Effects of Different Support Modeling Assumptions on Seismic Response of Ordinary Bridges (BP222)

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Generally in performance-based design:

- Demand vs. Capacity
- Displacement-based analysis: Evaluating the potential damage to a structure based on displacement-related quantities.
Displacement-based design:

Displacement Capacity ($\Delta_C$)

I- Capacity Analysis ($\Delta_C$ and $\Delta_y$)

Displacement Ductility (\(\mu_\Delta\)) \(\rightarrow\) $\Delta_y$

II- Demand Analysis ($\Delta_D$)

$$\Delta_D \leq \Delta_C$$

\(\mu_\Delta\) should meet required criteria
I- Capacity Analysis

Nonlinear time history analysis (the ideal approach when subjected to earthquake loadings) → difficulties in GM selection and computational process

Nonlinear static pushover analysis (a compromise between the simplification of the linear analysis and the accuracy of the nonlinear dynamic analysis)
Conventional Pushover Methods: application of an increasing, but \textit{invariant}, lateral load pattern on the structural system.

Fundamental mode shape proportional

Single-mode pushover: based on one, predominant, mode shape.

Multi-modal pushover (MMP): estimates the pushover result for a number of modes.
II- Demand Analysis

✓ Independently Determined Demand
California Seismic Design Criteria SDC–2010 (Caltrans, 2010).

✓ Capacity–dependant Demand:
Generally known as Capacity Spectrum Methods (CSMs): determine the performance point ($\Delta_D = \Delta_P$)
AASHTO Specifications Procedure:

Seismic Design Categories

Table 3.5-1

<table>
<thead>
<tr>
<th>$SD_1 = F_vS_1$</th>
<th>SDC</th>
</tr>
</thead>
<tbody>
<tr>
<td>$SD_1 &lt; 0.15$</td>
<td>A</td>
</tr>
<tr>
<td>$0.15 \leq SD_1 &lt; 0.30$</td>
<td>B</td>
</tr>
<tr>
<td>$0.30 \leq SD_1 &lt; 0.50$</td>
<td>C</td>
</tr>
<tr>
<td>$0.50 \leq SD_1$</td>
<td>D</td>
</tr>
</tbody>
</table>
AASHTO Specifications Procedure:

Core Flowchart

SDC "A"
- Yes: Minimum Requirements → Complete
- No

SDC "B"
- Yes: Demand Analysis → Implicit Capacity
  - Yes: Demand Analysis → Implicit Capacity
  - No

SDC "C"
- Yes: Identify ERS → Demand Analysis → Implicit Capacity
  - Yes: Demand Analysis → Implicit Capacity
  - No

SDC "D"
- Yes: Demand Analysis → Pushover Capacity Analysis
  - Yes: Demand Analysis → Pushover Capacity Analysis
  - No: Adjust Bridge Characteristics

Depends on Adjustments

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✓ AASHTO Specifications Procedure:

SDC D Demand Analysis Procedures

Table 4.2-2

<table>
<thead>
<tr>
<th>Regular Bridge</th>
<th>Not Regular Bridge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equivalent Static or Elastic Dynamic</td>
<td>Elastic Dynamic</td>
</tr>
</tbody>
</table>

Regularity requirements (T 4.2.3; Art. 4.2)
AASHTO Specifications Procedure:

Elastic Dynamic Analysis (EDA)

- Response spectra analysis (AASHTO–USGS maps)
- Orthogonal combination (Art. 4.4)
- General considerations (Art. 5.4.3)
- Mathematical modeling (Art. 5.5)
- Effective section properties (Art. 5.6)

Seismic lateral displacement demand (Art. 4.3)
AASHTO Specifications Procedure:

Displacement Modifications:

• Other than 5% damped; $R_D$ (Art. 4.3.2)
• Short-period structure; $R_d$ (Art. 4.3.3)
Case Study Bridges:

1. The State Route 21 over Interstate 69 Bridge (SR21–I69): two-span continuous with prestressed bulb T girders and four-column bent frame.
SR21–I69 Bridge:
SR21–I69 Bridge:
2. The Forrester Road over Interstate 69 Bridge (Forrester Rd–I69): two-span continuous with steel plate girders and two-column bent frame.
✓ Forrester Rd–I69 Bridge:
Forrester Rd–I69 Bridge:
Forrester Rd–I69 Bridge:

<table>
<thead>
<tr>
<th>Section</th>
<th>Web</th>
<th>Top Flange</th>
<th>Bottom Flange</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>64 x 9/16</td>
<td>20 x 1-1/8</td>
<td>24 x 1-1/8</td>
</tr>
<tr>
<td>2</td>
<td>64 x 9/16</td>
<td>20 x 1-1/8</td>
<td>24 x 2-1/8</td>
</tr>
<tr>
<td>3</td>
<td>64 x 9/16</td>
<td>28 x 1-1/4</td>
<td>30 x 1-1/4</td>
</tr>
<tr>
<td>4</td>
<td>64 x 5/8</td>
<td>28 x 1-3/4</td>
<td>30 x 1-3/4</td>
</tr>
<tr>
<td>5</td>
<td>64 x 5/8</td>
<td>28 x 3-1/4</td>
<td>30 x 3-1/4</td>
</tr>
</tbody>
</table>
✓ General Modeling Properties:

- Idealized mathematical model
General Modeling Properties:
- The seismic behavior of both bridges was evaluated in the transverse direction only.
- **Basic support configuration:**
  Fixed column footings;
  Fixed abutments for all rotations and vertical translation; and
  Linear springs for abutments in longitudinal and transverse translations.
General Modeling Properties:

- Nonlinear springs support configuration:
  Fixed column footings for all rotations and vertical translation;
  Fixed abutments for all rotations and vertical translation; and
  Nonlinear springs for abutments and column footings in longitudinal and transverse translations.
SR21–I69 Bridge:

Abutments in Longitudinal Direction
SR21–I69 Bridge:

Abutments in Transverse Direction
SR21–I69 Bridge:

Column Footings in Both Directions
Forrester Rd–I69 Bridge:

Abutments in Both Directions

Displacement (ft)

Force (kips)

Transverse Direction

Longitudinal Direction
Forrester Rd–I69 Bridge:

Column Footings in Both Directions

![Graph showing force and displacement for column footings in both directions.]
<table>
<thead>
<tr>
<th>Case Study</th>
<th>Support Model</th>
<th>Mode Number</th>
<th>Period (sec)</th>
<th>Modal Participating Mass Ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR 21 – I 69 Bridge</td>
<td>Basic Support Config</td>
<td>2</td>
<td>0.84</td>
<td>0.997</td>
</tr>
<tr>
<td></td>
<td>Nonlinear Springs</td>
<td>1</td>
<td>0.71</td>
<td>0.789</td>
</tr>
<tr>
<td></td>
<td>Support Config</td>
<td>6</td>
<td>0.3</td>
<td>0.126</td>
</tr>
<tr>
<td>Forrester Rd – I 69 Bridge</td>
<td>Basic Support Config</td>
<td>1</td>
<td>0.75</td>
<td>0.998</td>
</tr>
<tr>
<td></td>
<td>Nonlinear Springs</td>
<td>1</td>
<td>0.61</td>
<td>0.961</td>
</tr>
</tbody>
</table>
Pushover Analysis with SAP2000:

![Graph showing base shear vs control node displacement for different support configurations.](image)

**SR21–I69 Bridge**
Pushover Analysis with SAP2000:

Forrester Rd–I69 Bridge
## Pushover Analysis with SAP2000:

<table>
<thead>
<tr>
<th>Support Model</th>
<th>Yielding Displacement $\Delta_y$ (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR21-I69 Basic Support Model</td>
<td>0.115</td>
</tr>
<tr>
<td>SR21-I69 Nonlinear Springs Support Model (SMP)</td>
<td>0.134</td>
</tr>
<tr>
<td>SR21-I69 Nonlinear Springs Support Model (MMP)</td>
<td>0.125</td>
</tr>
<tr>
<td>Forrester Rd-I69 Basic Support Model</td>
<td>0.134</td>
</tr>
<tr>
<td>Forrester Rd-I69 Nonlinear Springs Support Model</td>
<td>0.148</td>
</tr>
</tbody>
</table>
Displacement-based Analysis Procedures:

Seismic Demand
AASHTO Specifications Procedure:

**Demand analysis:**
- Response spectrum method;
- Four orthogonal combinations;
- CQC modal combination; and
- $\Delta_D = \text{max. transverse displacement}$.

$\mu_\Delta = \Delta_D / \Delta_y$
AASHTO Specifications Procedure:

<table>
<thead>
<tr>
<th></th>
<th>Seismic Displacement Demand, $\Delta_D$ (ft)</th>
<th>Displacement Ductility, $\mu_\Delta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR21-I69 (Basic)</td>
<td>0.374</td>
<td>3.26</td>
</tr>
<tr>
<td>SR21-I69 (Non. Springs; SMP)</td>
<td>0.302</td>
<td>2.24</td>
</tr>
<tr>
<td>SR21-I69 (Non. Springs; MMP)</td>
<td>0.302</td>
<td>2.42</td>
</tr>
<tr>
<td>Forrester Rd-I69 (Basic)</td>
<td>0.335</td>
<td>2.49</td>
</tr>
<tr>
<td>Forrester Rd-I69 (Non. Springs)</td>
<td>0.25</td>
<td>1.69</td>
</tr>
</tbody>
</table>
Conclusions:

- Basic Support Configuration
- Nonlinear Springs Support Configuration (Single Mode Pushover)
- Nonlinear Springs Support Configuration (Multi-modal Pushover)

Seismic Displacement Demand, $\Delta_D$, (ft)
Conclusions:

- Basic Support Configuration
- Nonlinear Springs Support Configuration (Single Mode Pushover)
- Nonlinear Springs Support Configuration (Multi-modal Pushover)

![Bar chart comparing Displacement Ductility, $\mu_\Delta$, for SR21-I69 and Forrester Rd-I69 between support configurations.]
References:


Thank you for your attention!