I-73 Phase 1 Overview

- I-95 to US-501
- $166 Million Construction Cost
- About 5.7 mi of Interstate Hwy.
- 10 Bridges
- Partial Interchange at I-95
Bridge 4B Design

- Ramp from I-95 South to I-73 South
- Crossing over I-95 and I-73
- 2,514 ft. in length
- 8 spans
- Post-tensioned concrete segmental box girder
- Hammerhead piers on drilled shaft groups
- Steel piles at abutments
Geotechnical Design Procedure

- Geotechnical Exploration and Laboratory Testing
- Conduct Site Response Analysis
  - Design Acceleration Response Spectra
  - Design Acceleration Time History Data Sets
  - Analysis of Seismic Hazards
- Design of Bridge Foundations
- Design of Embankments and Retaining Walls
- Foundation Substructure Analysis
  - Dynamic Stiffness and Damping compatible with Superstructure Model
Geotechnical Exploration

• Preliminary (Right-of-way) Phase
  – 5 SPT borings
  – Seismic CPT soundings
  – Deep boring to 500 feet with shear wave velocity measurements

• Final (Construction Plans) Phase
  – Borings at abutments and interior bents
  – Borings at approach embankments and MSE wall locations

• Laboratory Testing
Subsurface Conditions

- 25 to 40 feet of Pleistocene soils
  - Sands with clay and silt
  - Measured SPT from WOH to 26

- 10 to 25 feet of Bear Bluff soils
  - Sands with clay and silt, some fat clay
  - Measured SPT from 3 to 28

- Black Creek soils to bottom of borings
  - Sands and silty sands, low plasticity fines, some cementation
  - Measured SPT from 5 to 86
Site Response Analysis

- SEE and FEE Design Scenarios
- SHAKE Analysis – South Carolina Soils
- Development of site specific Acceleration Response Spectra
  - Horizontal
  - Vertical
- Development of spatially incoherent and spectrum compatible acceleration time histories for SEE
  - 3 sets total
  - Horizontal and vertical components
  - Developed at support locations (abutments and interior bents)
Design Response Spectra : 5% Damping

Bridge 4 Seismic Analysis
Site Response Analysis

Development of Spectrum Compatible Horizontal and Vertical Acceleration Time Histories

- Variability – subsurface conditions
- Spatial variability of motion – wave passage effects
- Incoherency of motion
Design Horizontal Acceleration Response Spectra at GROUND SURFACE
Damping = 5 %

Boring BA-09
Boring BA-10
Boring BA-11
Boring BA-12
Boring BA-13
Wave Passage Effects

- Spatial Variability of Motion
- Incoherency of Motion
Spatial Variability

- Columbia
- Summerville
- Myrtle Beach
- Bridge
Incoherency of Motions

Inhomogeneous soil, USGS soil types A,C $t=2$ sec

(a) Gaussian ground accelerations at $t = 2$ sec

(b) Non-Gaussian ground accelerations at $t = 2$ sec
Seismic Hazards

- Idriss and Boulanger, 2008 Monograph + SCDOT GDM
- Site Specific Demands from SHAKE (CSR)
- Liquefaction and Cyclic Softening
- Seismically Induced Settlements
- Horizontal Movements
- Residual Shear Strengths
- Downdrag loads
- Mitigation at abutments – earthquake drains
Design of Bridge Foundations

- AASHTO LRFD 2010 + SCDOT GDM
- Driven pile group at abutments
- Drilled shaft group at interior bents
- Limit States
  - Service
  - Strength
  - Construction (Strength)
  - Extreme Event
Design of Bridge Foundations

- Group analysis using FB-Multipier
  - Movements: Service
  - Shaft demands: Strength and Extreme Event
  - Equivalent linear stiffness – compatible with superstructure analyses

- Shaft axial resistance
  - AASHTO + SCDOT Resistance Factors
  - Load test data
  - Group effects
  - Downdrag from seismic settlements
FB-Multipier Models
Shaft Axial Resistance – Bent 4
Diameter = 7.0-ft

Bridge 4 Design

![Diagram showing Drilled Shaft Tip Elevation (ft) vs. Factored Axial Resistance, Redundant Design (kips) with two lines representing Strength Limit State and Extreme Event LS with Downdrag.](image-url)
## Drilled Shaft Design

<table>
<thead>
<tr>
<th>Bent</th>
<th>Strength Limit State</th>
<th>Extreme Event Limit State: SEE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum Factored Load (kips)</td>
<td>Minimum Tip Elevation - Strength (ft)</td>
</tr>
<tr>
<td></td>
<td>Construction</td>
<td>Strength</td>
</tr>
<tr>
<td>2</td>
<td>2,406</td>
<td>2,545</td>
</tr>
<tr>
<td>3</td>
<td>2,406</td>
<td>2,545</td>
</tr>
<tr>
<td>4</td>
<td>2,518</td>
<td>2,939</td>
</tr>
<tr>
<td>5</td>
<td>2,518</td>
<td>2,939</td>
</tr>
<tr>
<td>6</td>
<td>2,518</td>
<td>2,939</td>
</tr>
<tr>
<td>7</td>
<td>2,390</td>
<td>2,484</td>
</tr>
<tr>
<td>8</td>
<td>2,390</td>
<td>2,484</td>
</tr>
</tbody>
</table>
Foundation Model for Time History Analysis

- Equivalent static stiffness for SEE loads
  - 6x6 stiffness matrix for group
  - Iterations for compatibility

- Frequency dependent damping
  - Shear wave velocity/Shear Modulus profile
  - Frequency dependent damping ratio/dashpots
  - Horizontal, rocking, vertical and cross-coupling terms
Shear Wave Velocity Model based on SHAKE site-specific analyses models
Shaft Head Damping – Lateral Swaying
Shaft Head Damping – Vertical (Axial)

Graph showing the relationship between damping ratio and frequency.
Seismic Analysis of Superstructure

- Michael Baker Corp. and CDM Smith
  - Response Spectrum
  - Pushover
  - Time History
- Multiple iterations to achieve compatibility between substructure and superstructure models
I-73/I-95 Interchange Bridge 4B

• Questions?