Seismic Performance of One-piece Pipe Pin Connections and Precast Rebar Hinges in Bridge Piers

A. Mehrsoroush$^1$, M. Saiidi$^2$, K. Ryan$^3$

$^1$Professional Bridge Engineer, Nevada Department of Transportation
$^2$Professor, Dept. of Civil and Environmental Eng., University of Nevada, Reno
$^3$Associate Professor, Dept. of Civil and Environmental Eng., University of Nevada, Reno

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Research Objectives

Development of Earthquake-resistant Precast Pier Systems for accelerated bridge construction in Nevada

- Conduct a comprehensive literature search on five types of novel precast connections.
- Develop a rating system for evaluation of different connection types (pin and moment connections).
- Investigate the seismic performance of precast connections in a two-column pier model.
Hinge Connection Types

Pipe Pin

Rebar Hinge

Clustered Bar Hinge

Mesneger Hinge

Freyssinet Hinge

Stone Hinge

Lead Joint Hinge

Steel Hinge
Two-column Pier Model Shake Table Test

Precast Columns:
- Dc=1’ 2” Octagonal Sec.
- Hc=5’ 1.75”
- S=7’ [2,134 mm]
- $\rho_l=1.23\%$ (10 #4)
- $\rho_s=1.81\%$ (#3 @ 2” pitch)
- ALI=6.8%

Precast Cap Beam:
- 1’ 10”×1’ 8”×11’

Precast Footing:
- 4’x1’ 9”x11’

Note: ALI=Axial Load Index; Dc=Column Diameter; Hc=Column Clear Height; S=Span; $\rho_l$=Longitudinal Steel Ratio; $\rho_s$=Transverse Steel Ratio
Pin Connection Details

**Pipe Pin**
- Corrugated Metal Pipe: 2\(\frac{2}{3}\)" x 0.5" [88x13]-16 Gauge, I.D.=12" [305]
- Debonded Bars: L=2" [51]
- High-strength Grout
- Precast Cap Beam

**Rebar Hinge**
- Corrugated Metal Pipe: 2\(\frac{2}{3}\)" x 0.5" [88x13]-16 Gauge, I.D.=12" [305]
- Isolated Pipe: L=2" [51], t=\(\frac{1}{2}\)" [13]
- High-strength Grout
- Precast Column

**Column Section**
- #3 Spiral: @ 2" [51]
- CC=0.75 [19]
- 10 #4 [Ø=13]
- CC=1.33 [36]

**Pipe Section**
- 4x4 Shear Studs: Ø=\(\frac{3}{8}\)" [10]
- L=2" [51]
- Infilled St. Pipe: O.D.=5" [127], I.D.=4\(\frac{1}{2}\)" [114]
Construction
Shake Table Test Setup

Mass Rig

Load Transfer Beam
Loading Protocol

1994 Northridge EQ, Sylmar Converter Station

<table>
<thead>
<tr>
<th>Run No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scale Factor</td>
<td>0.1</td>
<td>0.2</td>
<td>0.4</td>
<td>0.6</td>
<td>0.8</td>
<td>1.0</td>
<td>1.2</td>
<td>1.4</td>
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<tr>
<td>PGA (g)</td>
<td>0.092</td>
<td>0.185</td>
<td>0.369</td>
<td>0.554</td>
<td>0.738</td>
<td>0.923</td>
<td>1.108</td>
<td>1.292</td>
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<tr>
<td>% Dgn. Motion</td>
<td>18</td>
<td>35</td>
<td>70</td>
<td>105</td>
<td>140</td>
<td>175</td>
<td>210</td>
<td>245</td>
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Hysteresis Response

Displacement Ductility

<table>
<thead>
<tr>
<th>Drift Ratio (%)</th>
<th>Force (kips)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>30</td>
</tr>
<tr>
<td>8</td>
<td>40</td>
</tr>
<tr>
<td>10</td>
<td>50</td>
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<td>12</td>
<td>60</td>
</tr>
<tr>
<td>14</td>
<td>70</td>
</tr>
<tr>
<td>16</td>
<td>80</td>
</tr>
</tbody>
</table>

Notes:
- $D_{y,1st} =$ First Yield Drift Ratio;
- $D_{y,eff} =$ Effective Yield Drift Ratio;
- $D_u =$ Ultimate Drift Ratio;
- $V_{max} =$ Maximum Base Shear;
- $\mu_d =$ Displacement Ductility

$D_{y,1st} = 0.71\%$
$D_{y,eff} = 1.05\%$
$D_u = 11.96\%$
$\mu_d = 10.9$
$V_{max} = 52.5$ kips
Summary of Test Results

<table>
<thead>
<tr>
<th>Run No.</th>
<th>SF</th>
<th>PGA (g)</th>
<th>T_n (sec)</th>
<th>DM (%)</th>
<th>D_max (in.)</th>
<th>Drift (%)</th>
<th>μ_d</th>
<th>V/D_max (kips)</th>
<th>D_r (in.)</th>
<th>Drift (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.1</td>
<td>0.110</td>
<td>0.233</td>
<td>27.1</td>
<td>0.06</td>
<td>0.09</td>
<td>0.1</td>
<td>9.82</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td>2</td>
<td>0.2</td>
<td>0.275</td>
<td>0.249</td>
<td>47.6</td>
<td>0.30</td>
<td>0.48</td>
<td>0.4</td>
<td>25.17</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td>3</td>
<td>0.4</td>
<td>0.429</td>
<td>0.284</td>
<td>65.9</td>
<td>0.76</td>
<td>1.23</td>
<td>1.1</td>
<td>42.29</td>
<td>0.02</td>
<td>0.03</td>
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<tr>
<td>4</td>
<td>0.6</td>
<td>0.521</td>
<td>0.324</td>
<td>111.1</td>
<td>1.24</td>
<td>2.01</td>
<td>1.8</td>
<td>47.60</td>
<td>-0.36</td>
<td>-0.59</td>
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<tr>
<td>5</td>
<td>0.8</td>
<td>0.629</td>
<td>0.516</td>
<td>151.7</td>
<td>2.51</td>
<td>4.07</td>
<td>3.7</td>
<td>48.67</td>
<td>-0.08</td>
<td>-0.14</td>
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<tr>
<td>6</td>
<td>1</td>
<td>0.682</td>
<td>0.604</td>
<td>179.8</td>
<td>4.13</td>
<td>6.69</td>
<td>6.1</td>
<td>51.86</td>
<td>0.08</td>
<td>0.13</td>
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<tr>
<td>7</td>
<td>1.2</td>
<td>0.741</td>
<td>0.653</td>
<td>203.0</td>
<td>6.41</td>
<td>10.30</td>
<td>0.4</td>
<td>50.70</td>
<td>1.74</td>
<td>2.82</td>
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<tr>
<td>8</td>
<td>1.4</td>
<td>0.863</td>
<td>0.699</td>
<td>225.2</td>
<td>9.51</td>
<td>15.40</td>
<td>14.0</td>
<td>30.32</td>
<td>6.71</td>
<td>10.87</td>
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</tbody>
</table>

Notes:
- $D_{\text{max}}$ = Maximum Displacement
- $D_r$ = Residual Drift
- % DM = Fraction of Design Motion
- PGA = Peak Ground Acceleration
- SF = Scale Factor
- $T_{\text{cr}}$ = Cracked Period
- $T_n$ = Natural Period
- $V/D_{\text{max}}$ = Base Shear at $D_{\text{max}}$
- $\mu_d$ = Displacement Ductility
Observations

Rebar Hinge

Pipe Pin

Design Level

After Failure
# Measured Strains

<table>
<thead>
<tr>
<th>Component</th>
<th>Element</th>
<th>DM [με]</th>
<th>Max [με]</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rebar Hinge</td>
<td>Long. Bars</td>
<td>26,667</td>
<td>46,127</td>
<td>Hinge Gap Center</td>
</tr>
<tr>
<td></td>
<td>Spiral</td>
<td>269</td>
<td>4,728</td>
<td>-</td>
</tr>
<tr>
<td>Pipe Pin</td>
<td>Pipe Long. Fiber</td>
<td>7,390</td>
<td>21,339</td>
<td>1” above Cap Beam</td>
</tr>
<tr>
<td></td>
<td>Pipe Trans. Fiber</td>
<td>1,394</td>
<td>4,018</td>
<td>Hinge Gap Center</td>
</tr>
<tr>
<td>Cap Beam</td>
<td>Longitudinal Bars</td>
<td>1,119</td>
<td>1,609</td>
<td>PP-Col Pocket Area</td>
</tr>
<tr>
<td></td>
<td>Ties</td>
<td>150</td>
<td>262</td>
<td>Edge of PP-Col Pocket</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>#3</th>
<th>#4</th>
<th>#5</th>
<th>Pipe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield Strain [με]</td>
<td>2,578</td>
<td>2,283</td>
<td>2,749</td>
<td>3,155</td>
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</tbody>
</table>
Conclusions

- The pier model showed a displacement ductility capacity was 10.9 at 12% drift indicating **very successful overall performance**!
- One-piece pipe pin detail was successful. No damage was observed up to the end of testing.
- One piece pipe pins are suggested as alternative for rebar hinges due to improved seismic performance and ease of construction.
- Precast ap Beam remained elastic and damage free.
- Pocket connection was a successful detailing in hinging the columns outside the connection region.
Thank You

a.mehrsoroush@nevada.unr.edu