Bar Couplers

<table>
<thead>
<tr>
<th>Item/Coupler</th>
<th>Shear Screw</th>
<th>Headed Bar</th>
<th>Grouted Sleeve</th>
<th>Threaded</th>
<th>Swaged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bar End Preparation</td>
<td>No Need</td>
<td>Heading</td>
<td>No Need</td>
<td>Threading</td>
<td>No Need</td>
</tr>
<tr>
<td>Special Equipment</td>
<td>Wrench or Nut Runner</td>
<td>Wrench, Heading Machine</td>
<td>Grout Pump</td>
<td>Die and Tap</td>
<td>Press Machine</td>
</tr>
<tr>
<td>Additional Material/Piece</td>
<td>Screw</td>
<td>No Need</td>
<td>Grout/Sealing</td>
<td>No Need</td>
<td>No Need</td>
</tr>
<tr>
<td>Tolerance and Alignment</td>
<td>Loose</td>
<td>Tight</td>
<td>Loose</td>
<td>Tight</td>
<td>Loose</td>
</tr>
<tr>
<td>Suitability for Repair</td>
<td>Yes</td>
<td>Yes</td>
<td>No (due to Size)</td>
<td>No (due to threading)</td>
<td>Yes</td>
</tr>
<tr>
<td>Suitability for Old/Plain Bars</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Suitability in New Construction</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Field Erection Speed for precasting</td>
<td>Very Fast</td>
<td>Fast</td>
<td>Very Fast</td>
<td>Fast</td>
<td>Fast</td>
</tr>
<tr>
<td>Time to Complete one Connection</td>
<td>1 min</td>
<td>5 min</td>
<td>24 hours</td>
<td>5 min</td>
<td>5 min</td>
</tr>
</tbody>
</table>

### Evaluate Construction Time - Example

NCHRP 698- Cast-in-Place Bent (Marsh et al. 2011)

<table>
<thead>
<tr>
<th>Construction Step</th>
<th>CIP</th>
<th>Shear Screw</th>
<th>Headed Bar</th>
<th>Grouted Sleeve</th>
<th>Threaded</th>
<th>Swaged</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Column-to-Footing Connections</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excavate Footing</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Build Formwork</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total Construction Time for Bent</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Bent Construction Time</strong></td>
<td>23.5</td>
<td>8.25</td>
<td>8.75</td>
<td>10</td>
<td>8.75</td>
<td>9.75</td>
</tr>
<tr>
<td>Total Time Saving for Precast Bent (%)</td>
<td>--</td>
<td>68</td>
<td>66</td>
<td>61</td>
<td>66</td>
<td>62</td>
</tr>
</tbody>
</table>
Effect of Couplers on Spread of Yielding

CIP

HRC Couplers

Grouted Sleeve

Footing

Column

Grouted Coupler Device

Headed Coupler Device

Effective stress-strain diagram

Parametric Study

Low Rigid Length Factor (\( \beta = 0.25 \))

High Rigid Length Factor (\( \beta = 0.75 \))

560 column analyses–


\[
\frac{\mu_{sp}}{\mu_{CIP}} = (1 - 0.18\beta)\left(\frac{H_{sp}}{L_{sp}}\right)^{0.1\beta}
\]
Preliminary Design Guidelines for Bridge Columns Incorporating Mechanical Bar Splices (Sample provisions)

**Main**

R1. Analysis and design of precast columns incorporating mechanical bar splices in the plastic hinge zones shall be in accordance to the AASHTO Guide Specifications (2014) except those requirements specified herein.

**Commentary**

C1. Mechanically spliced precast bridge columns are analyzed and designed according to the AASHTO Guide Specifications (2014) but some of the modeling methods and design limitations need revision to take into account the mechanical bar splice (commonly referred to as “coupler”) effects. Although the bulk of data that was utilized to develop these guidelines was obtained from precast column studies, these recommendations are also applicable to cast-in-place columns with couplers in plastic hinges.

**Main**

R2. The coupler length \( L_{sp} \) shall not exceed 15 times the column longitudinal reinforcing bar diameter \( d_b \). When bars with two different sizes are linked by the coupler, \( L_{sp} \) shall be calculated based on the smaller bar diameter.

**Commentary**

C2. Since couplers generally reduce column rotational capacity in the spliced zone, the length of

Design Examples (in progress)

CIP Two-Column Bent Details, units: ft [m]  
Bent with Grouted Couplers, units: ft [m]

Pushover: 6.45  
Pushover: 6.14

Equation: 6.0
ECC; NiTi; Copper Based SMA; Rubber; CFRP Shell- Threaded Couplers

(Patent Filed)

- No Damage
- High Disp. Capacity
- Low Residual Disp.

Two-Span Bridge Test- Threaded Couplers in Plastic Hinges

Overview - Shake table test of a reassembled precast modular 2-span bridge model with innovative materials (Bridge #2)

2/6/2015
Run 7 - 1.225 x Rinaldi (PGA=1.2 g)

PI: Dr. M. 'Saiiid' Saiidi
Graduate Assistant: Sebastian Varela, PhD student
University of Nevada, Reno
Field Application: Seattle Alaskan Way Viaduct, SR-99- Headed Bar Couplers

SMA (shape memory alloy) Bar Connections:

[Image of Headed Bar Coupler]

#10 (Ø32 mm) SMA Bars

Field Applications- Headed Bar Couplers

SMA-Reinforced ECC (engineered cementitious composite) Columns:

Seattle, Washington- FHWA IBRD Project

http://www.wsdot.wa.gov/projects/viaduct