RETROFIT OF SPLIT BRIDGE COLUMNS
Supporting Appendices

WA-RD 482.2

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Washington State Transportation Commission
Planning and Capital Program Management
in cooperation with:
U.S. DOT - Federal Highway Administration
Research Report – Supporting Appendices

Research Project 9902-26
Split Columns

RETROFIT OF SPLIT BRIDGE COLUMNS

APPENDICES

RETROFIT DESIGN CALCULATIONS

by

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Federal Highway Administration

October, 2001
APPENDIX A

FYFE COMPANY RETROFIT DESIGN CALCULATIONS
WSU COLUMN RETROFIT

Equations utilized in following spreadsheet:

Effective column height based on provided moment values and corresponding diagrams.
Plastic hinge length: (0.8)(Effective column height)+0.15(60ksi)(bar diameter).
Ideal yield curvature is taken from the moment-curvature analysis.
Yield displacement: (Ideal yield curvature)*(effective column height)*2/3.
Neutral axis depth is taken from the moment-curvature analysis.
Mu is taken from the moment-curvature analysis.
Required ultimate curvature = (curvature ductility)(ideal yield curvature).
Required ultimate compressive strain = (required ultimate curvature)(neutral axis depth)
Required volumetric ratio = 0.8(required ultimate compressive strain-0.004)(1.5fc)(fu/eu)
fu = ultimate composite stress = 60ksi
eu = ultimate composite strain = 0.02
Required jacket thickness = 0.5(required volumetric ratio)(depth*width)/(depth*width)
Required number of layers for required curvature = required thickness/0.051
Max. Shear is from a 50% overstrength value.

<table>
<thead>
<tr>
<th>width (in.)</th>
<th>depth (in.)</th>
<th>f’c (ksi)</th>
<th>bar dia. (in.)</th>
<th>height (in.)</th>
<th>eff. ht. (in.)</th>
<th>hinge length</th>
<th>ductility</th>
<th>curv req</th>
<th>Ideal yield curv.</th>
<th>yield displ. (in.)</th>
<th>N/A (in.)</th>
<th>Mu (kips/in.)</th>
<th>req. ult. comp. strain</th>
<th>req. vol ratio</th>
<th>req. jckt. thick (in.)</th>
<th>req. # of layers</th>
<th>max. shear (kip)</th>
<th>req. thick (in.)</th>
<th># lrs for shear</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>13</td>
<td>5</td>
<td>0.375</td>
<td>96</td>
<td>96</td>
<td>10.155</td>
<td>8</td>
<td>24.29</td>
<td>2.38E-04</td>
<td>7.31E-01</td>
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<td>0.0069</td>
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<tr>
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<td>-0.0102</td>
<td>-0.20</td>
<td>8.7281</td>
<td>0.019563</td>
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</tbody>
</table>

OUT OF PHASE LOADING

<table>
<thead>
<tr>
<th>width (in.)</th>
<th>depth (in.)</th>
<th>f’c (ksi)</th>
<th>bar dia. (in.)</th>
<th>height (in.)</th>
<th>eff. ht. (in.)</th>
<th>hinge length</th>
<th>ductility</th>
<th>curv req</th>
<th>Ideal yield curv.</th>
<th>yield displ. (in.)</th>
<th>N/A (in.)</th>
<th>Mu (kips/in.)</th>
<th>req. ult. comp. strain</th>
<th>req. vol ratio</th>
<th>req. jckt. thick (in.)</th>
<th>req. # of layers</th>
<th>max. shear (kip)</th>
<th>req. thick (in.)</th>
<th># lrs for shear</th>
</tr>
</thead>
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<tr>
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<td>69</td>
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<td>6</td>
<td>15.633</td>
<td>4.26E-04</td>
<td>5.11E-01</td>
<td>0.7</td>
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<td>0.0047</td>
<td>0.0031</td>
<td>0.0069</td>
<td>0.14</td>
<td>9.915</td>
<td>0.016296</td>
</tr>
</tbody>
</table>

REFERENCES.

1. ICBO Acceptance Criteria for Concrete Strengthening Using Fiber-Reinforced Composite Systems, ACI25, April 1997, Sect. 7.3.2.4.
OUT-OF-PHASE

SECTION PROPERTIES:

- Section Depth = 16.0 in.
- Section Width = 13.0 in.
- Cover to Main Steel = 0.7 in.
- Concrete Strength = 5.00 ksi
- Concrete Model = Mander
- Steel Strength = 40.0 ksi
- Young's Modulus = 29000.0 ksi
- Steel Model = Mild Strength Steel
- Tension Side Reinforcement = 4 Bars (#3 Bars)
- Compression Side Reinforcement = 4 Bars (#3 Bars)
- Side Reinforcement = 4 Bars (#3 Bars) each side
- Hoop Size = #3 Bars
- Hoop Spacing = 12.0 in.
- Average Number of Legs = 2.0
- Hoop Strength = 40.0 ksi

SECTION ANALYSIS RESULTS:

- Applied Axial Load = 0.0 Kips
- Moment Capacity = 56.4 Kips ft (677.4 Kips in.)
- Section N.A. Depth = 1.0 in.
- Section Curvature = 3.95e-03 1/in.
- Maximum Concrete Strain = 4.0000e-03
- Extreme Steel Strain = 5.5818e-02
SECTION PROPERTIES:

- Section Depth = 16.0 in.
- Section Width = 13.0 in.
- Cover to Main Steel = 0.7 in.
- Concrete Strength = 5.00 ksi
- Concrete Model = Mander
- Steel Strength = 40.0 ksi
- Young's Modulus = 29000.0 ksi
- Steel Model = Mild Strength Steel
- Tension Side Reinforcement = 4 Bars (#3 Bars)
- Compression Side Reinforcement = 4 Bars (#3 Bars)
- Side Reinforcement = 4 Bars (#3 Bars) each side
- Hoop Size = #3 Bars
- Hoop Spacing = 12.0 in.
- Average Number of Legs = 2.0
- Hoop Strength = 40.0 ksi

MOMENT CURVATURE ANALYSIS RESULTS:
The Ideal Moment Capacity is based on the concrete strain of 0.005.

- Applied Axial Load = 0.0 Kips
- Eeff = 2.32e+04 Kips sq.ft
- Curvature Ductility = 23.1 1/in.

Moment Curvature Plot

1. Theoretical Yield = 31.1 Kips ft
2. Ideal Yield = 58.1 Kips ft
3. Ultimate = 58.1 Kips ft

Moment

Curvature

1. 1.12e-04 1/in.
2. 2.09e-04 1/in.
3. 4.81e-03 1/in.
<table>
<thead>
<tr>
<th>Conc. Strain</th>
<th>N.A. Depth</th>
<th>Steel Strain</th>
<th>Moment Cap.</th>
<th>Curvature</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0001</td>
<td>3.1 in.</td>
<td>-0.00040</td>
<td>9.6 Kips ft</td>
<td>3.27e-05 1/in.</td>
</tr>
<tr>
<td>0.0002</td>
<td>3.1 in.</td>
<td>-0.00080</td>
<td>19.2 Kips ft</td>
<td>6.55e-05 1/in.</td>
</tr>
<tr>
<td>0.0003</td>
<td>3.1 in.</td>
<td>-0.00120</td>
<td>28.7 Kips ft</td>
<td>9.81e-05 1/in.</td>
</tr>
<tr>
<td>0.0004</td>
<td>2.9 in.</td>
<td>-0.00171</td>
<td>35.7 Kips ft</td>
<td>1.38e-04 1/in.</td>
</tr>
<tr>
<td>0.0005</td>
<td>2.6 in.</td>
<td>-0.00244</td>
<td>38.6 Kips ft</td>
<td>1.92e-04 1/in.</td>
</tr>
<tr>
<td>0.0006</td>
<td>2.3 in.</td>
<td>-0.00333</td>
<td>40.3 Kips ft</td>
<td>2.57e-04 1/in.</td>
</tr>
<tr>
<td>0.0007</td>
<td>2.1 in.</td>
<td>-0.00439</td>
<td>41.3 Kips ft</td>
<td>3.32e-04 1/in.</td>
</tr>
<tr>
<td>0.0008</td>
<td>1.9 in.</td>
<td>-0.00559</td>
<td>42.0 Kips ft</td>
<td>4.17e-04 1/in.</td>
</tr>
<tr>
<td>0.0009</td>
<td>1.8 in.</td>
<td>-0.00693</td>
<td>42.4 Kips ft</td>
<td>5.11e-04 1/in.</td>
</tr>
<tr>
<td>0.0010</td>
<td>1.6 in.</td>
<td>-0.00839</td>
<td>42.8 Kips ft</td>
<td>6.13e-04 1/in.</td>
</tr>
<tr>
<td>0.0011</td>
<td>1.5 in.</td>
<td>-0.00998</td>
<td>43.0 Kips ft</td>
<td>7.22e-04 1/in.</td>
</tr>
<tr>
<td>0.0012</td>
<td>1.4 in.</td>
<td>-0.01165</td>
<td>43.2 Kips ft</td>
<td>8.38e-04 1/in.</td>
</tr>
<tr>
<td>0.0013</td>
<td>1.4 in.</td>
<td>-0.01341</td>
<td>43.4 Kips ft</td>
<td>9.60e-04 1/in.</td>
</tr>
<tr>
<td>0.0014</td>
<td>1.3 in.</td>
<td>-0.01523</td>
<td>43.5 Kips ft</td>
<td>1.08e-03 1/in.</td>
</tr>
<tr>
<td>0.0015</td>
<td>1.2 in.</td>
<td>-0.01713</td>
<td>43.6 Kips ft</td>
<td>1.22e-03 1/in.</td>
</tr>
<tr>
<td>0.0016</td>
<td>1.2 in.</td>
<td>-0.01906</td>
<td>43.7 Kips ft</td>
<td>1.35e-03 1/in.</td>
</tr>
<tr>
<td>0.0017</td>
<td>1.2 in.</td>
<td>-0.02082</td>
<td>44.4 Kips ft</td>
<td>1.47e-03 1/in.</td>
</tr>
<tr>
<td>0.0018</td>
<td>1.1 in.</td>
<td>-0.02251</td>
<td>45.2 Kips ft</td>
<td>1.59e-03 1/in.</td>
</tr>
<tr>
<td>0.0019</td>
<td>1.1 in.</td>
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<td>46.1 Kips ft</td>
<td>1.70e-03 1/in.</td>
</tr>
<tr>
<td>0.0020</td>
<td>1.1 in.</td>
<td>-0.02592</td>
<td>46.9 Kips ft</td>
<td>1.82e-03 1/in.</td>
</tr>
<tr>
<td>0.0025</td>
<td>1.0 in.</td>
<td>-0.03415</td>
<td>50.4 Kips ft</td>
<td>2.39e-03 1/in.</td>
</tr>
<tr>
<td>0.0030</td>
<td>1.0 in.</td>
<td>-0.04191</td>
<td>53.0 Kips ft</td>
<td>2.93e-03 1/in.</td>
</tr>
<tr>
<td>0.0035</td>
<td>1.0 in.</td>
<td>-0.04934</td>
<td>54.9 Kips ft</td>
<td>3.45e-03 1/in.</td>
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<td>1.0 in.</td>
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<td>56.4 Kips ft</td>
<td>3.95e-03 1/in.</td>
</tr>
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<td>1.0 in.</td>
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<td>57.5 Kips ft</td>
<td>4.42e-03 1/in.</td>
</tr>
<tr>
<td>0.0050</td>
<td>1.0 in.</td>
<td>-0.06874</td>
<td>58.1 Kips ft</td>
<td>4.81e-03 1/in.</td>
</tr>
</tbody>
</table>

*Ultimate concrete strain was exceeded.*
SECTION PROPERTIES:

- **Section Depth** = 7.0 in.
- **Section Width** = 13.0 in.
- **Cover to Main Steel** = 0.7 in.
- **Concrete Strength** = 5.00 ksi
- **Concrete Model** = Mander
- **Steel Strength** = 40.0 ksi
- **Young's Modulus** = 29000.0 ksi
- **Steel Model** = Mild Strength Steel
- **Tension Side Reinforcement** = 4 Bars (#3 Bars)
- **Compression Side Reinforcement** = 4 Bars (#3 Bars)
- **Side Reinforcement** = 1 Bars (#3 Bars) each side
- **Hoop Size** = #3 Bars
- **Hoop Spacing** = 12.0 in.
- **Average Number of Legs** = 2.0
- **Hoop Strength** = 40.0 ksi

SECTION ANALYSIS RESULTS:

- **Applied Axial Load** = 0.0 Kips
- **Moment Capacity** = 13.0 Kips ft (156.6 Kips in.)
- **Section N.A. Depth** = 0.7 in.
- **Section Curvature** = 5.74e-03 1/in.
- **Maximum Concrete Strain** = 4.0000e-03
- **Extreme Steel Strain** = 3.1231e-02
SECTION PROPERTIES:

Section Depth
Section Width
Cover to Main Steel
Concrete Strength
Concrete Model
Steel Strength
Young's Modulus
Steel Model
Tension Side Reinforcement
Compression Side Reinforcement
Side Reinforcement
Hoop Size
Hoop Spacing
Average Number of Legs
Hoop Strength

7.0 in.
13.0 in.
0.7 in.
5.00 ksi
Mander
40.0 ksi
29000.0 ksi
Mid Strength Steel
4 Bars (#3 Bars)
4 Bars (#3 Bars)
1 Bars (#3 Bars) each side
#3 Bars
12.0 in.
2.0
40.0 ksi

MOMENT CURVATURE ANALYSIS RESULTS:
The Ideal Moment Capacity is based on the concrete strain of 0.005.

Applied Axial Load
Eleft
Curvature Ductility

0.0 Kips
2.60e+03 Kips sq.ft
15.9 1/in.

Moment Curvature Plot

1. Theoretical Yield 8.9 Kips ft 2.85e-04 1/in.
2. Ideal Yield 13.3 Kips ft 4.26e-04 1/in.
3. Ultimate 13.3 Kips ft 6.77e-03 1/in.
<table>
<thead>
<tr>
<th>Conc. Strain</th>
<th>N.A. Depth</th>
<th>Steel Strain</th>
<th>Moment Cap.</th>
<th>Curvature</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0001</td>
<td>1.5 in.</td>
<td>-0.00031</td>
<td>2.1 Kips ft</td>
<td>6.55e-05 1/in.</td>
</tr>
<tr>
<td>0.0002</td>
<td>1.5 in.</td>
<td>-0.00063</td>
<td>4.3 Kips ft</td>
<td>1.31e-04 1/in.</td>
</tr>
<tr>
<td>0.0003</td>
<td>1.5 in.</td>
<td>-0.00094</td>
<td>6.4 Kips ft</td>
<td>1.96e-04 1/in.</td>
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<td>0.0005</td>
<td>1.4 in.</td>
<td>-0.00171</td>
<td>9.9 Kips ft</td>
<td>3.49e-04 1/in.</td>
</tr>
<tr>
<td>0.0006</td>
<td>1.3 in.</td>
<td>-0.00238</td>
<td>10.3 Kips ft</td>
<td>4.71e-04 1/in.</td>
</tr>
<tr>
<td>0.0007</td>
<td>1.1 in.</td>
<td>-0.00316</td>
<td>10.5 Kips ft</td>
<td>6.10e-04 1/in.</td>
</tr>
<tr>
<td>0.0008</td>
<td>1.0 in.</td>
<td>-0.00403</td>
<td>10.7 Kips ft</td>
<td>7.63e-04 1/in.</td>
</tr>
<tr>
<td>0.0009</td>
<td>1.0 in.</td>
<td>-0.00497</td>
<td>10.8 Kips ft</td>
<td>9.27e-04 1/in.</td>
</tr>
<tr>
<td>0.0010</td>
<td>0.9 in.</td>
<td>-0.00596</td>
<td>10.9 Kips ft</td>
<td>1.10e-03 1/in.</td>
</tr>
<tr>
<td>0.0011</td>
<td>0.9 in.</td>
<td>-0.00698</td>
<td>11.0 Kips ft</td>
<td>1.28e-03 1/in.</td>
</tr>
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<td>0.8 in.</td>
<td>-0.00803</td>
<td>11.0 Kips ft</td>
<td>1.46e-03 1/in.</td>
</tr>
<tr>
<td>0.0013</td>
<td>0.8 in.</td>
<td>-0.00910</td>
<td>11.1 Kips ft</td>
<td>1.64e-03 1/in.</td>
</tr>
<tr>
<td>0.0014</td>
<td>0.8 in.</td>
<td>-0.01017</td>
<td>11.1 Kips ft</td>
<td>1.83e-03 1/in.</td>
</tr>
<tr>
<td>0.0015</td>
<td>0.7 in.</td>
<td>-0.01125</td>
<td>11.2 Kips ft</td>
<td>2.01e-03 1/in.</td>
</tr>
<tr>
<td>0.0016</td>
<td>0.7 in.</td>
<td>-0.01232</td>
<td>11.2 Kips ft</td>
<td>2.20e-03 1/in.</td>
</tr>
<tr>
<td>0.0017</td>
<td>0.7 in.</td>
<td>-0.01339</td>
<td>11.2 Kips ft</td>
<td>2.38e-03 1/in.</td>
</tr>
<tr>
<td>0.0018</td>
<td>0.7 in.</td>
<td>-0.01444</td>
<td>11.3 Kips ft</td>
<td>2.57e-03 1/in.</td>
</tr>
<tr>
<td>0.0019</td>
<td>0.7 in.</td>
<td>-0.01548</td>
<td>11.3 Kips ft</td>
<td>2.75e-03 1/in.</td>
</tr>
<tr>
<td>0.0020</td>
<td>0.7 in.</td>
<td>-0.01650</td>
<td>11.3 Kips ft</td>
<td>2.92e-03 1/in.</td>
</tr>
<tr>
<td>0.0025</td>
<td>0.7 in.</td>
<td>-0.02120</td>
<td>11.6 Kips ft</td>
<td>3.74e-03 1/in.</td>
</tr>
<tr>
<td>0.0030</td>
<td>0.7 in.</td>
<td>-0.02517</td>
<td>12.3 Kips ft</td>
<td>4.45e-03 1/in.</td>
</tr>
<tr>
<td>0.0035</td>
<td>0.7 in.</td>
<td>-0.02885</td>
<td>12.7 Kips ft</td>
<td>5.11e-03 1/in.</td>
</tr>
<tr>
<td>0.0040</td>
<td>0.7 in.</td>
<td>-0.03231</td>
<td>13.0 Kips ft</td>
<td>5.74e-03 1/in.</td>
</tr>
<tr>
<td>0.0045</td>
<td>0.7 in.</td>
<td>-0.03562</td>
<td>13.3 Kips ft</td>
<td>6.34e-03 1/in.</td>
</tr>
<tr>
<td>0.0050</td>
<td>0.7 in.</td>
<td>-0.03785</td>
<td>13.3 Kips ft</td>
<td>6.77e-03 1/in.</td>
</tr>
</tbody>
</table>

*Ultimate concrete strain was exceeded.*
SECTION PROPERTIES:

Section Depth = 13.0 in.
Section Width = 7.0 in.
Cover to Main Steel = 0.7 in.
Concrete Strength = 5.0 ksi
Concrete Model = Mander
Steel Strength = 40.0 ksi
Young's Modulus = 29000.0 ksi
Steel Model = Mild Strength Steel
Tension Side Reinforcement = 4 Bars (#3 Bars)
Compression Side Reinforcement = 4 Bars (#3 Bars)
Side Reinforcement = 3 Bars (#3 Bars) each side
Hoop Size = #3 Bars
Hoop Spacing = 12.0 in.
Average Number of Legs = 2.0
Hoop Strength = 40.0 ksi

SECTION ANALYSIS RESULTS:

Applied Axial Load = 0.0 Kips
Moment Capacity = 35.5 Kips ft (425.6 Kips in.)
Section N.A. Depth = 1.2 in.
Section Curvature = 3.37e-03 1/in.
Maximum Concrete Strain = 4.0000e-03
Extreme Steel Strain = 3.6907e-02
SECTION PROPERTIES:

Section Depth = 13.0 in.
Section Width = 7.0 in.
Cover to Main Steel = 0.7 in.

Concrete Strength = 5.0 ksi
Concrete Model = Mander

Steel Strength = 40.0 ksi
Young’s Modulus = 29000.0 ksi
Steel Model = Mild Strength Steel

Tension Side Reinforcement = 4 Bars (#3 Bars)
Compression Side Reinforcement = 4 Bars (#3 Bars)
Side Reinforcement = 3 Bars (#3 Bars) each side

Hoop Size = #3 Bars
Average Number of Legs = 2.0
Hoop Spacing = 12.0 in.
Hoop Strength = 40.0 ksi

MOMENT CURVATURE ANALYSIS RESULTS:
The ideal Moment Capacity is based on the concrete strain of 0.005.

Applied Axial Load = 0.0 Kips
Ei eff = 1.25e+04 Kips sq ft
Curvature Ductility = 15.5 1/in.

Moment Curvature Plot

<table>
<thead>
<tr>
<th>Moment [Kips ft]</th>
<th>Moment</th>
<th>Curvature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Theoretical Yield</td>
<td>22.7</td>
<td>1.51e-04 1/in.</td>
</tr>
<tr>
<td>2. Ideal Yield</td>
<td>35.7</td>
<td>2.38e-04 1/in.</td>
</tr>
<tr>
<td>3. Ultimate</td>
<td>35.7</td>
<td>3.68e-03 1/in.</td>
</tr>
<tr>
<td>Conc. Strain</td>
<td>N.A. Depth</td>
<td>Steel Strain</td>
</tr>
<tr>
<td>-------------</td>
<td>-----------</td>
<td>--------------</td>
</tr>
<tr>
<td>0.0001</td>
<td>3.2 in.</td>
<td>-0.00028</td>
</tr>
<tr>
<td>0.0002</td>
<td>3.2 in.</td>
<td>-0.00057</td>
</tr>
<tr>
<td>0.0003</td>
<td>3.2 in.</td>
<td>-0.00085</td>
</tr>
<tr>
<td>0.0004</td>
<td>3.2 in.</td>
<td>-0.00114</td>
</tr>
<tr>
<td>0.0005</td>
<td>3.2 in.</td>
<td>-0.00143</td>
</tr>
<tr>
<td>0.0006</td>
<td>2.9 in.</td>
<td>-0.00191</td>
</tr>
<tr>
<td>0.0007</td>
<td>2.7 in.</td>
<td>-0.00249</td>
</tr>
<tr>
<td>0.0008</td>
<td>2.5 in.</td>
<td>-0.00315</td>
</tr>
<tr>
<td>0.0009</td>
<td>2.3 in.</td>
<td>-0.00390</td>
</tr>
<tr>
<td>0.0010</td>
<td>2.2 in.</td>
<td>-0.00473</td>
</tr>
<tr>
<td>0.0011</td>
<td>2.0 in.</td>
<td>-0.00564</td>
</tr>
<tr>
<td>0.0012</td>
<td>1.9 in.</td>
<td>-0.00651</td>
</tr>
<tr>
<td>0.0013</td>
<td>1.8 in.</td>
<td>-0.00763</td>
</tr>
<tr>
<td>0.0014</td>
<td>1.7 in.</td>
<td>-0.00871</td>
</tr>
<tr>
<td>0.0015</td>
<td>1.6 in.</td>
<td>-0.00984</td>
</tr>
<tr>
<td>0.0016</td>
<td>1.6 in.</td>
<td>-0.01101</td>
</tr>
<tr>
<td>0.0017</td>
<td>1.5 in.</td>
<td>-0.01219</td>
</tr>
<tr>
<td>0.0018</td>
<td>1.5 in.</td>
<td>-0.01343</td>
</tr>
<tr>
<td>0.0019</td>
<td>1.4 in.</td>
<td>-0.01467</td>
</tr>
<tr>
<td>0.0020</td>
<td>1.4 in.</td>
<td>-0.01592</td>
</tr>
<tr>
<td>0.0025</td>
<td>1.3 in.</td>
<td>-0.02197</td>
</tr>
<tr>
<td>0.0030</td>
<td>1.2 in.</td>
<td>-0.02734</td>
</tr>
<tr>
<td>0.0035</td>
<td>1.2 in.</td>
<td>-0.03266</td>
</tr>
<tr>
<td>0.0040</td>
<td>1.2 in.</td>
<td>-0.03754</td>
</tr>
<tr>
<td>0.0045</td>
<td>1.3 in.</td>
<td>-0.03981</td>
</tr>
<tr>
<td>0.0050</td>
<td>1.4 in.</td>
<td>-0.04041</td>
</tr>
</tbody>
</table>

*Ultimate concrete strain was exceeded.*
SECTION PROPERTIES:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section Depth</td>
<td>13.0 in.</td>
</tr>
<tr>
<td>Section Width</td>
<td>16.0 in.</td>
</tr>
<tr>
<td>Cover to Main Steel</td>
<td>0.7 in.</td>
</tr>
<tr>
<td>Concrete Strength</td>
<td>5.00 ksi</td>
</tr>
<tr>
<td>Concrete Model</td>
<td>Mander</td>
</tr>
<tr>
<td>Steel Strength</td>
<td>40.0 ksi</td>
</tr>
<tr>
<td>Young's Modulus</td>
<td>29000.0 ksi</td>
</tr>
<tr>
<td>Steel Model</td>
<td>Mild Strength Steel</td>
</tr>
<tr>
<td>Tension Side Reinforcement</td>
<td>6 Bars (#3 Bars)</td>
</tr>
<tr>
<td>Compression Side Reinforcement</td>
<td>6 Bars (#3 Bars)</td>
</tr>
<tr>
<td>Side Reinforcement</td>
<td>2 Bars (#3 Bars) each side</td>
</tr>
<tr>
<td>Hoop Size</td>
<td>#3 Bars</td>
</tr>
<tr>
<td>Hoop Spacing</td>
<td>12.0 in.</td>
</tr>
<tr>
<td>Average Number of Legs</td>
<td>2.0</td>
</tr>
<tr>
<td>Hoop Strength</td>
<td>40.0 ksi</td>
</tr>
</tbody>
</table>

SECTION ANALYSIS RESULTS:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied Axial Load</td>
<td>0.0 Kips</td>
</tr>
<tr>
<td>Moment Capacity</td>
<td>46.6 Kips ft (558.6 Kips in.)</td>
</tr>
<tr>
<td>Section N A Depth</td>
<td>0.8 in.</td>
</tr>
<tr>
<td>Section Curvature</td>
<td>4.86e-03 1/in.</td>
</tr>
<tr>
<td>Maximum Concrete Strain</td>
<td>4.0000e-03</td>
</tr>
<tr>
<td>Extreme Steel Strain</td>
<td>5.4985e-02</td>
</tr>
</tbody>
</table>
SECTION PROPERTIES:

Section Depth = 13.0 in.
Section Width = 16.0 in.
Cover to Main Steel = 0.7 in.
Concrete Strength = 5.00 ksi
Concrete Model = Mander
Steel Strength = 40.0 ksi
Young's Modulus = 29000.0 ksi
Steel Model = Mild Strength Steel
Tension Side Reinforcement = 6 Bars (#3 Bars)
Compression Side Reinforcement = 6 Bars (#3 Bars)
Side Reinforcement = 2 Bars (#3 Bars) each side
Hoop Size = #3 Bars
Hoop Spacing = 12.0 in.
Average Number of Legs = 2.0
Hoop Strength = 40.0 ksi

MOMENT CURVATURE ANALYSIS RESULTS:
The Ideal Moment Capacity is based on the concrete strain of 0.005.

Applied Axial Load = 0.0 Kips
E_{eff} = 1.65e+04 Kips sq.ft
Curvature Ductility = 24.4 1/in.

Moment Curvature Plot

1. Theoretical Yield 27.6 Kips ft 1.39e-04 1/in.
2. Ideal Yield 47.6 Kips ft 2.40e-04 1/in.
3. Ultimate 47.6 Kips ft 5.86e-03 1/in.
<table>
<thead>
<tr>
<th>Conc. Strain</th>
<th>N.A. Depth</th>
<th>Steel Strain</th>
<th>Moment Cap.</th>
<th>Curvature</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0001</td>
<td>2.5 in.</td>
<td>-0.00040</td>
<td>8.6 Kips ft</td>
<td>4.02e-05 1/in.</td>
</tr>
<tr>
<td>0.0002</td>
<td>2.5 in.</td>
<td>-0.00079</td>
<td>17.1 Kips ft</td>
<td>8.04e-05 1/in.</td>
</tr>
<tr>
<td>0.0003</td>
<td>2.5 in.</td>
<td>-0.00119</td>
<td>25.6 Kips ft</td>
<td>1.20e-04 1/in.</td>
</tr>
<tr>
<td>0.0004</td>
<td>2.3 in.</td>
<td>-0.00174</td>
<td>31.3 Kips ft</td>
<td>1.74e-04 1/in.</td>
</tr>
<tr>
<td>0.0005</td>
<td>2.0 in.</td>
<td>-0.00263</td>
<td>32.8 Kips ft</td>
<td>2.54e-04 1/in.</td>
</tr>
<tr>
<td>0.0006</td>
<td>1.7 in.</td>
<td>-0.00372</td>
<td>33.6 Kips ft</td>
<td>3.51e-04 1/in.</td>
</tr>
<tr>
<td>0.0007</td>
<td>1.5 in.</td>
<td>-0.00500</td>
<td>34.0 Kips ft</td>
<td>4.62e-04 1/in.</td>
</tr>
<tr>
<td>0.0008</td>
<td>1.4 in.</td>
<td>-0.00643</td>
<td>34.4 Kips ft</td>
<td>5.87e-04 1/in.</td>
</tr>
<tr>
<td>0.0009</td>
<td>1.2 in.</td>
<td>-0.00801</td>
<td>34.6 Kips ft</td>
<td>7.23e-04 1/in.</td>
</tr>
<tr>
<td>0.0010</td>
<td>1.2 in.</td>
<td>-0.00970</td>
<td>34.7 Kips ft</td>
<td>8.68e-04 1/in.</td>
</tr>
<tr>
<td>0.0011</td>
<td>1.1 in.</td>
<td>-0.01149</td>
<td>34.8 Kips ft</td>
<td>1.02e-03 1/in.</td>
</tr>
<tr>
<td>0.0012</td>
<td>1.0 in.</td>
<td>-0.01333</td>
<td>34.9 Kips ft</td>
<td>1.18e-03 1/in.</td>
</tr>
<tr>
<td>0.0013</td>
<td>1.0 in.</td>
<td>-0.01523</td>
<td>35.0 Kips ft</td>
<td>1.34e-03 1/in.</td>
</tr>
<tr>
<td>0.0014</td>
<td>0.9 in.</td>
<td>-0.01715</td>
<td>35.1 Kips ft</td>
<td>1.50e-03 1/in.</td>
</tr>
<tr>
<td>0.0015</td>
<td>0.9 in.</td>
<td>-0.01908</td>
<td>35.2 Kips ft</td>
<td>1.67e-03 1/in.</td>
</tr>
<tr>
<td>0.0016</td>
<td>0.9 in.</td>
<td>-0.02079</td>
<td>35.9 Kips ft</td>
<td>1.82e-03 1/in.</td>
</tr>
<tr>
<td>0.0017</td>
<td>0.9 in.</td>
<td>-0.02242</td>
<td>36.8 Kips ft</td>
<td>1.96e-03 1/in.</td>
</tr>
<tr>
<td>0.0018</td>
<td>0.9 in.</td>
<td>-0.02404</td>
<td>37.6 Kips ft</td>
<td>2.10e-03 1/in.</td>
</tr>
<tr>
<td>0.0019</td>
<td>0.9 in.</td>
<td>-0.02564</td>
<td>38.4 Kips ft</td>
<td>2.23e-03 1/in.</td>
</tr>
<tr>
<td>0.0020</td>
<td>0.8 in.</td>
<td>-0.02722</td>
<td>39.1 Kips ft</td>
<td>2.37e-03 1/in.</td>
</tr>
<tr>
<td>0.0025</td>
<td>0.8 in.</td>
<td>-0.03489</td>
<td>42.0 Kips ft</td>
<td>3.03e-03 1/in.</td>
</tr>
<tr>
<td>0.0030</td>
<td>0.8 in.</td>
<td>-0.04220</td>
<td>44.0 Kips ft</td>
<td>3.67e-03 1/in.</td>
</tr>
<tr>
<td>0.0035</td>
<td>0.8 in.</td>
<td>-0.04917</td>
<td>45.5 Kips ft</td>
<td>4.27e-03 1/in.</td>
</tr>
<tr>
<td>0.0040</td>
<td>0.8 in.</td>
<td>-0.05590</td>
<td>46.6 Kips ft</td>
<td>4.86e-03 1/in.</td>
</tr>
<tr>
<td>0.0045</td>
<td>0.8 in.</td>
<td>-0.06227</td>
<td>47.3 Kips ft</td>
<td>5.42e-03 1/in.</td>
</tr>
<tr>
<td>0.0050</td>
<td>0.9 in.</td>
<td>-0.06721</td>
<td>47.6 Kips ft</td>
<td>5.86e-03 1/in.</td>
</tr>
</tbody>
</table>

*Ultimate concrete strain was exceeded.*
General Notes:
1. Ensure a 1/4" min. radius at column edges.
2. Broom-clean column surfaces.
3. Apply specified layers of Type SEH System.
4. Apply specified layers of Type WS Epoxy System.

Column Side View – Elevation

Column Split View – Elevation

A Section

B Section

0-1/2" gap
max. 1 yp.

1 Layer Type SEH System

2 Layers Type SEH System

0-1/2" gap
max. 1 yp.

1 Layer Type SEH System

2 Layers Type SEH System

1-5'

4-0'

4-0'

1-6'

3-0'

1-4'

2-0'

1-2'

A-15
APPENDIX B

SUMITOMO RETROFIT DESIGN CALCULATIONS
'OUT-OF-PHASE'

SPECIMEN DETAILS & TEST SETUP
Test setup for out-of-phase Loading
f'c = 4.0 ksi
fy = 44.0 ksi

Confinement: Other
cir cover = 0.67 in
spacing = 2.27 in
10-#3 at 1.21%
= 1 in^-2
Ix = 1282 in^4
Iy = 372 in^4
Xo = 0.00 in
Yy = 0.00 in

---

1993 PCA

Licensed To: Licensee name not yet specified.

File name: O:\1997\A97106\DOT-SP-1\GAO\OUTPHASE.DOC

Project: DOT Split Column Retrofit
Column Id: out-of-phase
Engineer: YOG
Date: 12/16/98  Time: 10:24:59
Code: ACI 318-89
Units: in-lb

Material Properties:
Ec = 3834 ksi  eu = 0.003 in/in
fc = 3.40 ksi  Es = 29000 ksi

E betal = 0.85

Stress Profile: Block
phi(c) = 1.00  phi(b) = 1.00

Y-axis slenderness is not considered.
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General Information:
----------------------
File Name: D:\1997\A07106\DOT-SP-1\GAO\OUTEPHASE.COL
Project: DOT Split Column Retrof Code: ACI 318-89
Column: out-of-phase Units: US in-lbs
Engineer: YOC Date: 12/16/98 Time: 10:24:59
Run Option: Investigation Short (non-sledder) column
Run Axis: Y-axis Column Type: Structural

Material Properties:
---------------------
\( f'c = 4 \) ksi  
\( Ec = 3834.25 \) ksi  
\( Ec = 3.4 \) ksi  
\( eu = 0.003 \) in/in
Stress Profile: Block  
\( \beta_{el} = 0.85 \)

Geometry:
---------
Rectangular: Width = 7 in Depth = 13 in
Gross section area, \( A_g = 91 \) in\(^2\)
\( Ix = 1281.58 \) in\(^4\)  
\( Iy = 371.583 \) in\(^4\)

Reinforcement:
---------------
Rebar Database: ASTM
<table>
<thead>
<tr>
<th>Size</th>
<th>Diam</th>
<th>Area</th>
<th>Size</th>
<th>Diam</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.38</td>
<td>0.11</td>
<td>4</td>
<td>0.50</td>
<td>0.20</td>
</tr>
<tr>
<td>6</td>
<td>0.75</td>
<td>0.44</td>
<td>7</td>
<td>0.88</td>
<td>0.60</td>
</tr>
<tr>
<td>9</td>
<td>1.13</td>
<td>1.00</td>
<td>10</td>
<td>1.27</td>
<td>1.27</td>
</tr>
<tr>
<td>14</td>
<td>1.69</td>
<td>2.25</td>
<td>18</td>
<td>2.26</td>
<td>4.00</td>
</tr>
</tbody>
</table>

Confinement: User-defined; \( \phi(c) = 1 \), \( \phi(b) = 1 \), \( a = 1 \)
#3 ties with #10 bars, #4 with larger bars.

Layout: Rectangular
Pattern: Sides Different [Cover to longitudinal reinforcement]

Total steel area, \( A_s = 1.10 \) in\(^2\) at 1.21%

<table>
<thead>
<tr>
<th>Top</th>
<th>Bottom</th>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bars</td>
<td>3 - #3</td>
<td>3 - #3</td>
<td>2 - #3</td>
</tr>
<tr>
<td>Cover(in)</td>
<td>0.67</td>
<td>0.67</td>
<td>0.67</td>
</tr>
</tbody>
</table>

B-8
<table>
<thead>
<tr>
<th>Bending about</th>
<th>Load, P (kips)</th>
<th>X-Mom. (ft-k)</th>
<th>Y-Mom. (ft-k)</th>
<th>M.A. depth (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y Pure Comp.</td>
<td>354</td>
<td>0</td>
<td>0</td>
<td>12.43</td>
</tr>
<tr>
<td>Balanced</td>
<td>154</td>
<td>0</td>
<td>31</td>
<td>4.08</td>
</tr>
<tr>
<td>Pure Bend.</td>
<td>-0</td>
<td>0</td>
<td>12</td>
<td>0.82</td>
</tr>
</tbody>
</table>

Program completed as requested:
Rotational Flexibility / Fixed or Not?

\[ K_{\text{eff}} = \frac{V}{\Lambda} = \frac{E I}{L^3} \left[ 12 - \frac{9}{1 + \frac{k_f L}{4E I}} \right] \]

- Pinned
- Fixed
- \( k_f = \frac{4E I}{L} \)

Session 1 Page 29 of 53
UMD-ITV
Seismic Bridge Design Applications
25 July 1996, NHL Course Code No. 13063
Test setup for transverse loading

Reaction Frame

Section A-A

10 ft

4 ft x 4 ft footing

5 ft

1.5 ft

1"
f'c = 4.0 ksi
fy = 44.0 ksi
Confinement: Other
cir cover = 0.67 in
spacing = 2.27 in
10-#3 at 1.214
= 1 in2
Ix = 1282 in4
Iy = 372 in4
Xo = 0.00 in
Yo = 0.00 in

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Licensed To: Licensee name not yet specified.

File name: O:\1997\A97106\DOT-SP-1\GAO\TRANSV.COL

Project: DOT Split Column Retrofit
Material Properties:
Column Id: Transverse
Ec = 3834 ksi
fc = 3.40 ksi
Eu = 0.003 in/in
Es = 29000 ksi
Engineer: YOG
Date: 12/16/98
Time: 10:24:59
BetaI = 0.85
Code: ACI 318-89
Stress Profile: Block
-Liks: in-lb
phi(c) = 1.00, phi(b) = 1.00

X-axis slenderness is not considered.
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General Information:

File Name: 0:1997\A97106\DOT-SP-1\GAO\TRANSV.COL
Project: DOT Split Column Retrofit Code: ACT 318-89
Column: Transverse Units: US in-lbs
Engineer: YOG Date: 12/16/98 Time: 10:24:59
Run Option: Investigation
Run Axis: Z-axis
Run Axis: Short (nonslender) column
Column Type: Structural

Material Properties:

\[ \begin{align*}
& f'c = 4 \text{ ksi} \quad & f_y = 44 \text{ ksi} \\
& E_c = 3834.25 \text{ ksi} \quad & E_s = 29000 \text{ ksi} \\
& f_c = 3.4 \text{ ksi} \quad & e_{up} = 0 \text{ in/in} \\
& e_u = 0.003 \text{ in/in} \quad & \beta_{eal} = 0.85 \\
& \text{Stress Profile: Block} \\
\end{align*} \]

Geometry:

\[ \begin{align*}
\text{Rectangular: Width} &= 7 \text{ in} \\
\text{Depth} &= 13 \text{ in} \\
\text{Gross section area, } A_g &= 91 \text{ in}^2 \\
I_x &= 1281.58 \text{ in}^4 \\
I_y &= 371.583 \text{ in}^4 \\
X_o &= 0 \text{ in} \\
Y_o &= 0 \text{ in} \\
\end{align*} \]

Reinforcement:

\[ \begin{align*}
\text{Rebar Database: ASTM} \\
\text{Size} & \quad \text{Diam} & \text{Area} \\
3 & 0.38 & 0.11 & 0.50 & 0.20 & 0.63 & 0.31 \\
6 & 0.75 & 0.44 & 0.88 & 0.60 & 1.00 & 0.79 \\
9 & 1.33 & 1.00 & 1.27 & 1.27 & 1.41 & 1.56 \\
14 & 1.69 & 2.23 & 2.26 & 4.00 & & \\
\end{align*} \]

Confinement: User-defined; \( \phi(c) = 1, \phi(b) = 1, \phi = 1 \)

#3 ties with #10 bars, #4 with larger bars.

Layout: Rectangular
Pattern: Sides Different [Cover to longitudinal reinforcement]

Total steel area, \( A_s = 1.10 \text{ in}^2 \) at 1.21%

\[ \begin{align*}
\text{Bars} & \quad \text{Top} & \text{Bottom} & \text{Left} & \text{Right} \\
3 & 3 & 3 & 3 & 3 \\
2 & 3 & 3 & 2 & 2 \\
\text{Cover (in)} & 0.67 & 0.67 & 0.67 & 0.67 \\
\end{align*} \]
<table>
<thead>
<tr>
<th>Bending about</th>
<th>Load, P (kips)</th>
<th>X-Mom. (ft-k)</th>
<th>Y-Mom. (ft-k)</th>
<th>N.A. depth (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X Pure Comp.</td>
<td>354</td>
<td>-0</td>
<td>-0</td>
<td>24.57</td>
</tr>
<tr>
<td>Balanced</td>
<td>169</td>
<td>56</td>
<td>-0</td>
<td>8.06</td>
</tr>
<tr>
<td>Pure Bend.</td>
<td>0</td>
<td>23</td>
<td>-0</td>
<td>1.27</td>
</tr>
</tbody>
</table>

Program completed as requested.
FIG 5. Carbon Jacket Regions for Bridge Column Retrofit, Single Bending

FIG 6. Carbon Jacket Regions for Bridge Column Retrofit, Double Bending
DRAWINGS
FIG 5. Carbon Jacket Regions for Bridge Column Retrofit. Single Bending

FIG 6. Carbon Jacket Regions for Bridge Column Retrofit. Double Bending
List of Reference Materials

1. Frieder Seible, M.J. Nigel Priestley, Donato Innamorato, Earthquake Retrofit of Bridge column with Continuous Carbon Fiber Jackets, Report No. ACTT-95/08, University of California at San Diego, August 1996

Facsimile Cover Sheet

TO: David McLean
Firm: WSU CEE
Address: Pullman, WA
Fax Number: 509-335-7632
cc: Michael W LaNier

FROM: Lee Marsh
Firm: BERGER/ABAM Engineers Inc.
Address: 33301 Ninth Avenue South
Federal Way, WA 98003
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Telephone: 206/431-2300

Total Number of Pages Transmitted (Including Cover Sheet): 7
Date Transmitted: 5/13/99
Time Transmitted: 2:10
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BERGER/ABAM Job Number: PY810H

RE: WSU/WSDOT Split Column Tests

David,

In a recent conversation with one of your researchers, Paul Rogness, it came to my attention that the calculations and design drawings for the transverse loading specimen of the above referenced tests did not properly include the splice confinement. The methodology that we followed, that developed by the University of California at San Diego, explicitly calculates the confinement for reinforcement lap splice zones. However, this methodology also recognizes that confinement of rectangular splice zones with rectangular jackets is not entirely possible. Since your tests were conducted on such a configuration, and since this effect was one of the parameters that you were investigating, I calculated the numbers of Replark 30 wraps that would have been recommended for the tests of the splice zone. The attached calculations indicate that 11 or so wraps would have been required. We understand that the performance of the specimens with the 6 wraps that were provided was fairly good. We would expect that if 11 wraps had been used, the performance may have been somewhat better. Therefore, the results probably form a lower bound to the performance expected if the calculated number of wraps are used. I hope that this additional information can be of help to you. If you have any questions, please give me a call.

Regards,

Lee [Signature]

BERGER/ABAM Engineers Inc., 33301 Ninth Avenue South • Federal Way, WA 98003-6290
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B-62
Alternate method of determining jacket thickness:

\[ P_s = 2 \left( \frac{A_{f_{2}}}{4p_{ls}} - 1 \right) \]

where:

- \( f_{2} = \frac{A_{f_{2}}}{4p_{ls}} \)

\[ f_{2} = 1.21 \frac{f_{y}}{E} \]

\[ f_{y} = 1.21(60,000) = 0.47 \text{ ksi} \]

So this is less conservative.

\[ P_{j} = 2 \left( \frac{0.47}{0.0015} \right) = 0.0169 \]

\[ P_s = 2f_{j} \left[ \frac{b+h}{bh} \right] \]

\[ f_{j} = \frac{P_s}{2} \left\{ \frac{bh}{b+h} \right\} = \frac{0.0169 (7.13)}{2} \]

\[ f_{j} = 0.043 \text{ in} \]

Note: If use \( f_{j} = 0.47 \text{ in} \),

\[ 2E = 0.0015 \]

\[ f_{j} = \frac{500(16.73)47}{33486} = 0.071 \]

\[ \text{# wraps} = \frac{0.071}{0.006} = 11.8 \text{ wraps} \]

- or about the same as before.

\[ \text{Replot 30 wraps reqd} \]

but ACI method may be a better predictor, since \( P_s \) is not truly applicable.
APPENDIX C

XXSYS RETROFIT DESIGN CALCULATIONS
**Column Specifications:**

- Column Height, \( L := 60 \) (in)
- Shear Span, \( L_e := 30 \) (in)
- Column Width, \( B := 13 \) (in)
- Column Depth, \( D := 7 \) (in)
- Concrete Cover, \( c_c := 0.67 \) (in)
- Concrete Compressive Strength, \( f_c := 5000 \) (psi)

- Longitudinal Reinforcement 10 #3 \( f_{y_l} := 40 \) (ksi)
- Number of Bars \( n := 10 \)
- Bar Diameter \( d_b := 0.375 \) (in)
- Bar Area \( A_b := 0.11 \) (in²)
- Steel Modulus \( E_s := 29000 \) (ksi)

- Transverse Reinforcement 0.12 @ 4 in. \( f_{y_t} := 40 \) (ksi)
- Bar Diameter \( d_s := 0.12 \) (in)
- Bar Area \( A_s := 0.011 \) (in²)
- Spacing \( s := 4 \) (in)

- Lap Splice Length, \( L_s := 7.5 \) (in)

**Section Properties:**

- Axial Load, \( P := 0 \) (kips)
- Moment Capacity, \( M_{yi} := 152.4 \) (kip in)
- Yield Curvature, \( \phi_y := 0.000426 \) (1/in)
- Neutral Axis Depth, \( c_u := 0.7 \) (in)

**Jacket Material Properties:**

- Jacket Modulus, \( E_j := 12000 \) (ksi)
- Ultimate Jacket Strength, \( f_{ju} := 120 \) (ksi)
- Ultimate Strain, \( \epsilon_{ju} := 0.01 \) (in/in)

**Required Displacement Ductility:** \( \mu_{\Delta} := 8 \)


**Shear Strength Retrofit:**

Plastic shear including overstrength =

\[ V_o := 1.5 \left( \frac{M_{yi}}{L_c} \right) \]

\[ V_o = 7.6 \quad \text{(kips)} \]

Concrete shear contribution =

\[ k := \begin{cases} 
\mu_{\Delta} < 2.3, & \text{if } \mu_{\Delta} < 4.5 - \mu_{\Delta}, \text{if } \mu_{\Delta} < 8, 1.5 - \frac{\mu_{\Delta}}{8}, \text{if } \mu_{\Delta} \geq 8, 0.5, 0.5 \end{cases} \]

\[ k = 0.5 \]

\[ V_{ci} := k \cdot \sqrt{f_c \cdot 0.8 \cdot (D \cdot B) \cdot 10^{-3}} \quad V_{ci} = 2.6 \quad \text{(kips)} \]

\[ V_{co} := 3 \cdot \sqrt{f_c \cdot 0.8 \cdot (D \cdot B) \cdot 10^{-3}} \quad V_{co} = 15.4 \quad \text{(kips)} \]

Hoop reinforcement shear contribution =

\[ D_c := D - 2 \cdot cc + d_b \]
\[ \theta := 45 \]
\[ \alpha := \theta \cdot \frac{\pi}{180} \quad \text{(change to radians)} \]
\[ nbar := 2 \quad \text{(# transverse bars)} \]

\[ V_s := \frac{nbar \cdot A_s \cdot f_y \cdot D_c}{s} \cdot \cot(\alpha) \quad V_s = 1.3 \quad \text{(kips)} \]

Axial load shear contribution =

\[ V_p := \frac{P \cdot (D - c_u)}{2 \cdot L_c} \quad V_p = 0 \quad \text{(kips)} \]

Jacket thickness inside the plastic hinge region \( t_{ji} = \)

Strength reduction factor \( \phi \quad \phi = 0.85 \)

\[ t_{vi} := \frac{125}{(E \cdot j \cdot D)} \left[ \frac{V_o}{\phi} - (V_{ci} + V_s + V_p) \right] \quad t_{vi} = 0.008 \quad \text{(in)} \]

Jacket thickness outside the plastic hinge region \( t_{jo} = \)

\[ t_{vo} := \frac{125}{(E \cdot j \cdot D)} \left[ \frac{V_o}{\phi} - (V_{co} + V_s + V_p) \right] \quad t_{vo} = -0.012 \quad \text{(in)} \]
**Flexural Plastic Hinge Confinement:**

Equivalent column diameter $D_e =$

\[ A := D \]
\[ k := \left( \frac{A}{B} \right)^\frac{2}{3} \]
\[ b := \sqrt{\frac{A}{(2 \cdot k)}} \left[ \frac{A}{(2 \cdot k)} + \frac{(B)^2}{(2)} \right] \]
\[ a := k \cdot b \]
\[ R_1 := \frac{b^2}{a} \]
\[ R_2 := \frac{a^2}{b} \]
\[ D_e := R_1 + R_2 \]
\[ D_e = 16.331 \text{ (in)} \]

Plastic hinge length =

\[ L_p := L_e \cdot 0.08 + 0.15 \cdot f_y \cdot d \]
\[ L_p = 4.7 \text{ (in)} \]

Curvature ductility demand =

\[ \mu_\phi := 1 + \frac{\mu_\Delta - 1}{3 \cdot \left( \frac{L_p}{L_e} \right) \cdot \left[ 1 - 0.5 \cdot \left( \frac{L_p}{L_e} \right) \right]} \]
\[ \mu_\phi = 17 \]

Required ultimate compression strain in the concrete =

\[ \varepsilon_{cu} := \mu_\phi \cdot \phi \cdot f_y \cdot c_u \]
\[ \varepsilon_{cu} = 0.0052 \]

Jacket thickness $t_{c1}$ and $t_{c2} =$

\[ t_{c1} := \left[ \frac{D_e \cdot (\varepsilon_{cu} - 0.004) \cdot 1.5 \cdot f_c}{0.1 \cdot f_{ju} \cdot \varepsilon_{ju}} \right] \cdot 10^{-3} \]
\[ t_{c1} = 0.024 \text{ (in)} \]
\[ t_{c2} = \frac{t_{c1}}{2} \]
\[ t_{c2} = 0.012 \text{ (in)} \]

Thickness to prevent bar buckling =

\[ t_b := \frac{n \cdot D'}{E_j} \]
\[ t_b = 0.006 \text{ (in)} \]
Jacket Specifications:

Shear Strength Component = 
\[ L_{vi} = 1.5 \cdot D \]
\[ L_{vo} = L - 2 \cdot L_{vi} \]

\[ L_{vi} = 10.5 \text{ (in)} \quad >>>>> \quad t_{vi} = 0.008 \text{ (in)} \]
\[ L_{vo} = 39 \text{ (in)} \quad >>>>> \quad t_{vo} = -0.012 \text{ (in)} \]

Confinement Component =
\[ L_{c1} := \text{if } \left( 0.5 \cdot D \geq 0.125 \cdot L_e, 0.5 \cdot D, 0.125 \cdot L_e \right) \]
\[ L_{c2} := \text{if } \left( 0.5 \cdot D \geq 0.125 \cdot L_e, 0.5 \cdot D, 0.125 \cdot L_e \right) \]

\[ L_{c1} = 3.75 \text{ (in)} \quad >>>>> \quad t_{c1} = 0.024 \text{ (in)} \]
\[ L_{c2} = 3.75 \text{ (in)} \quad >>>>> \quad t_{c2} = 0.012 \text{ (in)} \]
\[ t_b = 0.006 \text{ (in)} \]
EVALUATION RELEASE OF SEQMC MAY NOT BE UTILIZED FOR PRODUCTION.
For license information contact: SC Solutions, 3211 Scott Blvd., Santa Clara, CA 95054, (408) 486-6060

SECTION PROPERTIES:

- Section Depth = 7.0 in.
- Section Width = 13.0 in.
- Cover to Main Steel = 0.7 in.
- Concrete Model = Mander (no tensile strength)
- Concrete Strength = 5.00 ksi
- Steel Model = Mild Strength Steel
- Steel Strength = 40.0 ksi
- Young's Modulus = 29000.0 ksi
- Tension Side Reinforcement = 4 Bars (#3 Bars)
- Compression Side Reinforcement = 4 Bars (#3 Bars)
- Side Reinforcement = 1 Bars (#3 Bars) each side
- Hoop Size = 0.12 Bars
- Hoop Spacing = 4.0 in.
- Average Number of Legs = 2.0
- Hoop Strength = 40.0 ksi

MOMENT CURVATURE ANALYSIS RESULTS:
The Ideal Moment Capacity is based on the concrete strain of 0.004.

- Applied Axial Load = 0.0 Kips
- Eff = 2.49e+03 Kips sq.ft
- Curvature Ductility = 13.9

\[
\begin{align*}
\text{Ag} & = 91.0 \text{ sq.in} \\
\text{ig} & = 3.72e+02 \text{ in}^4 \\
\text{ieff} & = 8.43e+01 \text{ in}^4
\end{align*}
\]

Moment Curvature Plot

<table>
<thead>
<tr>
<th>Moment (Kips ft)</th>
<th>Curvature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Theoretical Yield</td>
<td>8.9 Kips ft</td>
</tr>
<tr>
<td>2. Ideal Yield</td>
<td>12.7 Kips ft</td>
</tr>
<tr>
<td>3. Ultimate</td>
<td>13.0 Kips ft</td>
</tr>
</tbody>
</table>
EVALUATION RELEASE OF SEQMC MAY NOT BE UTILIZED FOR PRODUCTION.

<table>
<thead>
<tr>
<th>Conc. Strain</th>
<th>N.A. Depth</th>
<th>Steel Strain</th>
<th>Moment Cap.</th>
<th>Curvature</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0001</td>
<td>1.5 in.</td>
<td>-0.00030</td>
<td>2.1 Kips ft</td>
<td>6.55e-05 1/in.</td>
</tr>
<tr>
<td>0.0002</td>
<td>1.5 in.</td>
<td>-0.00060</td>
<td>4.1 Kips ft</td>
<td>1.31e-04 1/in.</td>
</tr>
<tr>
<td>0.0003</td>
<td>1.5 in.</td>
<td>-0.00091</td>
<td>6.2 Kips ft</td>
<td>1.96e-04 1/in.</td>
</tr>
<tr>
<td>0.0004</td>
<td>1.5 in.</td>
<td>-0.00121</td>
<td>8.3 Kips ft</td>
<td>2.62e-04 1/in.</td>
</tr>
<tr>
<td>0.0005</td>
<td>1.5 in.</td>
<td>-0.00161</td>
<td>9.7 Kips ft</td>
<td>3.44e-04/1/in. Yield</td>
</tr>
<tr>
<td>0.0006</td>
<td>1.3 in.</td>
<td>-0.00224</td>
<td>10.1 Kips ft</td>
<td>4.63e-04 1/in.</td>
</tr>
<tr>
<td>0.0007</td>
<td>1.2 in.</td>
<td>-0.00297</td>
<td>10.3 Kips ft</td>
<td>5.97e-04 1/in.</td>
</tr>
<tr>
<td>0.0008</td>
<td>1.1 in.</td>
<td>-0.00377</td>
<td>10.5 Kips ft</td>
<td>7.44e-04 1/in.</td>
</tr>
<tr>
<td>0.0009</td>
<td>1.0 in.</td>
<td>-0.00463</td>
<td>10.6 Kips ft</td>
<td>9.00e-04 1/in.</td>
</tr>
<tr>
<td>0.0010</td>
<td>0.9 in.</td>
<td>-0.00553</td>
<td>10.7 Kips ft</td>
<td>1.06e-03 1/in.</td>
</tr>
<tr>
<td>0.0011</td>
<td>0.9 in.</td>
<td>-0.00646</td>
<td>10.8 Kips ft</td>
<td>1.23e-03 1/in.</td>
</tr>
<tr>
<td>0.0012</td>
<td>0.9 in.</td>
<td>-0.00741</td>
<td>10.9 Kips ft</td>
<td>1.40e-03 1/in.</td>
</tr>
<tr>
<td>0.0013</td>
<td>0.8 in.</td>
<td>-0.00838</td>
<td>11.0 Kips ft</td>
<td>1.58e-03 1/in.</td>
</tr>
<tr>
<td>0.0014</td>
<td>0.8 in.</td>
<td>-0.00935</td>
<td>11.0 Kips ft</td>
<td>1.75e-03 1/in.</td>
</tr>
<tr>
<td>0.0015</td>
<td>0.8 in.</td>
<td>-0.01032</td>
<td>11.1 Kips ft</td>
<td>1.92e-03 1/in.</td>
</tr>
<tr>
<td>0.0016</td>
<td>0.8 in.</td>
<td>-0.01128</td>
<td>11.1 Kips ft</td>
<td>2.10e-03 1/in.</td>
</tr>
<tr>
<td>0.0017</td>
<td>0.7 in.</td>
<td>-0.01224</td>
<td>11.2 Kips ft</td>
<td>2.27e-03 1/in.</td>
</tr>
<tr>
<td>0.0018</td>
<td>0.7 in.</td>
<td>-0.01319</td>
<td>11.2 Kips ft</td>
<td>2.44e-03 1/in.</td>
</tr>
<tr>
<td>0.0019</td>
<td>0.7 in.</td>
<td>-0.01412</td>
<td>11.2 Kips ft</td>
<td>2.61e-03 1/in.</td>
</tr>
<tr>
<td>0.0020</td>
<td>0.7 in.</td>
<td>-0.01503</td>
<td>11.2 Kips ft</td>
<td>2.77e-03 1/in.</td>
</tr>
<tr>
<td>0.0025</td>
<td>0.7 in.</td>
<td>-0.01936</td>
<td>11.3 Kips ft</td>
<td>3.56e-03 1/in.</td>
</tr>
<tr>
<td>0.0030</td>
<td>0.7 in.</td>
<td>-0.02290</td>
<td>12.0 Kips ft</td>
<td>4.22e-03 1/in.</td>
</tr>
<tr>
<td>0.0035</td>
<td>0.7 in.</td>
<td>-0.02613</td>
<td>12.4 Kips ft</td>
<td>4.82e-03 1/in.</td>
</tr>
<tr>
<td>0.0040</td>
<td>0.7 in.</td>
<td>-0.02913</td>
<td>12.7 Kips ft</td>
<td>5.39e-03 1/in.</td>
</tr>
<tr>
<td>0.0045</td>
<td>0.8 in.</td>
<td>-0.03192</td>
<td>13.0 Kips ft</td>
<td>5.93e-03 1/in.</td>
</tr>
</tbody>
</table>

Ultimate concrete strain was exceeded.
Goal: limit crack width to 1 mm in the 16" x 13" wide section to assure aggregate interlock in the concrete.

1) \(1 \text{ mm} \times 1 \text{ in}/25.4 \text{ mm} = .03937"\) total crack width in concrete section

2) This crack width spread over the 16" wide section would be:
\(.03937"/16" = .00246 \text{ in/in}\) of width = .246% strain = the strain limit in composite

3) Now, using: \(\sigma_{\text{applied}} = \varepsilon E\)
   then: \(\sigma_{\text{applied}} = (.00246)(12,000,000)\)
   \(= 29,520 \text{ lbs/in}^2\) would be developed in the composite at that strain level.

4) Using a material with a strength of 120,000 lb/in\(^2\), we would need 29,520/120,000 or .246 in\(^2\) of material to restrain the concrete.

5) If this area was spread out over 6", it would be .041" thick (.246in\(^2\)/6" = .041"
   Over 12", it would be .0205" thick.

6) Therefore, as a safe design that both restrains the crack and allows for a smooth transition of load resistance, we will apply (2) layers of .0266" thick GA180 fabric to the column: (1) 12" wide section overlaid by a (1) 6"-wide section applied to the top 6". The bottom 6" would have a thickness of .0266" and the top 6" would have a thickness of .0532".
**XXSYS "GROUTED" COLUMN DESIGN**

**Column Specifications:**

- Column Height, \( L := 104 \) (in)
- Shear Span, \( L_e := 104 \) (in)
- Column Width, \( B := 16 \) (in)
- Column Depth, \( D := 13 \) (in)
- Concrete Cover, \( cc := 0.67 \) (in)
- Concrete Compressive Strength, \( f_c := 5000 \) (psi)

  Longitudinal Reinforcement 20 #3 \( f_y_l := 40 \) (ksi)
  Number of Bars \( n := 16 \)
  Bar Diameter \( d_b := 0.375 \) (in)
  Bar Area \( A_b := 0.11 \) (in²)
  Steel Modulus \( E_s := 29000 \) (ksi)

  Transverse Reinforcement 0.12 @ 4 in. \( f_y_t := 40 \) (ksi)
  Bar Diameter \( d_s := 0.12 \) (in)
  Bar Area \( A_s := 0.011 \) (in²)
  Spacing \( s := 4 \) (in)

- Lap Splice Length, \( L_s := 7.5 \) (in)

**Section Properties:**

- Axial Load, \( P := 0 \) (kips)
- Moment Capacity, \( M_{y_l} := 547.2 \) (kip in)
- Yield Curvature, \( \phi_y := 0.000235 \) (1/in)
- Neutral Axis Depth, \( c_u := 0.9 \) (in)

**Jacket Material Properties:**

- Jacket Modulus, \( E_j := 12000 \) (ksi)
- Ultimate Jacket Strength, \( f_{j_u} := 120 \) (ksi)
- Ultimate Strain, \( \varepsilon_{j_u} := 0.01 \) (in/in)

**Required Displacement Ductility:** \( \mu_A := 8 \)
Shear Strength Retrofit:

Plastic shear including overstrength =

\[ V_0 = 1.5 \cdot \left( \frac{M_{yi}}{L_c} \right) \quad V_0 = 7.9 \text{ (kips)} \]

Concrete shear contribution =

\[ k := \text{if} \left( \mu_A < 2.3 \text{, if} \left( \mu_A < 4.5 \text{, if} \left( \mu_A < 8, 1.5 - \frac{\mu_A}{8}, \text{if} \left( \mu_A \geq 8, 0.5, 0.5 \right) \right) \right) \right) \quad k = 0.5 \]

\[ V_{ci} := k \cdot \sqrt{f_c \cdot 0.8 \cdot (D - B) \cdot 10^{-3}} \quad V_{ci} = 5.9 \text{ (kips)} \]

\[ V_{co} := 3 \cdot \sqrt{f_c \cdot 0.8 \cdot (D - B) \cdot 10^{-3}} \quad V_{co} = 35.3 \text{ (kips)} \]

Hoop reinforcement shear contribution =

\[ D_c := D - 2 \cdot cc + d_b \]

\[ \theta := 45 \]

\[ \alpha := \theta \cdot \frac{\pi}{180} \quad \text{(change to radians)} \]

\[ nbar := 2 \quad \text{(# transverse bars)} \]

\[ V_s := \frac{nbar \cdot A_s f_{yt} D_c}{s} \cdot \cot(\alpha) \quad V_s = 2.6 \text{ (kips)} \]

Axial load shear contribution =

\[ V_p := P \cdot \frac{D - c_u}{2 \cdot L_c} \quad V_p = 0 \text{ (kips)} \]

Jacket thickness inside the plastic hinge region \( t_{vi} = \)

Strength reduction factor \( \phi \quad \phi = 0.85 \)

\[ t_{vi} := \frac{125}{(E_j D)} \left[ \frac{V_0}{\phi} - \left( V_{ci} + V_s + V_p \right) \right] \quad t_{vi} = 6.044 \cdot 10^{-4} \text{ (in)} \]

Jacket thickness outside the plastic hinge region \( t_{vo} = \)

\[ t_{vo} := \frac{125}{(E_j D)} \left[ \frac{V_0}{\phi} - \left( V_{co} + V_s + V_p \right) \right] \quad t_{vo} = -0.023 \text{ (in)} \]

C-10
**Flexural Plastic Hinge Confinement:**

Equivalent column diameter $D_e =$

\[
A := D \\
k := \left( \frac{A}{B} \right)^{\frac{2}{3}} \\
b := \sqrt{\frac{A}{(2 \cdot k)}} + \frac{B}{2} \\
a := k \cdot b \\
R_1 := \frac{b^2}{a} \\
R_2 := \frac{a^2}{b} \\
D_e := R_1 + R_2
\]

$D_e = 20.862$ (in)

Plastic hinge length $= L_p := L_e \cdot 0.08 + 0.15 \cdot f y l \cdot d_b$ $L_p = 10.6$ (in)

Curvature ductility demand $= \mu_\phi := 1 + \frac{\mu_\Delta - 1}{3 \cdot \left( \frac{L_p}{L_e} \right) \left[ 1 - 0.5 \cdot \left( \frac{L_p}{L_e} \right) \right]}$ $\mu_\phi = 25$

Required ultimate compression strain in the concrete $= \varepsilon_{cu} := \mu_\phi \cdot \varepsilon_{cu}$ $\varepsilon_{cu} = 0.0053$

Jacket thickness $t_{c1}$ and $t_{c2} =$

\[
t_{c1} := \left[ \frac{D_e \cdot (\varepsilon_{cu} - 0.004) \cdot 1.5 \cdot f_c}{0.1 \cdot \frac{f_{ju} \cdot \varepsilon_{ju}}{10^{-3}}} \right]^{\frac{1}{2}} \\
t_{c1} = 0.035 \text{ (in)}
\]

\[
t_{c2} := \frac{t_{c1}}{2} \\
t_{c2} = 0.017 \text{ (in)}
\]

Thickness to prevent bar buckling $= t_b := \frac{n \cdot D'}{E_j}$ $t_b = 0.017$ (in)

C-11
Lap Splice Clamping:

Available lateral clamping pressure =
\[ f_h = 0 \]

Required clamping pressure =
\[ \begin{align*}
dd &= \left[ D - 2 \cdot (d_b + cc) \right] \\
bb &= \left[ B - 2 \cdot (d_b + cc) \right] \\
p &= 2 \cdot (dd + bb)
\end{align*} \]
\[ f_1 = \frac{A_b \cdot f_{yl}}{\left[ \frac{p}{2 \cdot n} + 2 \cdot (d_b + cc) \right] \cdot L_s} \]
\[ f_1 = 0.161 \text{ (ksi)} \]

Required jacket thickness =
\[ t_s = \left[ 500 \cdot \frac{D e}{E_j} \cdot (f_1 - f_h) \right] \cdot 2 \]
\[ t_s = 0.28 \text{ (in)} \]
Jacket Specifications:

Shear Strength Component =
\[ L_{vi} := 1.5 \cdot D \]
\[ L_{vo} := L - 2 \cdot L_{vi} \]

\[ L_{vi} = 19.5 \text{ (in)} \]
\[ L_{vo} = 65 \text{ (in)} \]
\[ t_{vi} = 6.044 \cdot 10^{-1} \text{ (in)} \]
\[ t_{vo} = -0.023 \text{ (in)} \]

Confinement Component =
\[ L_{c1} := \text{if} \left( 0.5 \cdot D \geq 0.125 \cdot L_{e}, 0.5 \cdot D, 0.125 \cdot L_{e} \right) \]
\[ L_{c2} := \text{if} \left( 0.5 \cdot D \geq 0.125 \cdot L_{e}, 0.5 \cdot D, 0.125 \cdot L_{e} \right) \]
\[ L_{c1} = 13 \text{ (in)} \]
\[ L_{c2} = 13 \text{ (in)} \]
\[ t_{c1} = 0.035 \text{ (in)} \]
\[ t_{c2} = 0.017 \text{ (in)} \]
\[ t_{b} = 0.017 \text{ (in)} \]
SECTION PROPERTIES:

Section Depth = 13.0 in.
Section Width = 16.0 in.
Cover to Main Steel = 0.7 in.
Concrete Model = Mander (no tensile strength)
Concrete Strength = 5.00 ksi
Steel Model = Mild Strength Steel
Steel Strength = 40.0 ksi
Young's Modulus = 29000.0 ksi
Tension Side Reinforcement = 6 Bars (#3 Bars)
Compression Side Reinforcement = 6 Bars (#3 Bars)
Side Reinforcement = 2 Bars (#3 Bars) each side
Hoop Size = 0.12 Bars
Hoop Spacing = 4.0 in.
Average Number of Legs = 2.0
Hoop Strength = 40.0 ksi

MOMENT CURVATURE ANALYSIS RESULTS:
The Ideal Moment Capacity is based on the concrete strain of 0.004.

Applied Axial Load = 0.0 Kips
Eeff = 1.62e+04 Kips sq.ft
Curvature Ductility = 21.6
Ag = 208.0 sq.in
Ig = 2.93e+03 in^4
Ieff = 5.48e+02 in^4

Moment Curvature Plot

1. Theoretical Yield 27.5 Kips ft 1.42e-04 1/in.
2. Ideal Yield 45.6 Kips ft 2.35e-04 1/in.
3. Ultimate 46.4 Kips ft 5.07e-03 1/in.
EVALUATION RELEASE OF SEQMC MAY NOT BE UTILIZED FOR PRODUCTION.

<table>
<thead>
<tr>
<th>Conc. Strain</th>
<th>N.A. Depth</th>
<th>Steel Strain</th>
<th>Moment Cap.</th>
<th>Curvature</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0001</td>
<td>2.5 in.</td>
<td>-0.00039</td>
<td>8.4 Kips ft</td>
<td>4.02e-05 1/in.</td>
</tr>
<tr>
<td>0.0002</td>
<td>2.5 in.</td>
<td>-0.00078</td>
<td>16.8 Kips ft</td>
<td>8.05e-05 1/in.</td>
</tr>
<tr>
<td>0.0003</td>
<td>2.5 in.</td>
<td>-0.00116</td>
<td>25.2 Kips ft</td>
<td>1.21e-04 1/in.</td>
</tr>
<tr>
<td>0.0004</td>
<td>2.3 in.</td>
<td>-0.00170</td>
<td>31.0 Kips ft</td>
<td>1.73e-04 1/in.</td>
</tr>
<tr>
<td>0.0005</td>
<td>2.0 in.</td>
<td>-0.00256</td>
<td>32.5 Kips ft</td>
<td>2.52e-04 1/in.</td>
</tr>
<tr>
<td>0.0006</td>
<td>1.7 in.</td>
<td>-0.00360</td>
<td>33.3 Kips ft</td>
<td>3.46e-04 1/in.</td>
</tr>
<tr>
<td>0.0007</td>
<td>1.5 in.</td>
<td>-0.00482</td>
<td>33.8 Kips ft</td>
<td>4.55e-04 1/in.</td>
</tr>
<tr>
<td>0.0008</td>
<td>1.4 in.</td>
<td>-0.00618</td>
<td>34.1 Kips ft</td>
<td>5.75e-04 1/in.</td>
</tr>
<tr>
<td>0.0009</td>
<td>1.3 in.</td>
<td>-0.00767</td>
<td>34.3 Kips ft</td>
<td>7.06e-04 1/in.</td>
</tr>
<tr>
<td>0.0010</td>
<td>1.2 in.</td>
<td>-0.00926</td>
<td>34.5 Kips ft</td>
<td>8.45e-04 1/in.</td>
</tr>
<tr>
<td>0.0011</td>
<td>1.1 in.</td>
<td>-0.01093</td>
<td>34.6 Kips ft</td>
<td>9.91e-04 1/in.</td>
</tr>
<tr>
<td>0.0012</td>
<td>1.1 in.</td>
<td>-0.01264</td>
<td>34.7 Kips ft</td>
<td>1.14e-03 1/in.</td>
</tr>
<tr>
<td>0.0013</td>
<td>1.0 in.</td>
<td>-0.01440</td>
<td>34.8 Kips ft</td>
<td>1.29e-03 1/in.</td>
</tr>
<tr>
<td>0.0014</td>
<td>1.0 in.</td>
<td>-0.01619</td>
<td>34.9 Kips ft</td>
<td>1.45e-03 1/in.</td>
</tr>
<tr>
<td>0.0015</td>
<td>0.9 in.</td>
<td>-0.01798</td>
<td>35.0 Kips ft</td>
<td>1.60e-03 1/in.</td>
</tr>
<tr>
<td>0.0016</td>
<td>0.9 in.</td>
<td>-0.01968</td>
<td>35.2 Kips ft</td>
<td>1.75e-03 1/in.</td>
</tr>
<tr>
<td>0.0017</td>
<td>0.9 in.</td>
<td>-0.02128</td>
<td>36.2 Kips ft</td>
<td>1.89e-03 1/in.</td>
</tr>
<tr>
<td>0.0018</td>
<td>0.9 in.</td>
<td>-0.02275</td>
<td>36.9 Kips ft</td>
<td>2.02e-03 1/in.</td>
</tr>
<tr>
<td>0.0019</td>
<td>0.9 in.</td>
<td>-0.02422</td>
<td>37.7 Kips ft</td>
<td>2.15e-03 1/in.</td>
</tr>
<tr>
<td>0.0020</td>
<td>0.9 in.</td>
<td>-0.02567</td>
<td>38.4 Kips ft</td>
<td>2.28e-03 1/in.</td>
</tr>
<tr>
<td>0.0025</td>
<td>0.9 in.</td>
<td>-0.03266</td>
<td>41.2 Kips ft</td>
<td>2.90e-03 1/in.</td>
</tr>
<tr>
<td>0.0030</td>
<td>0.9 in.</td>
<td>-0.03927</td>
<td>43.2 Kips ft</td>
<td>3.48e-03 1/in.</td>
</tr>
<tr>
<td>0.0035</td>
<td>0.9 in.</td>
<td>-0.04548</td>
<td>44.6 Kips ft</td>
<td>4.03e-03 1/in.</td>
</tr>
<tr>
<td>0.0040</td>
<td>0.9 in.</td>
<td>-0.05141</td>
<td>45.6 Kips ft</td>
<td>4.56e-03 1/in.</td>
</tr>
<tr>
<td>0.0045</td>
<td>0.9 in.</td>
<td>-0.05708</td>
<td>46.4 Kips ft</td>
<td>5.07e-03 1/in.</td>
</tr>
</tbody>
</table>

*Ultimate concrete strain was exceeded.*
Composite Lay-up for WSU Split Column Tests

Out-of-Phase, Longitudinal Loading, Double Bending
("Chopsticks")

Plastic Hinge Region
Standard 12" wide GA090 fabric (.0134" thick) was applied wet to the resin-coated concrete surfaces of the four plastic hinge regions; another layer of GA090 was then applied wet to the top and bottom 6" of each PH.

Crack Propagation Region
Standard 12" wide GA130 fabric (.0266" thick) was applied dry to the adhesive-coated concrete. After the adhesive set up, resin was applied to wet out the fabric. Another layer of GA130 (pre-cut to 6" wide) was then applied wet to the top 6" to increase the thickness to .0513".

Loading Conditions 1 and 2

Transverse Loading, Single Bending
("Grouted")

Secondary PH region
Primary PH region

Plastic Hinge Region
Standard 12" wide GA130 fabric (.0199" thick) and GA130 fabric (.0266" thick) were applied dry to the adhesive-coated concrete of the secondary and primary plastic hinge regions respectively. After the adhesive set up, resin was applied to wet out both sections. A standard 12" wide layer of GA090 fabric (.0134" thick) was then applied wet to the primary plastic hinge region to increase the thickness to .0400".

Loading Conditions 1 and 2
## Quantities of products used to construct the lay-ups

<table>
<thead>
<tr>
<th>Carbon Fiber Fabric</th>
<th>&quot;Chopsticks&quot;</th>
<th>&quot;Grouted&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plastic Hinges (4 places)</td>
<td>Crack</td>
</tr>
<tr>
<td>GA090 8.9 oz/yd² .0134&quot; thick</td>
<td>(1) 47 3/4&quot; x 12&quot;</td>
<td>--</td>
</tr>
<tr>
<td>GA130 13.2 oz/yd² .0199&quot; thick</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>GA180 17.7 oz/yd² .0266&quot; thick</td>
<td>--</td>
<td>(1) 65&quot; x 12&quot;</td>
</tr>
</tbody>
</table>

(all fabrics are 12K, all come 12" wide standard (6" wide sections had to be cut, thickness assumes 50% Vf)

<table>
<thead>
<tr>
<th>Adhesive</th>
<th>&quot;Chopsticks&quot;</th>
<th>&quot;Grouted&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bondtite R37</td>
<td>Plastic Hinges (4 places)</td>
<td>Crack</td>
</tr>
<tr>
<td></td>
<td>not used</td>
<td>1.210 lbs.</td>
</tr>
<tr>
<td>Bondtite H37</td>
<td>not used</td>
<td>.403 lbs.</td>
</tr>
</tbody>
</table>

(3:1 max ratio; coverage rate .333 lbs/sf²)

<table>
<thead>
<tr>
<th>Resin</th>
<th>&quot;Chopsticks&quot;</th>
<th>&quot;Grouted&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plastic Hinges (4 places)</td>
<td>Crack</td>
</tr>
<tr>
<td>826</td>
<td>(2) 2.274 lbs.</td>
<td>2.178 lbs.</td>
</tr>
<tr>
<td>3379</td>
<td>(2) 1.370 lbs.</td>
<td>1.122 lbs.</td>
</tr>
</tbody>
</table>

Note: 2 kits of the size shown were made to wet out the "Chopsticks" PH regions - 1 kit was made for the two "bottom" PHs and another kit was made for the two "top" PHs. Since the "top" PHs were the last to be applied and wetted out, an additional .379 lbs. of 826 and .195 lbs. of 3379 were added to the kit in order to have some resin left over to wet out any "dry" or "drier looking" areas on either test column. As it turned out, this extra resin wasn't really needed, but was applied anyway.