Research Supporting Seismic Bridge Design in Alabama
AASHTO T3 – Technical Committee on Seismic Design
June 24, 2019

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Graduate Students:
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Outline

• Seismicity of Alabama
• History of Seismic Research Projects at AU
• Period of Vibration Approximation
• Short Column Ductility Capacity
Alabama Seismicity

Seismic Design Category

- SDC A1 ($S_{D1} < 0.10g$)
- SDC A2 ($0.10g \leq S_{D1} < 0.15g$)
- SDC B

Site Class A & B

Site Class C
Alabama Seismicity

Seismic Design Category
- SDC A1 ($S_{D1} < 0.10g$)
- SDC A2 ($0.10g \leq S_{D1} < 0.15g$)
- SDC B

Site Class D

Seismic Design Category
- SDC A2 ($0.10g \leq S_{D1} < 0.15g$)
- SDC B
- SDC C

Site Class E
Seismic Research Projects at Auburn University

- Influence of the LRFD Bridge Design Specifications on Seismic Design in Alabama
- Update of Bridge Design Standards in Alabama for AASHTO LRFD Seismic Design Requirements
- Simplified and Standardized Seismic Design and Detailing for Alabama Bridges
Approximation of Fundamental Period of Vibration

- Parametric study designed to generate regression-based equations to approximate fundamental period in the longitudinal and transverse direction
- Used bridge geometry from actual Alabama bridges to seed the sample space
- Only applies to Prestressed Concrete Girder Bridges
- Assumed simple span bridges with expansion joints at each support using standard Alabama details
Variables Considered in Parametric Study

- Span Length (35 ft – 140 ft)
- Number of spans (1 – 5)
- Girder Size (Type I, II, III, BT-54, BT-63, BT-72)
- Column Diameter (4 ft, 4.5 ft, 5 ft, 5.5 ft)
- Column Height (5 ft – 55 ft)
- Number of Columns per bent (2, 3)
- Foundation Stiffness (Translational and Rotational)
- Bolt Diameter (1 in, 1.25 in, 1.5 in, 1.75 in)
Variables Considered in Parametric Study

One Span

A

Two Span

A

A

Three Span

A

A

A

B

A

B

Four Span

A

A

A

A

B

A

A

B

A

A

B

B

Five Span

A

A

A

A

A

B

A

A

A

A

B

B
Analysis Model

- **Superstructure**
  - Deck – Elastic Shell Element
  - Girder – Elastic Beam Elements

- **Substructure**
  - Cap Beam – Elastic Beam Elements
  - Columns – Elastic Frame Elements
  - Deep Foundations – Link Springs (from FB Multiplier)
Analysis Model

- Superstructure-to-Substructure Connection
  - Bearing Pad – Link Element
  - Clip Angles and Anchor Bolts – Link Element

- Abutments
  - Assumed Fixed
# Substructure-to-Superstructure Connection Modeling

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<th>Maximum Span Length</th>
<th>Height(ft)</th>
<th>Distance to Fillet (ft)</th>
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</table>
Determination of Fundamental Period of Vibration

- Effective Modal Mass ≥ 0.70
- Period for which Cumulative Modal Mass > 0.70
- Validated using AASHTO Single Mode Spectral Analysis
Single-Span Regression Results

Longitudinal Direction

\[ T_{\text{Long1}} = 0.161 + 0.00553 \times \text{Span}_1 \]

Transverse Direction

\[ T_{\text{Trans1}} = 0.0132 + 0.00302 \times \text{Span}_1 \]

10 Single-Span Bridge Variations
Three-Span Regression Results

Longitudinal Direction

\[ T_{\text{Long3}} = 0.0288 + 0.00205 \times \text{Span}_1 + 0.00349 \times \text{Span}_2 + 0.00703 \times \text{Pierheight}_1 + 0.00610 \times \text{Pierheight}_2 - 0.0420 \times \text{Pier_num} \]

Transverse Direction

\[ T_{\text{Trans3}} = 0.106 + 0.000590 \times \text{Span}_1 + 0.00137 \times \text{Span}_2 + 0.00304 \times \text{Pierheight}_1 + 0.00294 \times \text{Pierheight}_2 - 0.0431 \times \text{Pier_num} \]
Five-Span Regression Results

\[
T_{\text{Long}_5} = -0.139 + 0.00171 \times \text{Span}_1 + 0.00314 \times \text{Span}_2 \\
+ 0.00227 \times \text{Pierheight}_1 + 0.00548 \times \text{Pierheight}_2 \\
+ 0.00876 \times \text{Pierheight}_3 + 0.00707 \times \text{Pierheight}_4 \\
- 0.0714 \times \text{Pier}_\text{num}
\]

65 Five-Span Bridge Variations

\[
T_{\text{Trans}_5} = 0.136 + 0.000193 \times \text{Span}_1 + 0.00214 \times \text{Span}_2 \\
+ 0.00139 \times \text{Pierheight}_1 + 0.00193 \times \text{Pierheight}_2 \\
+ 0.00196 \times \text{Pierheight}_3 + 0.000861 \times \text{Pierheight}_4 \\
- 0.0745 \times \text{Pier}_\text{num}
\]
Ductility Capacity Determination for Short Columns

- Determination of ductility capacity for columns shorter than the current limits in the AASHTO Guide Specification for Seismic Design
Column Displacement Capacity

- **Seismic Design Category B**
  \[ \Delta_C^L = 0.12H_o (-1.27 \ln(x) - 0.32) \geq 0.12H_o \]

- **Seismic Design Category C**
  \[ \Delta_C^L = 0.12H_o (-2.32 \ln(x) - 1.22) \geq 0.12H_o \]

Equations are calibrated for bridge column clear heights > 15 ft
Column Ductility Capacity Parametric Study

- Focused on range of column heights not currently covered in the LRFD Guide Specification
- Utilize nonlinear solid finite element analysis to evaluate ductility capacity of reinforced concrete columns
- Pushover analyses conducted in ABAQUS (3-D solid elements) and SAP2000 (fiber beam elements)
Primary Variables in Parametric Study

- Aspect Ratio, \( h/d \), (3.2 to 10.0)
  - Column Height
  - Column Diameter
- Reinforcement Ratio, \( \rho \), (0.01, 0.025, 0.04)
- Axial Load (0, 0.1\( A_g f'c \))
- Transverse Reinforcement
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<th>Model Name</th>
<th>Column Diameter (ft)</th>
<th>Column Height (ft)</th>
<th>Aspect Ratio</th>
<th>Longitudinal Reinforcing Bars and Ratio</th>
<th>Axial Force (kip)</th>
<th>Plastic Hinge Zone Length (in)</th>
<th>Transverse Reinforcing Spacing (middle, PHZ) (in)</th>
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Abaqus Model

- **Concrete**
  - C3D8R – Reduced integration 8 node 3-D element
  - Inelastic concrete response using Concrete Damage Plasticity Model
  - Limited allowance for tension in concrete was included
- **Reinforcing Steel**
  - 3D Line Element (Beam)
  - Embedded into Concrete
  - Standard reinforcing steel (60 ksi) stress-strain curve including yielding and plastic flow
SAP2000 Model

- Fiber Model using Lumped Plasticity Hinges (P-M-M)
- Length of hinge based on analytical plastic hinge length
- Cover concrete modeled as unconfined concrete
- Core concrete modeled as confined concrete
- Standard reinforcing steel (60 ksi) stress-strain curve
Estimated Ductility Demand

- Ductility Demand Estimation for SDC B = 2
- Ductility Demand Estimation for SDC C = 3

Imbsen, 2006
Determination of Yield Curvature

- Moment-Curvature Response
- First Yield Point (Yielding of reinforcement)
- Yield Curvature $\phi_Y$
Model Comparison to Experiment

![Graph showing model comparison to experiment]
Pushover Analysis Results
SDC B Regression Results

\[ \Delta_L^C = 0.12H_0 (0.59 \ln(x)^2 + 0.69 \ln(x) + 1.01) \quad 0.2 \leq x \leq 0.5 \]
\[ \Delta_C^L = \begin{cases} 0.12H_o (0.88 \ln(x)^2 + 1.03 \ln(x) + 1.52) & 0.2 \leq x \leq 0.3 \\ 0.12H_o (-2.32 \ln(x) - 1.22) \geq 0.12H_o & 0.3 < x \leq 0.5 \end{cases} \]
Conclusions and Summary

• The moderate seismic hazard of Alabama results in design impacts on bridge substructures
• Regression equations based on a parametric study provides a simplified approximation of the fundamental period for regular Alabama bridges
• Regression equations provide ductility capacity for concrete columns that are currently outside the Guide Specification limitations
Questions/Comments/Discussion

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