Highlights of Recent and Current Bridge Earthquake Engineering Research at UNR—A Few Examples

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NCHRP

Caltrans

DEPARTMENT OF TRANSPORTATION UNITED STATES OF AMERICA

University of Nevada, Reno

NEES
Topics

(Project websites available—Contact Saiidi@unr.edu)

1. Next generation of bridge columns for ABC (Caltrans)
2. Pipe pin connections for CIP and ABC in high seismic zones (Caltrans)
3. Deconstructible bridges w/ advanced materials (NSF)
4. Guidelines for earthquake-resistant novel columns (NCHRP 12–101)
5. ABC–UTC seismic studies at UNR (USDOT)
1– Next generation of bridge columns for ABC

- What is “Next generation?”
- Prefabricated columns, including connections, that
  - Meet seismic performance requirements
  - Constructible
  - Do not introduce unusual durability, maintenance, or inspectability issues
- Resilient– minimum damage; serviceable after EQ
- Conform to current ban on splices in plastic hinges
OPTIONS W/ NO-COUPLEERS

- Precast Element
- Grout or concrete filling
- Footing/Bent
  - Block-out section
- Corrugated steel tube
- Grout or concrete filling
- Extended bars from precast column
- Corrugated steel ducts
- Grout filling
Footing depth for grouted ducts:

- 70 in. for f'c=4000 psi,
- 64 in. for f'c=5000 psi
- 58 in. for f'c=6000 psi

Footing depth for UHPC–filled ducts:

- 34 in. for f'c=4000 psi, f'uhpc=20000 psi
- 31 in. for f'c=5000 psi, f'uhpc=20000
- 28 in. for f'c=6000 psi, f'uhpc=20000
Ultra-high Performance Concrete (UHPC)

- Significantly higher compressive and tensile ductility

Compared to Conventional Concrete

Courtesy: Lafarge.com
Grouted Ducts w/ UHPC

Two parts:
1– Bond strength studies
2– Implementation in large-scale columns tested under cyclic loading

Completed Summer 2014
14 Pullout Tests

Variables:
- Embedment Length: $3d_b$, $5d_b$, $8d_b$, and $12d_b$
- Bar Size: #8 (Ø25 mm) and #11 (Ø36 mm)
- Duct Size: nominal 3 in. (75 mm), 4 in. (100 mm) and 5 in. (125 mm)
- Bundled Bar: a pair of bars in a connection
- Multiple Ducts: two ducts in a connection
System Bond performance: **Test Results**

- Only in three tests bar/duct pulled out
- Bars ruptured at the threads for other specimens

**Duct Pullout**

**SP4 – Group I**
Bundled #8 Bars
Emb. Length: $8d_b$

**SP11 – Group I**
Single #11 Bar
Emb. Length: $8d_b$
“System” Bond performance: \textit{Test Results}

- Bond strength of bar in UHPC was eight times higher than that in conventional concrete

- Design Development Length:

\[
L_d = \max (L_{d,duct}, L_{d,bar})
\]

\[
L_{d,duct} = \frac{d^2_b \cdot f_s}{27d_d \cdot \sqrt{f'_c}}
\]

\[
L_{d,bar} = \frac{d_b \cdot f_s}{120\sqrt{f'_{UHPC}}}
\]

Compared to conventional connections designed according to:

- ACI 318–11
- AASHTO LRFD 2010
- Grout–Filled Ducts

At least 50% Reduction in Required Embedment Length
UHPC-Filled Duct Column Connections

- **Two Column Models**
  - Conventional Materials in Plastic Hinge ("PNC")
  - SMA-ECC in Plastic Hinge ("HCS")

- **Connection to Footing**
  - UHPC-Filled Duct Connections

- **Column Geometry**
  - Half-Scale; Hollow; Filled SCC after connecting
    - 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 ABC Connections w/ UHPC Grouted Ducts

Precast Element

Extended bars from precast column

Footing/Bent

Corrugated steel ducts

Grout filling

Precast Column

UHPC Filled Ducts

Reinforcing Steel

Reinforcing SMA

Reinforcing Steel

Footing
9% Drift Capacity
UHPC-Filled Duct Connections

@ 5% Drift Ratio

Columns w/ UHPC-Filled Duct Connections

PNC  HCS  CIP
DRAFT

1. Mark each wall PC column center and centers of duct tube assembly in foundation.
2. Prepare rebar for placement of Multi-Course Reinforcement in footing.
3. For all reinforcement and hoops, see Design Plans.
4. Mark each pointing surface to ½" amplitude during pointing.
5. All hoops are "Ultimate" bar splice connections.

This drawing shows the position of each PC column and provides dimensions. Each PC column shall be dry and free of debris before re-pointing starts.

**NOTES**: The contractor shall verify all controlling fixed dimensions before disassembling or fabricating any material.

**CALIFORNIA DOT**: Department of Transportation

**STATE OF CALIFORNIA**: Division of Structures

**STRUCTURE DESIGN**

**ABC PRECAST COLUMN CONNECTION DETAIL NO. 1**

**SECTION A-A**

**Notes**: Fill with UBC, 4" 18 gal. (min)

**Legend**: 2" concrete fill with SCC in column void.
2– Pipe pin connections for CIP and ABC in high seismic zones (Caltrans)

Purpose: Eliminate moment, hence reduce column plastic shear and moment in adjoining member
Studies of Top Pipe Pins—Deliverable: Design Method
Pip Pins for Column Base

Column-Cap Beam
M=0

Pipe-pin at footing or pile shaft
M ≠ 0
Both cast-in-place and ABC connections

- Shear: Pipes Contact & Friction
- Uplift: Threaded Rod
- Compression: Bearing of Column
- Rotation: Hinge Gap
Testing

- No external axial load
- Quasi-static displacement–controlled cyclic loading
Observations

- Pipe Pin Connections

<table>
<thead>
<tr>
<th></th>
<th>Pipes Contact</th>
<th>Hinge Gap Closure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Push</td>
<td>Pull</td>
</tr>
<tr>
<td>ABC Column</td>
<td>0.25%</td>
<td>8%</td>
</tr>
<tr>
<td></td>
<td>5%</td>
<td>6%</td>
</tr>
<tr>
<td>CIP Column</td>
<td>4%</td>
<td>0.25%</td>
</tr>
<tr>
<td></td>
<td>5%</td>
<td>6%</td>
</tr>
</tbody>
</table>

5% 10% 5% 10%

ABC Column

CIP Column
Column–Pile Shaft Pipe Pin Connection

- Corrugated Pipe
- Precast Cap beam
- SCC
- Precast Column Shell
- Pipe-Pin Hinge or Distributed Bar Hinge
- Gap Filled w/ Filler Materials
Objectives:

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

5% of CO$_2$ emission in the world is from cement factories.
Approach

- Develop precast plastic hinge (PH) elements.
- Use novel materials in PH elements to
  - Minimize residual displacements
  - Minimize damage
- Develop capacity protected precast columns for outside PH.
- Select appropriate connections between PH elements and the rest of column.
- Evaluate and optimize details by extensive computer modeling
- Conduct shake table tests on single columns
- Conduct shake table tests on a two-span bridge with different PH elements.
Plastic Hinge Elements

1/2'' COVER
11 GA. STEEL SHIMS [0.1196’’]
16 EA.

2 1/2'' X-STRONG PIPE,
A53 GR. B

1/4'' THK. RUBBER LAYERS
17 EA.

3 3/4''
3 3/4''
3 3/4''

CJP

D.M. B

NO WELD @ TOP

2-1/2'' XS PIPE "PIN"

NO WELD, CAULK AS NEEDED

EDGE OF ECC

END REFERENCE 0°
Longitudinal Reinforcement in PH Shape Memory Alloys (SMA)

Ni–Ti

Superelastic NiTi SMA

Cu–Al–MN

Superelastic CuAlMn SMA
Capacity-protected column outside PH

Coil loop inserts for lift bolts at the top
Grout-filled steel pipe (for pipe-pin connection)

Concrete-filled CFRP tube
Nominal #3 hoops

Steel can embedded inside the column
Pocket cans for SMA bar heads w/filler disc plates

1/2"-20 UNF or 9/16"-18 UNF Disc-Lock locking nuts
#6 mild steel bars threaded to 5/8"-18UNF

ECC or Rubber rotational base element w/protruding pipe shear key
5/8"-18UNF Disc-Lock Locking nuts

CuAlMn or NiTi Superelastic SMA bars
Steel can embedded inside the footing

Precast RC footing (SMA-depandan)
Coupling nuts flush w/top footing level

Cap beam with steel can embedded
Bearing plate t=1", OD=8.75" (pipe-pin hinge throat)
High density Polystyrene filler
ECC; NiTi; Copper Based SMA; Rubber; CFRP Shell
(Patent Filed)
Two-Span DfD Bridge
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
OBJECTIVES:

- Propose AASHTO guidelines for the evaluation of new techniques for the design and construction of bridge columns with energy dissipation mechanisms to minimize seismic damage and bridge replacement.

- Develop design and construction concepts based on new materials and techniques (e.g., post-tensioning, shape memory alloy, engineered cementitious composite, elastomeric pads, and fiber-reinforced polymer wrapping) and analytical techniques (e.g., current design practice, direct displacement based design, and substitute structure design method).
Phases:

- Phase I: Planning
- Phase II: Analytical Approach
- Phase III: Guideline Development
- Phase IV: Final Products
Phases I (Completed):

- Task 1 – Literature Review
- Task 2 – Synthesize the Literature
- Task 3 – Identify New Concepts
- Task 4 – Develop Analytical Approach
- Task 5 – Prepare Interim Report 1
Phases II (Started in March 2015):

- Task 6– Execute Approved Work Plan
- Task 7– Prepare Detailed Outline for the Proposed Guidelines in AASHTO Format
- Task 8– Prepare Interim Report 2
Phases III:

- Task 9 – Develop Guidelines and Examples
- Task 10 – Qualitatively Identify the Benefits and Potential Economic Impact of the Proposed Guidelines
- Task 11 – Prepare Interim Report 3

Phases IV:

- Task 12 – Update Proposed Guidelines after Consideration of Review Comments
- Task 13 – Final Report
Evaluation of Novel Columns

What is a novel column?

A viable substitute to conventional columns with minimized damage and drift. The columns must be constructible, cost effective, easy to inspect, durable, with not adverse effect on the rest of the bridge.
Evaluation of Novel Columns

For Seismic Applications

Novel Column

Minimized Damage Mechanism

Minimized Residual Disp.

Large Disp. Capacity
Minimized Damage Mechanism:

**No-Damage:** Several combination of advanced materials
No plastic hinge damage, no permanent yielding, no or insignificant permanent lateral deformations

**Low Damage:** Several combination of advanced materials
cover failure or steel bar yielding

**Moderate Damage:** When SMA is used
cover failure, concrete core crushing

**Moderate Damage:** When ECC or UHPC is used
cover failure, large steel bar yielding

**Severe Damage:** Conventional columns
cover failure, concrete core crushing, large steel bar yielding, bar buckling or fracture
Evaluation of Novel Columns

Large Displacement Capacity:

High Displacement Capacity: When high performance materials such as SMA, ECC, FRP jack, and rubber are used
Higher displacement capacity compared to conventional columns is expected

Normal Displacement Capacity: Conventional columns
AASHTO allows large displacement capacity but limits the demand

Low Displacement Capacity: When linear-elastic materials are used
Displacement capacity is usually lower than that of conventional columns
Minimized Residual Displacement:

**Low Residual Displacement:** When SMA or post-tensioning is used, lower or negligible residual displacement compared to conventional columns is expected.

**Moderate Residual Displacement:** When FRP jacket or hybrid rocking is used, residual displacement is not significant.

**High Residual Displacement:** Conventional columns. Residual displacement is significant due to large yielding of steel bars.
Evaluation of Novel Columns – Prelim. Framework

Seismic Performance

Damage Mechanism
- Severe Damage
- Moderate Damage
- Low Damage
- No Damage

Displacement Capacity
- Low Disp. Capacity
- Normal Disp. Capacity
- High Disp. Capacity

Residual Displacement
- High Residual Disp.
- Moderate Residual Disp.
- Low Residual Disp.

Select a System

Construction Considerations

Owner Approval

Yes
New Column

No

“Owner” is the bridge owner who can be a federal or state/county/city agency, a private company, or an individual

Construction Considerations:
- Initial Cost
- Material Limitations
- Ease of Construction
- Inspectability
- Maintenance
- Post-Earthquake Repair Need
- System Performance
Specific Novel Columns for Detailed Study
5 – ABC–UTC seismic studies at UNR

a. Development and Seismic Evaluation of Pier Systems w/ Pocket Connections and CFRP PT/UHPC Columns

b. Evaluation of Seismic Performance of Bridge Columns w/ Couplers and Development of Design Guidelines

c. Behavior and design of precast bridge cap beams with pocket connections
Objectives:
- Develop earthquake-resistant, resilient ABC piers

Issues:
- Pocket connections in footings and cap beams are simple and desirable. NCHRP 12–74 has addressed one type for round columns. Connections for square columns are different.
- Combination of post-tensioning and UHPC can make ABC piers better than conventional CIP piers.
- CFRP PT tendons eliminate concerns about corrosion of unbonded steel tendons.

Deliverables:
- Design/construction guidelines
- Design examples
• Pocket connection at footing
• Post-tensioned w/ CFRP tendons
Construction to be completed by the end of April
Shake table test to be conducted late summer
Will webcast high-amplitude shake table tests
Objectives:
Utilize existing data to develop seismic design guidelines for prefabricated column–footing and column–cap beam connections w/ couplers

Issues:
◦ Plastic hinge length.
◦ Analysis method parallel to AASHTO Seismic Guide.

Deliverables:
◦ Design considerations for different coupler types
◦ Design examples
Task 1 – State-of-the-art review

(a) Shear Screw Coupler  
[ancon.co.uk]

(b) Headed Bar Coupler  
[hrc-usa.com]

(c) Grouted Sleeve Couplers  
[splicesleeve.com]

(d) Threaded Coupler  
[ericom.com]
[armaturis.com]

(e) Swaged Coupler  
[ancon.com.au]

Figure T1-2. Mechanical Reinforcing Bar Couplers
Preliminary acceptance criteria being developed based on

- Coupler length
- Stress–strain behavior
- Column ductility
- Column lateral strength
Objectives:
Compile and interpret data on seismic performance of cap beams with pocket connections and identify behavior, design, detailing, and construction considerations for successful implementation of this category of connections.
Connection zone may be CIP

Figure T1-1. Pocket Connections
Task 1 – Literature Search– Completed
Main performance criterion:
• No or limited yielding in cap beam;
• Plastic hinging in columns

• Using the literature;
• Conducting additional analytical modeling:
  Determine effect of strain hardening
  Effect of bundling bars at the edge of pocket
  Effect of column embedment length
NDOT and Caltrans Projects on Precast Bridge Deck Deck Connections (Seismic and non-seismic load)

UNR survey of state DOTs

PLEASE RESPOND!