Accelerated Bridge Construction (ABC)

- **Big Picture Problem**
  - Increasing Number of Deficient Bridge Structures
  - High Dependence on Surface Infrastructure
  - Increased City Densities and Driver Populous

- **Technology-Ready Solution: ABC**
  - Collection of Design and Construction Methods
  - Numerous Associated Benefits
  - The Use of Prefabricated Bridge Systems is Paramount

- **Challenges**
  - Contractor Learning Curve
  - Prefabricated Systems Can Pose Design Challenges

ABC Advantages

- Fabricated in a controlled environment
- Improved quality and durability
- Reduced traffic disruption
- Improved work zone safety
- Simple construction
- Fast assembly
- Low residual displacement (when post-tensioned)
Challenges for ABC in Seismic Zones

- Columns in Conventional Bridges
  - Support Superstructure
  - Dissipate Energy
  - Expected to Undergo Damage

- Design and Detailing of Connections is Critical

- Lack of Data Has Resulted in Limited use of ABC in Seismic Zones

4 Research Topics

1. Emulative Precast Column Footing Connections
2. Innovation in Column Connections for ABC
3. ABC Bridge Systems
4. ABC Design for Disassembly (DFD)
Emulative Precast Column Footing Connections

- **Objective:** Study seismic response of rigid connections between precast columns and footings.

Mechanical Rebar Couplers

- Tapered Thread (TT)
- Straight Thread (ST)
- Shear-Screw (SS)
- Upset Headed (UH)
- Grouted Sleeve (GS)
Mechanical Rebar Couplers

- Grouted Sleeve (GS)
- Service Coupler
- Upset Headed (UH) Ultimate coupler

Design Details
- 9ft Tall; 2ft Diameter
- 11 #8 Longitudinal Steel (1.9%)
- #3 Spiral @ 2in Pitch (1%)
- Axial Load = 226kip (0.1f’c A_g)

Precast Hollow Shell Design
- Filled with SCC
- Use of Precast Pedestal

5 Half-Scale Column Models

- Caltrans Seismic Design Criteria (Disp. Ductility ≥ 5)
- Design Details
  - 9ft Tall; 2ft Diameter
  - 11 #8 Longitudinal Steel (1.9%)
  - #3 Spiral @ 2in Pitch (1%)
  - Axial Load = 226kip (0.1f’c A_g)
- Precast Hollow Shell Design
- Filled with SCC
- Use of Precast Pedestal
Column Models

1. CIP: Cast-in-place benchmark
2. HCNP: Headed bar coupler; no pedestal
3. HCPP: Headed bar coupler; precast pedestal
4. GCNP: Grouted coupler; no pedestal
5. GCPP: Grouted coupler; precast pedestal

Connection Details - HC Models
HRC Couplers

Custom Built Length

Fillers

Close up

Connection Details – GC Models

Connection Dowela

Footing
Columns with Pedestal

Testing
<table>
<thead>
<tr>
<th>CIP</th>
<th>HCNP</th>
<th>GCNP</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \mu_D = 3.6 )</td>
<td>( \mu_D = 3.2 )</td>
<td>( \mu_D = 3.7 )</td>
</tr>
<tr>
<td>( F = 65.9 \text{ kip} )</td>
<td>( F = 67.8 \text{ kip} )</td>
<td>( F = 70.4 \text{ kip} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HCPP</th>
<th>GCPP</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \mu_D = 3.3 )</td>
<td>( \mu_D = 3.7 )</td>
</tr>
<tr>
<td>( F = 66.5 \text{ kip} )</td>
<td>( F = 67.9 \text{ kip} )</td>
</tr>
</tbody>
</table>
“Cigar Moment!”

Observations – Damage at Failure

- CIP (2nd Cycle 10% Drift)
- HCNP (2nd Cycle 10% Drift)
- GCNP (2nd Cycle 6% Drift)
Observations – Damage at Failure

HCPP
(10% Drift)

GCPP
(6% Drift)

Force–Displacement Responses
Effect of Pedestal in Grouted Ducts

Column-to-Footing Connection Detail (GCNP)

Connection Detail with Partial Pedestal (GCPP)
Longitudinal Bar Strains

Results – Pushover Curves
Observations:

- Headed couplers performed well and may be appropriate even under high seismic demand.

- Grouted couplers performed reasonably well. With a drift capacity of 6%, slight improvement might make them qualify as “ultimate couplers.”

- Grouted couplers are much easier to construct than HRC couplers.

Plastic Hinge Behavior

CIP  HCNP  GCNP
Precast Columns Incorporating UHPC-Filled Duct System:

- Two Column Models
  - Conventional Materials in Plastic Hinge (PNC)
  - Advanced Materials in Plastic Hinge (HCS)

- Connection
  - UHPC-Filled Duct Connections

- Column Geometry
  - Half-Scale
  - Height: 9 ft (2.74 m)
  - Diameter: 24 in. (610 mm)
  - 11–#8 (Ø25 mm) Longitudinal Bars ($\rho_l=1.92\%$)
  - Spiral, $\rho_s=1.03\%$
  - Axial Load Index: 10% (200-kip axial load on specimens)
Column w/ no couplers at 8% drift (failure)

Column w/ offset grouted couplers and unbonded pedestal bars at 8% drift (failure)
Unbonded Bars In Pedestal
Grouted Couplers w/ Unbonded Pedestal (GCDP)
ABC w/ SMA/ECC

Phase II – 3 Half-Scale Column Models

#10 SMA Bars w/ HRC Couplers
Innovation and ABC

- ABC—Innovation in **construction**

- In addition, ABC provides opportunity for innovation in connection **detailing and materials**.
Segmental Precast Columns -- Post-tensioned

Advantage: Recentering by PT
Disadvantage: Low energy dissipation; Damage

Conventional RC vs Conventional Post-tensioned Columns

**Conventional RC:**
- High energy dissipation
- Permanent drift
- Damage

**Conventional PT:**
- Low energy dissipation
- No permanent drift
- Damage
<table>
<thead>
<tr>
<th>Columns</th>
<th>Name Description</th>
<th>Detail</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC-2</td>
<td>Segmental with <strong>Concrete</strong></td>
<td>Conventional RC</td>
</tr>
<tr>
<td>SBR-1</td>
<td>Segmental with <strong>Built-in-Rubber Pad</strong></td>
<td>Built-in Elastomeric Pad</td>
</tr>
<tr>
<td>SF-2</td>
<td>Segmental with <strong>FRP</strong></td>
<td>CFRP Wrapped 2 Lower Segments</td>
</tr>
<tr>
<td>SE-2</td>
<td>Segmental with <strong>ECC</strong></td>
<td>ECC in 2 Lower Segments</td>
</tr>
<tr>
<td>SC-2R</td>
<td>Segmental with <strong>Concrete-Repaired</strong></td>
<td>Conventional RC-Repaired w/ FRP</td>
</tr>
</tbody>
</table>
Damage after 5% Drift Ratio

Damage after 10% Drift Ratio (Failure)
Precast Two–Column Bent

- Pipe pins used on top of columns
- One column was conventional RC with ECC in plastic hinge
- One column was FRP tube filled with concrete (FRP fibers were +/- 55 degree)
Bent Construction

Shake table test at UNR
Columns condition at 11% Drift (Failure)

- Ruptured bars
- Ruptured FRP Fibers

Force–Displacement Relationships
NSF-NEES 4-Span FRP Bridge

4 New Details

- Concrete filled tube precast columns
- Post-tensioned segmental columns
- Concrete filled tube cast-in-place columns

Pipe pins

Concrete-filled FRP tubes piers

Precast

Cast-in-place
Segmental Pier Construction
Precast vs. CIP Column Damage
Conclusions on ABC w/ Innovative Materials/Connections

- ABC provides the opportunity to go beyond emulative design using advanced materials.
- The high initial cost of high-performance materials should be viewed in light of life cycle cost.
- Specifications and codes are needed to help promote ABC with advanced materials.

Deconstructible bridges w/ advanced materials

Combines novel materials and ABC

Objectives:

Develop bridge columns that
1- Withstand strong earthquakes with no or minor damage so they are usable after earthquakes.
2- Can be disassembled and reused.

6% of CO₂ emission in the world is from cement factories.
Plastic Hinge Elements
Longitudinal Reinforcement in PH
Shape Memory Alloys (SMA)

Ni-Ti

Cu-Al-MN

ECC; NiTi; Copper Based SMA; Rubber; CFRP Shell
(Patent Filed)
Original Bridge– Test to 6% Drift
After disassembly

Reassembled Bridge Test to Failure (10% drift)

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. 'Saiid' Saiidi
Graduate Assistant: Sebastian Varela, PhD student
University of Nevada, Reno
Innovative concept for resilient DfD–ABC columns was successfully developed and tested on shake tables on ¼ scale single columns and 2–span bridges.

Damage to the plastic hinge elements was limited and could be easily repaired, while broken SMA bars could be replaced.

Very low residual drifts and loss of capacity: increased functionality after an intense earthquake.

DfD facilitates reuse and recycling of column components, thereby reducing energy consumption and CO₂ footprint during material extraction and manufacturing.