**Unconventional Reinforced Concrete Bridge Columns**

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**USE OF POST-TENSIONING AND PRETENSIONING IN COLUMNS TO MITIGATE EARTHQUAKE DAMAGE**

David H. Sanders  
Professor  
University of Nevada, Reno

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**Benefits of Post-Tensioning**
- Re-centering capabilities
- Reduced damage
- Unbonded post-tensioned tendons have shown reductions in residual displacement
- Localized inelastic straining can be avoided by using unbonded tendons as opposed to a bonded system

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**Issues of Post-Tensioning**
- Initial prestress force must be carefully selected to prevent tendon yielding at large drift ratios
- Previous work anchored the tendons in the base of the footing making it nearly impossible to gain access to replace them following an earthquake
- Long-term durability is a concern for unbonded tendons

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**Lots of Help and Sponsors**
- Graduate Research Assistants, University of Nevada, Reno  
  - Mark Cukrov, Alex Larkin, Sarira Motaref,  
- Professors  
  - David Sanders and M. Saiid Saiidi  
    University of Nevada, Reno  
  - John Stanton and Marc Eberhard (Travis Thonstad)  
    Univ. of Washington  
  - Paulziehl (Aaron Larosche)  
    University of South Carolina
**Precast Post-Tensioned Column**

**Column Parameters**

<table>
<thead>
<tr>
<th>Column</th>
<th>$P_t$</th>
<th>$P_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT-LL</td>
<td>0.685% (10.95%)</td>
<td>1.00%</td>
</tr>
<tr>
<td>PT-LL</td>
<td>1.33% (10.3%)</td>
<td>1.00%</td>
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</table>

- Diameter = 24”
- Aspect Ratio = 4.5
- Axial Load = 10% $f_{c}$
- Dead load = 40% $f_{c}$

**Test Setup**

- Four tendons pass through ducts, centered around column cross section
- Full-scale column of 60” (1524 mm) diameter would require 100 strands, unreasonable for one tendon

**Column Design**

- Longitudinal reinforcement = 10 #5's, compared to 10 #7's
- PT-LL failed at 7%, went from -7% drift right to -10%, then to +10%
- Ductility at first fracture = 6.9

**PT-LL Results**

- 1% Drift = 1.08”, 7% Drift = 7.56”
Tested material properties show that tendons yield at 8600 με.

Column rotated about axis running through tendons 2 and 4.

PT-LL Results

- Longitudinal reinforcement = 10 #7’s, compared to 10 #5’s
- Ductility at first fracture = 6.0

1% Drift = 1.08”, 7% Drift = 7.56”

Both columns provide re-centering

Tendons do not yield, even at a large drift ratio of 10%

Longitudinal reinforcement ratio plays significant roll for re-centering

- Average residual displacement of PT-LL at 7% drift = 2.94” (74.6 mm)
- Average residual displacement of PT-HL at 7% drift = 3.94” (100 mm)

Tendons exiting the corners of the footing (diamond configuration), do not display any negative effects

Similar damage to each column, PT-LL showing slightly more at 3% and 7% drifts

Testing results:

- Conventional Precast Column
- UNR Recommended Detail for Precast Column

Using Advanced Materials in Plastic Hinges

ECC “Bendable Concrete” (Engineered Cementitious Composite)

FRP (Fiber Reinforced Polymer) Wrapping

Elastomeric Bearing
Construction and Assembly

- Time for column assembly: 3 Hours!!!

Elastomeric Bearing

- First studied in Japan w/ partial success
- Second generation pad was developed at UNR
- Works in flexure NOT Shear
- A steel pipe at the center to restrain shear
- Holes to allow passing longitudinal reinforcement
- Steel shims to prevent buckling of the longitudinal reinforcement

SC-2 (Segmental with Concrete) 

- Base segment was connected to the footing via the longitudinal bars
- All segments were made out of conventional concrete
- An unbonded tendon rod at the center to connect all segments

SBR-1 (Segmental with Built in Rubber pad)

- Base segment used a combination of rubber pad and concrete
- Two reasons for using the rubber pad
  - Minimizing the damage
  - Increasing energy dissipation

SF-2 (Segmental with FRP)

- Base segment and second segment were wrapped with FRP
- Dissipation of EQ energy by yielding longitudinal bars at base segment
- Three reasons for using the FRP
  - Improving the concrete strength
  - Minimizing the damage
  - Improving the concrete ductility

SE-2 (Segmental with ECC)

- Base segment and second segment made out of ECC material
- Three reasons for using ECC
  - Improving ductility
  - Minimizing damage
  - Increasing energy dissipation
Loading Protocol
- Columns were tested on the shake table at UNR
- Series of Sylmar ground motion were applied
- Full Sylmar max. acceleration = 0.61g

SBR-1, Run 6 (Sylmar X 1.25), 7% Drift ratio

SBR-1 (Rubber) vs. SC-2 (Conventional)
- Higher capacity
- No drop in lateral load capacity
- Minimal damage at plastic hinge area
- Larger energy dissipation

SE-2 (ECC) vs. SC-2 (Conventional)
- No drop in lateral load capacity
- Minimal damage at plastic hinge area

SF-2 (Fiber) vs. SC-2 (Conventional)
- Higher capacity
- No drop in lateral load capacity
- Minimal damage at plastic hinge area
- Minimal damage at joint
- Larger energy dissipation

<table>
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<tr>
<th>Specimen</th>
<th>Energy Dissipation (Kip-inch)</th>
<th>Increase compared to SC-2</th>
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<tr>
<td>SC-2</td>
<td>539</td>
<td>0</td>
</tr>
<tr>
<td>SBR-1</td>
<td>616.3</td>
<td>14.3%</td>
</tr>
<tr>
<td>SF-2</td>
<td>788.4</td>
<td>46%</td>
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Conclusions

- Plastic hinges incorporating advanced material experienced minimal damage
- Residual displacement was negligible until very large motions
- Energy dissipation in innovative details were larger than SC-2
- Energy dissipation in all columns (with base segment connected to footing) was much larger than conventional precast column
- Amongst four columns detail, the one with lower segments wrapped by FRP had the best performance.

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<td>244%</td>
</tr>
<tr>
<td>SC-2</td>
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<td>200%</td>
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<td>340%</td>
</tr>
<tr>
<td>SE-2</td>
<td>637.4</td>
<td>250%</td>
</tr>
<tr>
<td>SC-2R</td>
<td>790</td>
<td>340%</td>
</tr>
<tr>
<td>Conventional Precast</td>
<td>176</td>
<td>0%</td>
</tr>
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Pre-tensioned Columns

- Precast Columns, Cap Beams and Girders
- Unbonded Pretensioned Columns
- Confined Rocking Interface

Experimental Results

0.5 Josh-T
1.0 Josh-T
2.0 Josh-T

Moment Rotation Curve

<table>
<thead>
<tr>
<th>Moment-Rotation</th>
<th>Strand</th>
<th>Rebar</th>
<th>Footing</th>
</tr>
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Moment Rotation Curve

Strand + Rebar = Total

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Strand + Rebar = Total

Moment Rotation Curve

Strand + Rebar = Total

Unbonded strands stay elastic
Sub Assembly Curves

Connection to Spread Footing

Connection to Cap Beam

Shake Table Model-1/4 scale

Need to do Better