I-40 Mississippi River Bridge Seismic Retrofit Project

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ABSTRACT:

The I-40 Mississippi River Bridge, also known as the Hernando de Soto Bridge, is a steel tied arch bridge carrying Interstate 40 across the Mississippi River between West Memphis, Arkansas and Memphis, Tennessee. This bridge is a vital transportation, commerce, and defense link, being one of only two crossings of the Mississippi River in the Memphis area. It carries approximately 60,000 vehicles daily and is situated at the southeastern edge of the New Madrid Seismic Zone, where three of the largest earthquakes in the Central United States occurred in the early 1800's. Considering the potential for another major earthquake, the Tennessee Department of Transportation (TDOT) and Arkansas Highway and Transportation Department gave priority status to the seismic evaluation and retrofit of the I-40 Bridge and its approaches. TRC was awarded a design contract with TDOT in 1992 to develop plans, specifications and estimate packages for $268 million worth of construction work. TRC’s design has been in accordance with the AASHTO-LFD design specifications and the most recent AASHTO LRFD Seismic Design Guidelines (2007). In 2000, TRC was selected by TDOT to provide construction engineering and inspection services to oversee the retrofit construction from our field office in Memphis. All construction work has been done while maintaining traffic on this major US highway and continues without a single lost time accident. This seismic retrofit project provides a "post-earthquake" lifeline link for emergency vehicles and the general public.

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INTRODUCTION

In 1992, the Tennessee Department of Transportation (TDOT) and the Arkansas Highway and Transportation Department (AHTD) contracted with TRC (formerly Imbsen & Associates, Inc.) to conduct a seismic evaluation and prepare retrofit design PS&E for the I-40 Bridge. In 2000 the project was expanded when TRC began overseeing the retrofit construction. In an effort to take advantage of available funding, the seismic upgrading has been separated into several construction phases as shown in Figure 1. The I-40 Bridge has a total length of 3.3 miles, including the main channel spans, approaches, and ramps. The bridge is comprised of 164 spans, 160 piers, and 10 abutments. The main channel spans consist of five steel box girder spans (2 @ 330’ and 3 @ 400’) and two steel tied arch truss spans (2 @ 900’). The west approach to the channel spans is primarily precast prestressed concrete I girder spans and steel plate girder spans; while the east approach and connecting ramps are entirely welded steel plate girder spans. Due to the significant amount of deterioration in the deck, the Group B structure on the west approach was completely replaced with a new steel plate girder structure (approximately ½ mile in length) and was included in Phase 6 construction.

Figure 1. I-40 Mississippi River Bridge Project
The construction costs for each phase are summarized in Table I below.

### TABLE I. CONSTRUCTION COSTS FOR EACH PHASE

<table>
<thead>
<tr>
<th>Phase</th>
<th>Project</th>
<th>Construction Period</th>
<th>Construction Cost (Millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,3,4 &amp; 5</td>
<td>2000-2002</td>
<td>$31.3</td>
</tr>
<tr>
<td>2</td>
<td>2A</td>
<td>2002-2003</td>
<td>$22.3</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>2001-2003</td>
<td>$5.3</td>
</tr>
<tr>
<td>4</td>
<td>2B</td>
<td>2003-2006</td>
<td>$16.4</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>2004-2008</td>
<td>$23.6</td>
</tr>
<tr>
<td>6</td>
<td>Group A &amp; B</td>
<td>2005-2009</td>
<td>$57.6</td>
</tr>
<tr>
<td>7</td>
<td>6</td>
<td>2009-2011</td>
<td>$17.7</td>
</tr>
<tr>
<td>8</td>
<td>I2 &amp; Ramps</td>
<td>2011-2014</td>
<td>$43.2</td>
</tr>
<tr>
<td>9</td>
<td>Group C &amp; D</td>
<td>2012-2015 (est.)</td>
<td>$51.0</td>
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<tr>
<td></td>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>$268.4</strong></td>
</tr>
</tbody>
</table>

### ALTERNATIVE CROSSINGS

Both the I-40 and the I-55 Mississippi River Bridges are vital transportation and defense links, being the only two crossings of the Mississippi River in the Memphis, Tennessee area, which is a major transportation and economic center in the United States. I-40 provides for much of the nation’s east-west interstate trucking traffic and I-55 accommodates north-south traffic. The I-40 and I-55 bridges are situated at the southeastern end of the New Madrid Seismic Zone, one of the most active seismic zones in the Central United States. TDOT, AHTD and TRC conducted preliminary studies into the bridge’s seismic vulnerabilities. The I-40 bridge shown in Figure 2 was constructed in the 1960’s with little seismic protection. The I-55 Bridge (see Figure 3), which was constructed in the mid-1940’s, has a higher degree of vulnerability than the I-40 bridge. Considering the potential for another major earthquake and closure of the two bridge crossings due to earthquake damage, TDOT and AHTD gave priority status to retrofit the I-40 Bridge.

![Figure 2. I-40 Bridge at Memphis](image1)

![Figure 3. Alternative I-55 Crossing](image2)
SEISMIC HAZARD

The I-40 Bridge is situated at the southeastern edge of the New Madrid Seismic Zone (as shown in Figure 4), one of the most active seismic zones in Central United States. The fault itself runs approximately 120 miles from Illinois to Arkansas, and the full seismic zone covers a much broader area. (In the winter of 1811-1812, three earthquakes, each with estimated magnitudes $M_w = 7.0$, occurred within this seismic zone.) The site condition is characterized by deep soil deposits up to 2500' deep that result in dominant long period motion in the ground input motion. In addition, the potential for liquefaction exists at isolated locations along the bridge. Spatially varying ground motion time histories were developed for the supports. The maximum probable "Contingency Level Earthquake" (2% chance to occur in 50 years, 2500 year return period as shown in Figure 5) of magnitude $mb 7$ from the New Madrid Seismic Zone was the primary seismic event investigated for the project. The earthquake is assumed to occur 40 miles from the bridge site at a depth of 12 miles. See Figure 6 for the Design Response Spectrum.

![Figure 4. New Madrid Seismic Intensity](image)

![Figure 5. Seismic Hazard Curve](image)

![Figure 6. Design Response Spectrum](image)
SEISMIC PERFORMANCE CRITERIA

Seismic performance goals, developed in conjunction with TDOT and AHTD, required that the bridge be designed to remain "operational / serviceable" following the maximum probable "Contingency Level Earthquake" (2500 year return period). The bridge is a vital defense and commerce transportation link. Bridge closures are expected to last no longer than three (3) days. Any damage is expected to be relatively minor and repairable under traffic. The seismic criteria performance may be summarized as follows:

- Serviceable following contingency level earthquake (2500 year return period)
- 2-3 day closure for inspection
- Repairs to secondary components performed under traffic
- Structure functional for emergency vehicles immediately after the earthquake
- Structure operational for general public following inspection

SEISMIC RESPONSE ANALYSIS

The bridges were first analyzed using the existing structure configurations, then reanalyzed for various types of trial retrofit strategies, and finally reanalyzed for the preferred final retrofit strategy. Originally, the bridge was primarily designed for transverse wind forces, not earthquakes. The original design only considered transverse seismic forces of between 2% to 2.5% of gravity so there were many seismic deficiencies in the existing bridge when considering the Contingency Level Earthquake. Three-dimensional analytical models of the structures were developed and a seismic analysis was conducted on the various structures as follows:

Phase 1 & 2, 4: Steel Tied Arch and Steel Box Girder – NEABS (Nonlinear Earthquake Analysis of Bridge Systems, 1991) program. Ground motion input consisted of spatially varying displacement time-histories at the multiple supports. The model also included soil-structure interaction, foundation radiation damping, and foundation rocking.

Phase 3: First half of East Memphis Approach Structure (Project 10) – WinSEISAB (Seismic Analysis of Bridges) program. Response spectrum analysis including “pushover” analysis.

Phase 5 & 7: East Memphis Approach Structure adjacent the tied arch (Group G) – NEABS program. Ground motion input consisting of uniform displacement time-histories at multiple supports. The model also included soil-structure interaction.

Phase 6: Group A existing structure and Group B replacement structure – WinSEISAB program. Response spectrum analysis including “pushover analysis.”


Phase 9: Group C and D existing structures – SAP2000 program. Ground motion input consisting of uniform displacement time-histories at multiple supports. The model also included soil-structure interaction.
RETROFIT STRATEGY

Strength and Ductility

Traditionally, the combination of “strength and ductility” have been the accepted approach to provide maximum seismic resistance. The strength approach provides retrofitting of inadequate bridge components to transfer loads through the entire system (i.e., superstructure, bearings, piers and foundations, etc.) Initially the retrofit strategy for the tied arch and box girder spans maintained all existing steel rocker bearings. These bearings required extensive retrofit strengthening and would be locked in by shear blocks in the transverse and longitudinal directions. This approach required extensive strengthening or complete replacement of numerous components in the superstructure and substructure in order to carry forces through the system. The estimated cost of the initial retrofit strategy escalated, totaling more than $45 million ($95 million 2011 costs) for the main tied arch and box girder spans.

Strength, Ductility and Isolation

With the recent advances in isolation bearing technology, isolation became a viable retrofit strategy for the I-40 bridge. Isolation provided a means to limit the structure forces; however larger superstructure displacements occurred. The force levels were reduced significantly in both the superstructure and substructure and displacements at the tops of the piers were reduced. Less retrofit work was required for the superstructure (50% or greater reduction) and significant reductions in strengthening were obtained for the substructure. More costly modular expansion joints were required at the expansion joints to accommodate the seismic movements from the tied arch spans and its neighboring spans. The estimated cost of the isolation strategy totaled $27 million ($57 million 2011 costs) for the tied arch and box girder spans – approximately a 40% reduction in construction cost from the initial strategy which maintained the existing bearings. Figure 7 shows the friction pendulum bearings that were used on the I-40 structure. The Pier B bearings (9’-2” diameter, Δ=18.75”) have the distinction of carrying the highest axial load (11,300 kips) of any friction pendulum bridge bearing designed to date. Figure 8 shows the installation of the modular expansion joint at Pier C. The modular expansion joints are designed to move ±22” in the longitudinal direction and ±18” in the transverse direction.

Figure 7. Friction Pendulum Bearing at Pier B

Figure 8. Modular Expansion Joint at Pier C
PHASE 5 AND 7 (GROUP G EAST APPROACH)

The Group G East Approach, which is composed of welded steel plate girder spans supported on concrete bent caps and multi-column bents, was divided into two construction phases based on available funding. Phase 5, the substructure retrofit, was constructed from 2004 to 2008 for $23.6 million. Phase 7, the superstructure retrofit, was constructed from 2009 to 2011 for $17.7 million. The location of Phase 5 and 7 from Pier C through Pier E12 are shown in Figure 9 below.

Figure 9. Location of Phase 5 and 7

The retrofit strategy used a combination of strength, ductility and isolation for this portion of the I-40 project. The retrofit strategy consisted of the following work:

Substructure (Phase 5)
- Bent Cap Retrofit / Widening
- Column Strengthening
- Webwall Retrofit
- Footing Retrofit / Enlarged Cap with additional piles

Superstructure (Phase 7)
- Diaphragm / Cross Frame Replacement
- Bottom Lateral Retrofit
- Bearing Replacement – 112 bearings
- Expansion Joint Replacement
- Ramp-NO isolation

Selected details from this portion of the project are shown in Figure 10 through Figure 15. The substructure retrofit at Pier E8, a three-column bent, was selected because it represents a typical bent. The original footing sizes at Pier E8 were 13'-6” by 15'-9” and 4'-6” in depth. The retrofittested footing sizes were 22’ by 24’ and 7'-0” in depth. The reinforcement added to the footings was #11 @ 12” (bottom mat), #6 @ 12” (top mat), and #6 @ 12” stirrups (See Figure 10). The footing at this location had to be demolished and constructed in stages to avoid
unloading the existing piles since the existing piles were being counted on to carry traffic loads on the bridge. Additional 24-inch diameter pipe piles were driven to withstand the seismic uplift forces (See Figure 11). The existing columns at Pier E8 are 5’-6” in diameter. They were strengthened with #11 longitudinal bars (total 40) and ½” thick steel column casings. The final diameter of the strengthened column was 7’-6”. The column strengthening is shown in Figure 12 and the final retrofitted pier in Figure 13. Typical isolator bearings (lead-core rubber) are shown in Figure 14 and a schematic of the joint retrofit at Pier E6 is shown in Figure 15. The lead core rubber isolation bearings are designed to move 16.5 inches in any direction.

Figure 10a. Pier E8 – Footing Retrofit

Figure 10b. Pier E8 – Footing Retrofit (cont.)

Figure 11. Pier E8 – Foundation Demolition and Pipe Piles

Figure 12. Pier E8 – Column Strengthening
Due to the significant amount of deterioration in the deck, the Group B structure on the Arkansas west approach was completely replaced with a new steel plate girder structure which was 2536’ in length and 107’ in width to accommodate three lanes of traffic in each direction. See Figure 16 for the location of the approach structure. The project required phased demolition and construction to maintain two lanes of traffic in each direction. The new structure was a continuous steel I girder bridge consisting of 17 spans with two expansion joints located at Piers 6 and 12. The abutments were seat-type abutments founded on 24 inch diameter pipe piles. Each bent consisted of integral concrete caps, six reinforced concrete columns, and pile cap footings that were founded on 24 inch diameter pipe piles as shown in Figure 17. Modular swivel-type joints were placed at the expansion joints and abutments to accommodate the large
seismic movements (see Figure 18). Seismic analysis and design were in conformance with the site-specific design criteria developed for the project. TRC provided construction oversight of the project. See Figure 19, which shows the staged construction. The total construction cost for the Group B bridge replacement was approximately $45 million.

Figure 16. Location of Group B (Structure Replacement)  
Figure 17. Typical Section of New Bridge Structure  
Figure 18. Modular Expansion Joint at Pier 12
CONCLUSION

The I-40 Bridge is only one of two crossings of the Mississippi River in the Memphis area and is a vital link for transportation, commerce and defense. Considering the potential for another major earthquake and closure of the two bridge crossings, the Tennessee Department of Transportation (TDOT) and Arkansas Highway and Transportation Department (AHTD) gave priority status to retrofit the I-40 Bridge and its approaches. The seismic retrofit project will increase the seismic resistance for this designated “lifeline” structure to enhance the long-term safety of the public. Isolation bearings were a key element for a cost effective and structurally safe retrofit design.

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REFERENCES

South Carolina Department of Transportation (SCDOT), Seismic Design Specification for Highway Bridges, October 2001, as amended by October 2002 Interim errata.