Seismic Performance Assessment of Steel Bridge Piers with Shape Memory Alloy in Plastic Hinge Length

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Presented by:
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Outline

• Conventional bridge piers
• Description of the specimen
• Finite element (FE) modeling procedure
• Utilizing Shape memory alloys (SMAs)
• Summary and conclusions
Conventional bridge piers
Conventional bridge piers

Residual displacement

Local buckling

Nishikawa et al. 1996
Description of the specimen

- Tested by Nishikawa et al. (1996)

  - Hollow circular section (900 mm OD)
  - SM490 steel (YS 344 MPa)
  - Axial load ratio, 0.138
FE modeling procedure

• Assumptions:
  - Welded components are assumed to be perfectly bonded.
  - Residual stresses due to welding and fabrication are neglected.

• Material models:
  - Nonlinear kinematic model (Chaboche kinematic hardening model) for the column
  - Elastic model for the links.
FE modeling procedure

• Mapped meshing:
  - Generates fewer nodes
  - Computationally efficient

• Elements:
  - Solid 185 (8-noded brick) for volumes.
  - LINK180 for rigid links.
FE modeling procedure

• Initial imperfection:
  - Introduced by a preliminary linear buckling analysis.
  - First ten mode shapes were considered.
  - Induced a maximum out of plane deformation of 1.7 mm (equal to 0.38% of the cross-section radius).

• Boundary conditions:
  - Fixed at the base.
• The results between the experiment and FE analysis are close each other.
• The type of failure which is known as “elephant foot bulge mode” occurs due to the development of local buckling, which is same with the experimental results.
Utilizing SMAs

To improve the performance of conventional steel bridge piers, the SMA tubes are proposed to take place of steel portion in plastic hinge length.

• Superelastic SMA has a flag-shaped stress–strain hysteresis
• Behavior remains flag-shaped as long as $\varepsilon \leq \varepsilon_{\text{max}}$
• Following types of SMA were used

<table>
<thead>
<tr>
<th>Case</th>
<th>Alloy</th>
<th>$E_{\text{SMA}}$ (GPa)</th>
<th>$f_y$ (MPa)</th>
<th>$f_{p1}$ (MPa)</th>
<th>$f_{T1}$ (MPa)</th>
<th>$f_{T2}$ (MPa)</th>
<th>$\varepsilon_s$ (%)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMA1</td>
<td>Fe-Mn-Al-Ni</td>
<td>46.9</td>
<td>320</td>
<td>443</td>
<td>300</td>
<td>211</td>
<td>6.1</td>
<td>(Omori et al. 2011)</td>
</tr>
<tr>
<td>SMA2</td>
<td>Fe-Mn-Al-Ni</td>
<td>98.5</td>
<td>390</td>
<td>490</td>
<td>360</td>
<td>200</td>
<td>6.3</td>
<td>(Tseng et al. 2016)</td>
</tr>
<tr>
<td>SMA3</td>
<td>Ni-Ti</td>
<td>35</td>
<td>370</td>
<td>540</td>
<td>320</td>
<td>150</td>
<td>6.94</td>
<td>(Kshitij et al. 2015)</td>
</tr>
</tbody>
</table>
Utilizing SMAs

• Buckling wave length of a circular tube under compression:

\[ \lambda = \pi \left( \frac{t_c^2 d_c^2}{3(1-v^2)} \right) \]

• Modified to consider initial imperfections and different boundary conditions:

\[ \lambda = \pi \left( \frac{\gamma^2 t_c^2 d_c^2}{3(1-v^2)} \right) \]

• The knock-down factor:

\[ \gamma = 1 - 0.901 \left( 1 - e^{-\frac{d_c}{16t_c}} \right) \quad \text{for} \quad \frac{d_c}{t_c} < 3000 \]

(NASA SP-8007, 1968)
Utilizing SMAs

Specimens:

- 9 models were built by considering different SMA types and buckling wave length.

- The connection between the SMA and steel tubes is assumed as fully bonded.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>SMA type</th>
<th>Length of the SMA tube mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>No6-0.5L-SMA1</td>
<td>SMA1</td>
<td>125</td>
</tr>
<tr>
<td>No6-1L-SMA1</td>
<td>SMA1</td>
<td>250</td>
</tr>
<tr>
<td>No6-2L-SMA1</td>
<td>SMA1</td>
<td>500</td>
</tr>
<tr>
<td>No6-0.5L-SMA2</td>
<td>SMA2</td>
<td>125</td>
</tr>
<tr>
<td>No6-1L-SMA2</td>
<td>SMA2</td>
<td>250</td>
</tr>
<tr>
<td>No6-2L-SMA2</td>
<td>SMA2</td>
<td>500</td>
</tr>
<tr>
<td>No6-0.5L-SMA3</td>
<td>SMA3</td>
<td>125</td>
</tr>
<tr>
<td>No6-1L-SMA3</td>
<td>SMA3</td>
<td>250</td>
</tr>
<tr>
<td>No6-2L-SMA3</td>
<td>SMA3</td>
<td>500</td>
</tr>
</tbody>
</table>
Utilizing SMAs

SMA1 (Fe-Mn-Al-Ni, YS 320 MPa)  
SMA2 (Fe-Mn-Al-Ni, YS 390 MPa)  
SMA3 (Ni-Ti, YS 370 MPa)

• In specimens with half length SMA tube, a portion of the buckling wave happens in the steel tube, resulting significant residual displacement.

• In the other two lengths, local buckling takes place in the SMA tubes and the specimens experience a transient local buckling owing to the super-elastic behavior of SMA.
Utilizing SMAs

- Response quantities:

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Initial stiffness</th>
<th>Lateral load capacity</th>
<th>Total dissipated energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.6</td>
<td>61543</td>
<td>1553.7</td>
<td>1536</td>
</tr>
<tr>
<td>No6-0.5L-SMA1</td>
<td>44162</td>
<td>1178.3</td>
<td>494.7</td>
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<tr>
<td>No6-1L-SMA1</td>
<td>36953</td>
<td>1121.4</td>
<td>230.6</td>
</tr>
<tr>
<td>No6-2L-SMA1</td>
<td>27527</td>
<td>1145.3</td>
<td>185.1</td>
</tr>
<tr>
<td>No6-0.5L-SMA2</td>
<td>52885</td>
<td>1418.8</td>
<td>733.5</td>
</tr>
<tr>
<td>No6-1L-SMA2</td>
<td>49691</td>
<td>1379.5</td>
<td>460.7</td>
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<tr>
<td>No6-2L-SMA2</td>
<td>43709</td>
<td>1451</td>
<td>320.6</td>
</tr>
<tr>
<td>No6-0.5L-SMA3</td>
<td>41560</td>
<td>1179.4</td>
<td>539</td>
</tr>
<tr>
<td>No6-1L-SMA3</td>
<td>31712</td>
<td>1152.2</td>
<td>276.1</td>
</tr>
<tr>
<td>No6-2L-SMA3</td>
<td>22150</td>
<td>1263.8</td>
<td>210.4</td>
</tr>
</tbody>
</table>

SMA1 (Fe-Mn-Al-Ni, YS 320 MPa)
SMA2 (Fe-Mn-Al-Ni, YS 390 MPa)
SMA3 (Ni-Ti, YS 370 MPa)
Summary and conclusions

• A validation study on the steel bridge pier was done and showed a good agreement between the experiment and FE results.

• Smart materials can be used in steel bridge piers in order to eliminate residual drifts.

• Local buckling inevitably occurs in the plastic hinge region regardless of the SMA tube length.

• If the buckling wave is within the SMA tube, the column can go back to its original position after unloading and a self-centering behavior is achieved.
Acknowledgements

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Thank you

Question?