Seismic Design of Concrete Bridges

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Midas Bridge Technical Webinar Resource Series

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Figuring It Out with a Growth Mindset

- ’01-’05 B.S. History
  United States Naval Academy, Annapolis, MD
- ’05-’09 Platoon Commander/Company XO
  United States Marine Corps
- ’09-’10 Account Executive
  Orion International
- ’10-’13 M.S. Structural Engineering
  University of California, San Diego
- ’13-’15 Bridge Engineer
  International Bridge Technologies
- ’15-’17 CEO/Co-Founder & Principal Investigator/Co-Inventor
  Structural Fuse
- ’17-Present Bridge Engineer
  Michael Baker International
Agenda

- Seismic Design Overview
  - Bridge Category
  - Philosophy
    - Capacity Protected Elements
    - Earthquake Resisting Elements
    - Sacrificial Elements
  - Analyses
    - Demand
    - Capacity
- Vineyard Ave OC (Replace) over I-10
  - Challenges
  - Bent Connection
  - Midas Seismic Models
- Q&A
Seismic Design References

DoT Guidance
Varies slightly to accommodate local effects and local structure consistency

Caltrans
Seismic specs since 1971 San Fernando Earthquake
FHWA adopted ATC-6 after 1989 Loma Prieta based on Caltrans
SDC since 1999 – AASHTO Guide Specs basis
OEE $3M+ Annual Seismic Research Budget

AASHTO/Imbsen & Priestly
Broadly applicable guidance
Seismic Design Overview – Bridge Category

**Safety Evaluation Earthquake**
5% Probability of Exceedance in 50 years (975-year return period)
i.e. 7% in 75 years (correlates to 75-year bridge lifespan)

**Functional Evaluation Earthquake**
20% Probability of Exceedance in 50 years (225-year return period)
i.e. Expensive

### Caltrans SDC: Table 1.3-1: Seismic Hazard Evaluation Levels and Expected Performance

<table>
<thead>
<tr>
<th>BRIDGE CATEGORY</th>
<th>SEISMIC HAZARD EVALUATION LEVEL</th>
<th>EXPECTED POST EARTHQUAKE DAMAGE STATE</th>
<th>EXPECTED POST EARTHQUAKE SERVICE LEVEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ordinary</td>
<td>SEE</td>
<td>Major</td>
<td>No Service</td>
</tr>
<tr>
<td>Recovery</td>
<td>SEE</td>
<td>Moderate</td>
<td>Limited Service-weeks</td>
</tr>
<tr>
<td>FEE</td>
<td>Minimal</td>
<td>Full Service</td>
<td></td>
</tr>
<tr>
<td>Important</td>
<td>SEE</td>
<td>Minimal to Moderate</td>
<td>Limited Service-days</td>
</tr>
<tr>
<td>FEE</td>
<td>None to Minimal</td>
<td>Full Service</td>
<td></td>
</tr>
</tbody>
</table>

- **Major Damage**
  Bridge Replacement Likely
- **Moderate Damage**
  Bridge Repair Likely – Replacement Unlikely
- **Minimal Damage**
  Essentially Elastic
Seismic Design Overview – Philosophy

Capacity Protected Elements

- Resists Overstrength Moment (Essentially Elastic)
  - Superstructure
  - Foundations (typically)

Sacrificial Elements

- Designed to be Replaced
  - Shear Keys
  - Abutment Backwall

Earthquake Resisting Elements

- Ductility (Deformation > Yield)
  - Local Ductility (Minimum Limit)
  - Global Ductility (Maximum Limit)

- Expected Material Properties
  - Greater than Specified Properties

- Effective Section Properties
  - Iterative Calculation Procedure
  - RC Columns ~0.35 Ig, Bent Cap ~0.70 Ig

- Foundation Flexibility
  - Contributes to Global Drift
  - Remove from Local Rotation Calculations
Plastic Hinges

- Plastic hinges are highly confined finite regions within the ERE that provide its ductile response
- Plastic rotation occurs within a defined length or lengths of the ERE and, combined with elastic displacements, produces total displacement at the superstructure level
Seismic Design Overview – Analyses

Displacement Demand Analyses

• **Equivalent Static Analysis (ESA)**
  - Lumped-Mass Single-Degree-of-Freedom Oscillator

• **Elastic Dynamic Analysis (EDA)**
  - Response Spectrum Analysis (90% Mass Participation)
  - Linear Elastic & Multi-Modal
  - Applied in orthogonal directions, combined with CQC3

• **Nonlinear Time-History Analysis (NTHA)**
  - Useful for Complex Bridge Types
  - Should be checked against simpler method
  - Models soil-structure interaction, joints, multiple support excitations, bearings, and nonlinear soil, material, and hysteretic behavior

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>ANALYSIS METHOD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ESA</td>
</tr>
<tr>
<td>Maximum bridge length</td>
<td>1000 ft</td>
</tr>
<tr>
<td>Maximum skew angle</td>
<td>30°</td>
</tr>
<tr>
<td>Maximum bearing difference between supports</td>
<td>5°</td>
</tr>
</tbody>
</table>

*Table 4.2-1 Applicability of Methods for Displacement Demand Analysis*
Seismic Design Overview – Analyses

Displacement Capacity Analyses

• **Inelastic Static Analysis (ISA)**
  - Incremental Quasi-Static Pushover to Collapse
  - Considers Defined Analytical Plastic Hinges
  - Considers Soil-Structure Interaction

• **Local Displacement Capacity**
  - A simplified ISA for use where ESA is used for Demand
  - Column Elastic Flexibility and Plastic Hinge Deformation Capacity

• **Moment-Curvature Analysis (M-Φ)**
  - Ductile Element Plastic Moment Capacity
  - Considers effects of axial load
  - Considers effective stiffness properties

Ductility Analysis

**Global Ductility** = Bridge Drift / Column Yield Displacement
- Limits Maximum Drift

**Local Ductility** = Column Displacement / Yield Displacement
- ERE’s Required to Achieve Minimum Ductility of 3 or meet minimum transverse reinforcement requirements.

<table>
<thead>
<tr>
<th>Plastic Hinge Location</th>
<th>Seismic Critical Member</th>
<th>Limiting Displacement Ductility Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ordinary Standard Bridge</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SEE</td>
</tr>
<tr>
<td>Substructure</td>
<td>Column in a single-column bent supported on a footing or Type II shaft</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>Column in a multi-column bent supported on a footing or Type II shaft</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>Pile extensions or Type I shaft, plastic hinge at cap/superstructure soft</td>
<td>5.0</td>
</tr>
<tr>
<td>Foundation</td>
<td>Pile extensions or Type I shaft, plastic hinge below ground</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>Pile groups in Class S2 soil, fixed pile to cap connection, plastic hinge on top of pile</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>Pile groups in Class S2 soil, pinned pile to cap connection</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Pile groups in Class S1 soil</td>
<td>*</td>
</tr>
</tbody>
</table>

Caltrans SDC
Vineyard Avenue Overcrossing (Replace)

I-10 Express Lanes Design-Build
San Bernardino County, California

A Unique Seismic Bent Connection
Each project, regardless of bridge type, presents a unique set of challenges. In my experience, the essential foundation of a successful project is TEAM COHESIVENESS. A working culture of open respectful communication within and between coordinating sub-disciplines can save time & cost, quickly uncover and correct mistakes or oversights, and grow each engineer’s broader knowledge base.
Vineyard Ave OC (Replace)

2-Span 222’-8” x 110’-10” Precast/Prestressed Concrete Girder Bridge
Temporary Pedestrian Catwalks Limit Overbuild for Staging

Vineyard Ave OC (Replace)
Variable Support Skews, Complex Horizontal Curves, Variable Girder Lengths & Skews, Variable Width Overhangs
Vineyard Ave OC (Replace)

Vertical Profile High-Point within Bridge, 18” Water Line in 24” Casing required Flex-Tend Couplers & Air Release Valve
Geometry Prevented Economic Post-Tensioning, which drove Unique Extended-Strand Connection of Wide-Flanges

62 Strands/Girder
14 Harped
26 Continuous Stressed
22 Added Unstressed
Columns are Fixed at the Bent and Pinned at the Pile Cap Foundation

NOTE: For information not shown, see "SECTION A-A"

SECTION G-G
\( \frac{1}{2}'' = 1\)'-0"

SECTION A-A
\( \frac{1}{2}'' = 1\)'-0"

SECTION B-B
\( \frac{1}{2}'' = 1\)'-0"

SECTION F-F
\( \frac{1}{2}'' = 1\)'-0"
2 Models were created in Midas for each analysis type
Each based on the Stage Construction Model
Each with varying boundary conditions specific the analysis objective

Seismic Design

Objectives of Seismic Analyses:
1) Show that local ductility at each column exceeds 3.
2) Show that global ductility of the bridge is limited to 5.
3) Ensure displacement capacity could withstand seismic displacement demand.
4) Design columns that possess adequate strength and ductility to resist the seismic demand.
5) Design capacity protected elements based on overstrength moment of the plastic hinges designed in each column.

Seismic Analyses Employed:
Demand – EDA: Response Spectrum Analysis
Capacity – ISA: Pushover Analysis
EDA – Response Spectrum Analysis to determine Longitudinal & Transverse Displacement Demand

- Inelasticity was simulated by reducing member stiffnesses expected to behave nonlinearly
- Effective Stiffnesses were derived from moment-curvature analyses of the ERE’s under iterative axial load
- Multi-Linear Force-Displacement Functions applied at Abutment Bearing Girder-Ends simulating soil stiffness
- Multi-Linear Force-Displacement Functions applied at Bent Footings simulating Foundation Flexibility
ISA – Pushover Analysis to determine Longitudinal & Transverse Displacement & Ductility Capacity

Similar to EDA Model except:

- No lateral resistance provided by the abutments, i.e. Shear Keys and Backwall provide no resistance
- Base of column modeled as free-rotating pin connection with no rotational stiffness
Thank you!

Questions?