

POPLAR STREET BRIDGE REHABILITATION AND WIDENING



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BIOGRAPHY

Gregory Kuntz, P.E. is Bridge Section Manager in HDR's St. Louis office. Greg is a graduate of the University of Missouri-Rolla and the University of Kansas. Greg has nearly 20 years of experience in the management, design and construction of highway bridge projects, including numerous major river crossings and complex rehabilitations.

Cory Imhoff, P.E. is a Vice President, Project Manager and Senior Bridge Engineer for HDR with over 20 years of experience in the industry, 18 of which have been at HDR in Kansas City. Cory serves as HDR's Missouri-Kansas Area Transportation Business Group Manager and has structural expertise in major river spans over the Missouri and Mississippi Rivers as well as complicated urban interchanges.

Ryan Shaw, P.E. is a bridge engineer in HDR's St. Louis office. He is a graduate of the University of Missouri-Columbia and has 6 years of experience in the design of highway bridge projects.

Stacy McMillan, P.E. is a Structural Liaison Engineer with the Missouri Department of Transportation. Stacy is a graduate of Kansas State University. In Stacy's current position he provides project management and expertise in structural matters pertaining to the design, maintenance, construction and inspection of Missouri highway structures.

SUMMARY

The Poplar Street Bridge is 50 year old five span (300'-500'-600'-500'-265') 2165' long structure which carries I-64, I-55 and I-70 over the Mississippi River in downtown St. Louis and connects Missouri and Illinois. The bridge has twin Eastbound and Westbound superstructures consisting of two variable depth steel box girders (25' max. depth) with an orthotropic steel deck on a shared substructure.

The Missouri Department of Transportation hired HDR to provide the following improvements to the Poplar Street Bridge: 1) Increase lane capacity of the EB Bridge from 4 to 5 lanes in conjunction with improving interchange ramp structures on the Missouri side, 2) provide a new and improved riding surface and 3) Rehabilitate the structure.

A unique aspect of the project was the sliding of the existing bridge. In lieu of a traditional widening, the eastbound superstructure was successfully slid 9' to the south onto widened piers on March 31, 2018 over the course of 2.5 hours and was widely reported as the 2nd longest bridge slide ever in the United States by length. The eastbound and westbound superstructures were then connected together using a concrete deck on a stringer-floor-beam type cross frame system which added redundancy and improved the performance of the structure.

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Introduction

The Missouri Department of Transportation (MoDOT) recently completed a major project to improve the I-64/I-55/I-70 interchange in downtown St. Louis. A portion of this project included the widening and rehabilitation of the Poplar Street Bridge over the Mississippi River. Figure 1 illustrates the project location.



Figure 1: Project Location

The project is one of several associated with the larger Mississippi River Bridge project which includes the construction of a new Mississippi River Bridge to the north, relocation of I-70 off the Poplar Street Bridge to the new bridge, removal of the I-70 ramps and construction of dual northbound to eastbound ramp to the Poplar Street Bridge. There were regional concerns with the loss of access from the proposed removal of the southbound to eastbound ramp to the Poplar Street Bridge (Ramp B), however analysis showed that any alternatives where the ramp was to remain caused MoDOT concerns with traffic congestions, safety issues and project budget.

HDR proposed to the regional governing agency a solution where the southbound to eastbound ramp would be removed as planned but a direct connect link would be constructed from the east terminus of the MLK Bridge to Rte. 3 in Illinois (westbound to southbound) to preserve access between downtown St. Louis and Illinois, see Figure 2. Another operational constraint was the four eastbound lanes of the Poplar Street Bridge itself, as any option that attempted to approach the bridge with five lanes was

shown to suffer from the merging of heavy traffic streams. HDR proposed a solution to widen the eastbound Poplar Street Bridge to five lanes (3 thru lanes and 2 lanes merging from new northbound to eastbound ramp) utilizing a bridge slide in lieu of a conventional widening to significantly reduce costs.



Figure 2: MLK Connector

Since the Poplar Street Bridge would be widened as part of the interchange improvements, MoDOT took the opportunity to include a major rehabilitation of the bridge to the scope which included: Providing a new wearing surface, repairing fatigue cracks in the structural steel, installing new seismic isolation bearings and repairing concrete piers. HDR provided the design for the widening and rehabilitation of the Poplar Street Bridge and the Illinois approach bridges.

The overall interchange and rehabilitation project was broken into two phases in cooperation with MoDOT and IDOT, see Figure 3 for a schematic of the work performed. The first phase was completed in 2015 and included:

- Construction of the MLK Connector
- Removal of the southbound to eastbound ramp
- Reconstruction (improved geometrics) of the westbound to northbound ramp and westbound to southbound ramp
- Installation of new driving surface on the westbound Poplar Street Bridge



Figure 3: I-64/I-55/I-70 Project Work

The second phase was completed in 2018 and included:

- Reconstruction of the northbound to eastbound ramp to a two lane ramp
- Installation of new driving surface on the eastbound Poplar Street Bridge
- Widening (via slide) of the eastbound Poplar Street Bridge from 4 to 5 lanes
- Widening of the Illinois approach bridges to the Poplar Street Bridge
- Rehabilitation of the Poplar Street Bridge and Illinois approach bridges

Project Goals

The goals of the interchange project, specifically related to the Poplar Street Bridge, were to reduce congestion, improve safety and upgrade the condition of the structure. To relieve congestion, the eastbound bridge was widened from four lanes to five lanes by sliding the eastbound bridge to the south on its existing supports. The safety of the bridge was improved by providing this additional eastbound lane and by replacing the existing wearing (driving) surface. Finally, the condition of the bridge was upgraded by rehabilitating the existing bridge superstructure, bearings and substructure.

Bridge Description

The Poplar Street Bridge is a five span (300'-500'-600'-500'-265') 2165' long structure which carries I-64, I-55 and I-70 over the Mississippi River in downtown St. Louis and is the most highly traveled route that connects Missouri and Illinois. The bridge

has twin eastbound and westbound superstructures each consisting of two variable depth steel box girders (25' max. depth) with an orthotropic steel deck on a shared substructure. The orthotropic steel deck with a thickness ranging from 9/16" to 3/4" serves as the top flange of the box girders. The wearing surface or overlay which serves as the riding surface is placed directly on the orthotropic steel deck plate. The original wearing surface was a 2.5" layer of asphalt. The bridge was built in the 1960's and has undergone numerous mill and overlays over the years and a seismic retrofit in early 2000's. The pre-widened configuration of the bridge included 4 lanes of traffic eastbound and westbound with a 104' roadway and 113' out-to-out. See Figure 4 for General Elevation, Plans and Typical Section of the bridge.

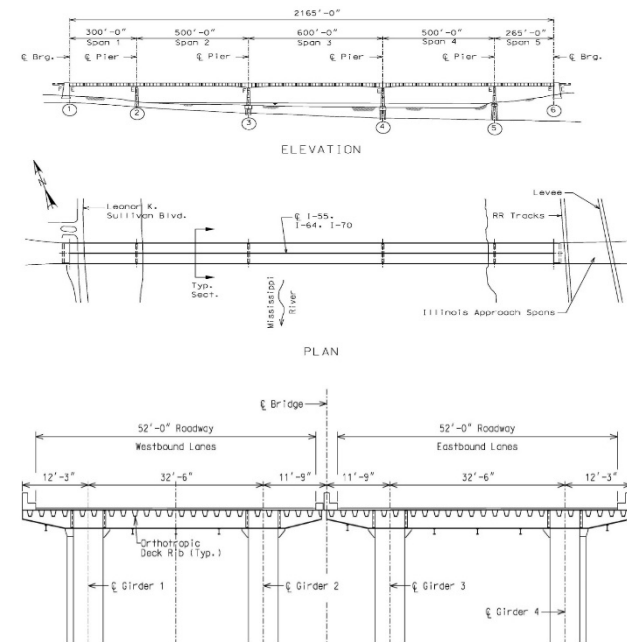


Figure 4: Bridge Elevation, Plan & Typ. Section
Bridge Widening & Slide

To ensure the operational improvement of the I-64/I-55/I-70 interchange, the Poplar Street Bridge needed to be expanded from 4 lanes to 5 lanes in the eastbound direction (3 thru lanes plus 2 lanes from the reconstructed northbound to eastbound ramp). A conventional widening of the Bridge had been contemplated numerous times, but was always deemed cost prohibitive due the new girder needing to match the stiffness of the existing box girders. This would result in a significant overbuild, extremely difficult fit-up and additional pier and foundation

work in the River.

With the proliferation in recent years of accelerated bridge construction, bridge slides and bridge roll-ins, HDR proposed to slide the existing eastbound Bridge superstructure 9' to the south on its existing supports and connect the WB and EB superstructures together. This concept was significantly less expensive than a conventional widening and also (through the connection of the superstructures) transformed the two 2-girder superstructures into a single 4 girder bridge, thereby adding redundancy to the structure. Figure 5 shows the basic concept of the slide.

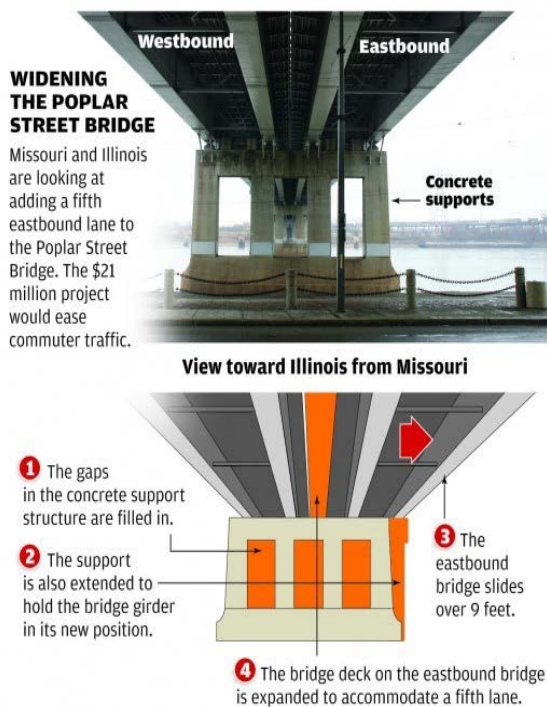


Figure 5: Basic Bridge Slide Concept

HDR confirmed that the existing substructure and superstructure elements were sufficient for the additional live load from the 5th eastbound lane. Connecting the superstructures together improved the performance of the girders as the live load was distributed across to the westbound girders. The connection or “infill” between the westbound and eastbound superstructures consisted of a lightweight concrete reinforced deck supported on a steel sub-stringer-floor-beam system as shown in Figure 6. Continuity was maintained between the infill and the orthotropic steel deck plate by embedding a studded channel into the concrete deck which was bolted to an angle welded to the underside of the orthotropic steel

deck plate.

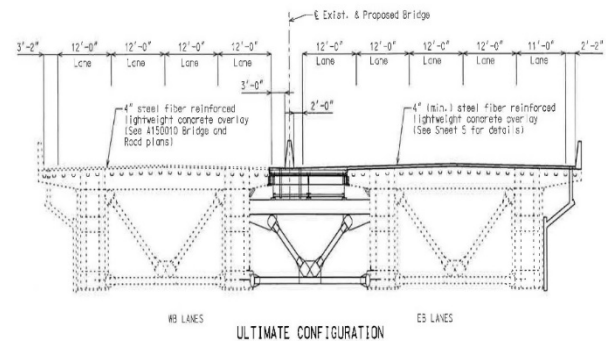


Figure 6: Structural Steel Infill

The existing piers were modified to accommodate the widened and translated bridge and checked to ensure they had enough capacity for the additional 5th lane of traffic. In the existing condition the four girders were located directly on top of the four columns and the pier cap beams were only required to support their self-weight. With the translation of the two eastbound girders 9' to the south, the cap beam had to be supported with a concrete infill between the two southern columns as Girder 3 would now rest on the cap beam between the columns. For symmetry, the infill cap beam support infill was also installed between the other columns. The cap beam cantilever was extended to the south 9' to accommodate the translation of the existing south fascia Girder 4. The south exterior column was widened as a ledge to support the extended cap cantilever. Even with this support, the cantilever extension was designed conservatively as if there was no support and utilized post-tensioning bars thru the extended cap and embedded in the existing cap beam. Figure 7 shows Pier 5 after it has modified to receive the translated superstructure.

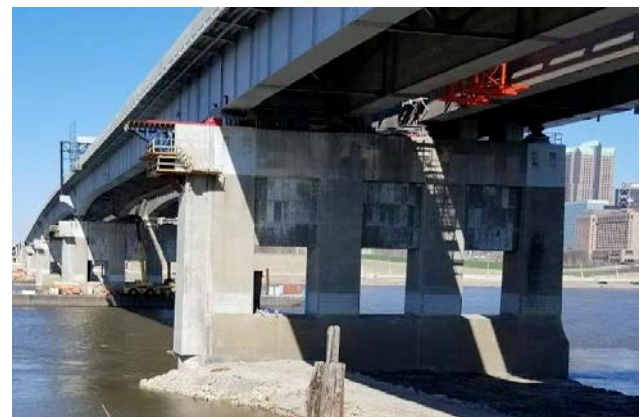


Figure 7: Pier 5 Modifications for Slide

The slide of the Poplar Street Bridge took place on March 31, 2018. The 2165' 20.4 million pound bridge constituted the 2nd largest bridge ever to be slid in the United States trailing only the Milton-Madison Bridge over the Ohio River connecting Indiana and Kentucky. It is the longest and heaviest existing bridge to be slid in the United States. In the preceding weeks under live traffic the two eastbound girders were lifted off their existing bearings at all six piers by vertical jacking onto a temporary support system.

The girder and temporary support system were lowered onto the slide or skid beams which were placed within the slide or skid tracks. Horizontal jacks were placed in the skid tracks to push the slide beam and translate the girders. Teflon pads were placed within the skid tracks to reduce friction and ease the movement of the slide beam. Figure 8 shows the slide track system.



Figure 8: Slide Track System

The eastbound bridge was closed for the weekend of the slide to eliminate live load traffic during the translation. The biggest challenge was to ensure that the rate of movement of the bridge was uniform at all six piers. Since the dead load reaction at each pier is different, the jacking force at each pier needed to be different and carefully coordinated to ensure uniform movement. This was especially critical prior to the girders overcoming friction and “breaking loose” to ensure that the girders began moving at the same time and the same rate.

The slide itself took approximately 2.5 hours, with 30 minutes to break the girders loose at the piers and then 2 hours to complete the 9' translation. Once the girders overcame friction the jacks would push the

slide beams over the Teflon pads at approximately 18” increments. It would take about 1-2 minutes to move the bridge the approximate 18” increments, then the process would stop for 15-20 minutes to re-stroke the pistons and make sure the girders at each pier were aligned and the crews were ready to continue. Figure 9 shows the bridge just after the slide with girders in their new location.



Figure 9: Post-Slide at Pier 2

After the eastbound bridge was translated to the south the steel infill was constructed to connect the westbound and eastbound structures together. Field drilling and slightly oversized holes were utilized to facilitate fit-up of the new steel to the existing girders and floor-beams. Connection members, such as WT's with 12” stems, were used to increase field tolerances as much as possible.

One challenge for fabrication and erection of the infill steel was accounting for the differential deflection of the westbound and eastbound structures. Due to the crown shift of the eastbound structure from the slide, the roadway crown was no longer at the same location as the crown of the orthotropic steel deck plate. This results in a variable depth overlay which at the north side of the eastbound bridge is thicker than the constant overlay of the westbound bridge. The connection members, floorbeams and stringers all had to be fabricated to account for the resulting differential deflection. Another challenge was that the infill steel all had to be fabricated early in the schedule, so field measurements post-slide were not available to aid in determining member dimensions. Figure 10 shows the partial installation of the structural steel infill. Once the structural steel was installed the lightweight concrete slab was poured,

thereby completing the widening of the eastbound bridge to 5 lanes.



Figure 10: Structural Steel Infill

Bridge Overlay

The second goal of the Poplar Street Bridge project was to provide a new overlay (or wearing surface) to the bridge to solve the numerous and persistent failures of recent overlays and to minimize future maintenance and repair needs over the remaining life of the bridge. The overlay on the bridge serves the critical function of providing the riding surface of the structure with failure leading to unsafe driving conditions. It also contributes to the overall stiffness of the deck system (even though this was not intended as a function of the original design) with failure leading to increased flexibility of the deck system and making the orthotropic steel deck plate susceptible to fatigue cracking.

The original wearing surface on the bridge was 2.5" thick although for recent overlays it was 2.5" thick at the expansion joints at the end piers and transitioned to 0.5" for the majority of the bridge. A 0.5" polymer concrete overlay was installed in 2006 and in 2013 it began to fail, de-bonding from the orthotropic steel deck in many locations. When saturated in hot conditions the overlay was extremely flexible and could be easily pulled off the steel deck plate. Figure 11 shows this failed overlay system.

Numerous overlay failures like this over the years have contributed to near-continuous extreme congestion on the bridge and safety issues with drivers riding directly on the orthotropic steel deck plate. These overlay failures have also led to the overall reduction in the stiffness of the deck system which may have contributed to fatigue cracking in the

orthotropic steel deck plate, ribs and floor-beams.



Figure 11: Failed Overlay

Initially HDR investigated using either a 2.5" layer of Epoxy Asphalt Concrete or a 2.5" layer of Polyester Concrete which would be chemically bonded to the orthotropic steel deck plate. However, research (1) of previous testing indicated that the stiffness of both of these materials is significantly reduced with high temperatures. Figure 12 shows a plot of the apparent modulus or stiffness of the material vs. temperature. Once the temperature reaches 80°F the modulus is less than 200 ksi for the polyester concrete and even lower for the epoxy asphalt. The air temperature in St. Louis in the summer time is routinely over 90°F and with this being a steel structure, the surface temperatures are even hotter, likely approaching 120°F or more. These materials would reduce the overall stiffness of the deck system making the deck plate susceptible to cracking.

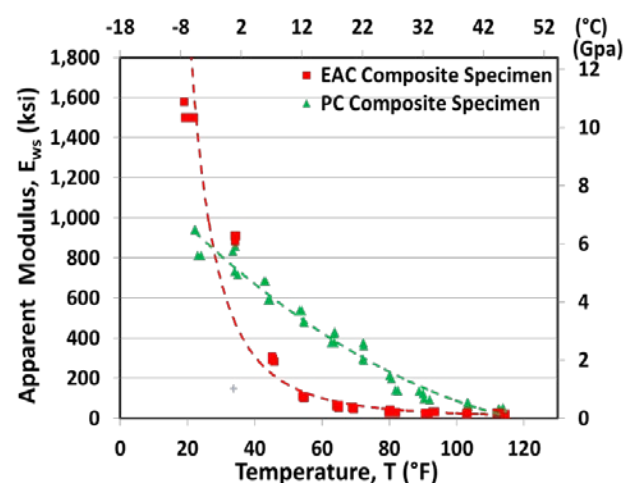


Figure 12: Stiffness vs. Temperature

HDR proposed an alternative solution to these

overlay materials: A 4" steel fiber reinforced lightweight concrete overlay with a layer of mild steel mechanically connected to the steel deck plate using end welded shear studs. The 4" thickness was needed because a 2.5" overlay without mild steel is susceptible to failure in high tensile areas and if mild reinforcement were added then there would be clearance and concrete consolidation issues. Since the proposed overlay is thicker than the original and existing overlays the existing superstructure and substructure capacities were checked for the additional dead load. The additional dead load was mitigated somewhat by using lightweight concrete with a density of 120 pounds per cubic foot. A benefit of using this concrete overlay is that it utilizes conventional analysis and construction methods. The steel fibers were included for durability to provide an improved riding surface and ensure sufficient deck stiffness for a 30-40 year life with minimal maintenance.

The steel fiber reinforced lightweight concrete overlay was installed using the following steps:

1. Remove existing wearing surface via heating and scraping
2. Repair gouges in the orthotropic steel deck plate caused by previous milling by filling weld material or cover plates
3. Blast clean the orthotropic steel deck and remove chloride ions
4. Install cover magnets on deck plate in shear stud grid pattern prior to metalizing for future stud welding to base metal
5. Zinc metallize orthotropic steel deck plate
6. Install shear studs to steel deck (over 1,000,000 in total)
7. Install epoxy coated mild reinforcement one layer in each direction
8. Mix, pour and finish steel fiber reinforced lightweight concrete

Since the bridge work was performed as part of phased construction the reinforcement was mechanically coupled together with reinforcement in the adjacent stage. Figure 13 shows the bridge prior to, during and after the lightweight concrete overlay was installed.

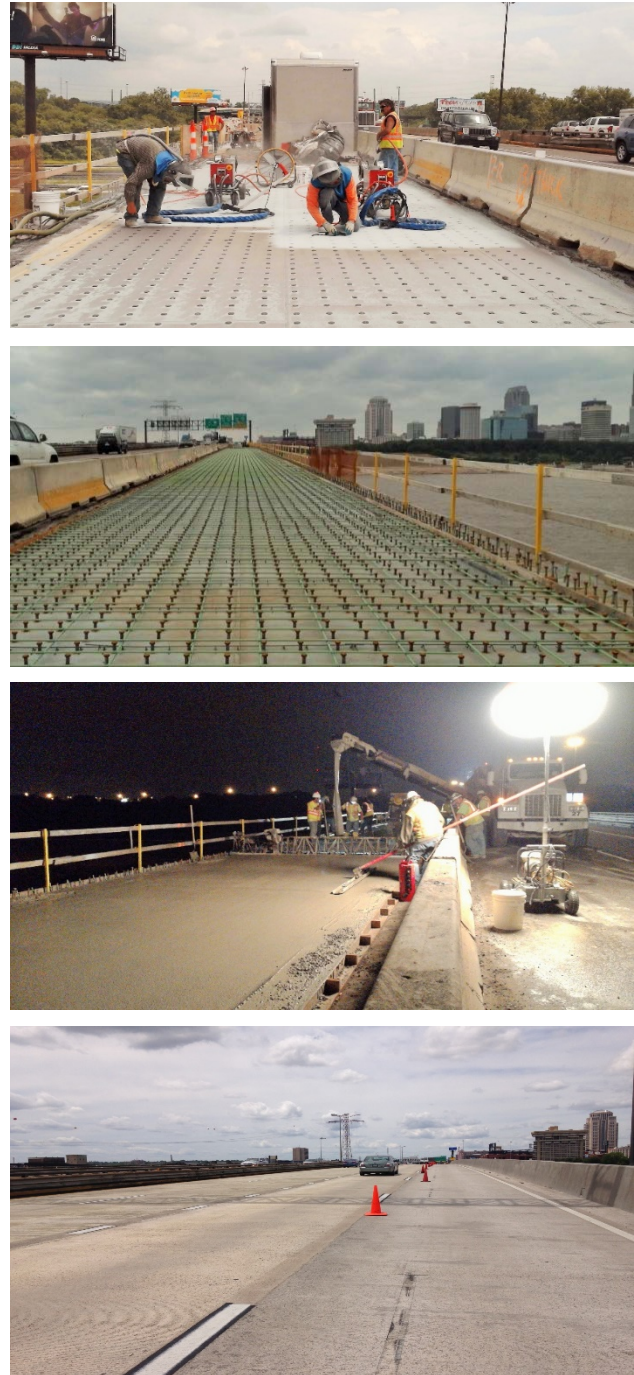


Figure 13: Overlay Installation

Rehabilitation

The third goal of the Poplar Street bridge project was to rehabilitate the existing main river bridge and Illinois approach bridge. HDR performed an in-depth and fracture critical inspection of the structures including the deck surface, orthotropic steel deck, interior and exterior of the girders, bearings, joints,

paint system and substructure units. One of the critical findings of the inspection was the numerous (over 100) fatigue cracks observed in the orthotropic steel deck plate to rib weld. Some of these had propagated into the web of the rib, with most occurring near floorbeam locations. While the average crack length was about 6", some had grown up to 60" maximum in length. Figure 14 shows a large fatigue crack that began in the deck plate to rib weld and propagated into the web of the rib.



Figure 14: Fatigue Cracking

HDR proposed repairing these cracks by drilling arrest holes and fabricating bolted cover plates connected to the underside of the steel deck plate and the rib web via welded threaded studs. HDR then investigated possible causes of this cracking. Figure 15 shows a chart of the crack locations plotted transversely along the width of the bridge. The length of the bars is relative to the number of observed instances of cracking.

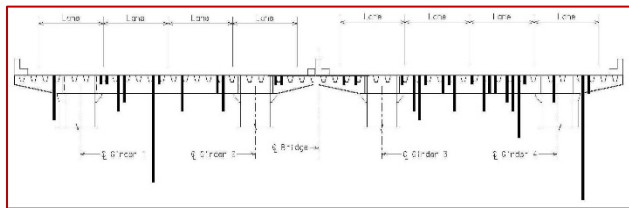


Figure 15: Fatigue Crack Locations

The chart seems to indicate the locations of the cracks generally correspond to the wheel line locations. There is more widespread cracking seen on the eastbound bridge likely due to additional weaving movements. The location of the cracks at the deck plate to rib welds near the wheel lines indicate that the flexibility of the deck system between the ribs is contributing to the cracking. The previous thin and de-bonded overlays were contributing little or no

stiffness to the deck system. Without stiffening the deck system with a thicker and more reliable overlay, the cracks would likely continue to develop and progress. As stated previously, HDR proposed a 4" steel fiber reinforced lightweight concrete overlay mechanically connected to the deck to stiffen up the deck system to aid in preventing further crack development. The 4" overlay was installed on the westbound lanes in 2015 but not until 2017 on the eastbound lanes. The existing cracks were not repaired until 2018. During the 2016 inspection there was significantly more crack development on the eastbound bridge compared to the westbound bridge. This may indicate that the thicker overlay and stiffer deck system is helping to contribute to the reduction of crack development and progression.

Another important rehabilitation need was the existing geared bearings. The inspection observed little evidence of paint wear on the gears indicating the bearings were not performing as intended, they weren't moving under thermal displacements. Also, the shock transmission units (STU's) installed as part of the 2000's seismic retrofit project showed signs of leaking fluid. Figure 16 shows the existing geared bearings and installed STU's.

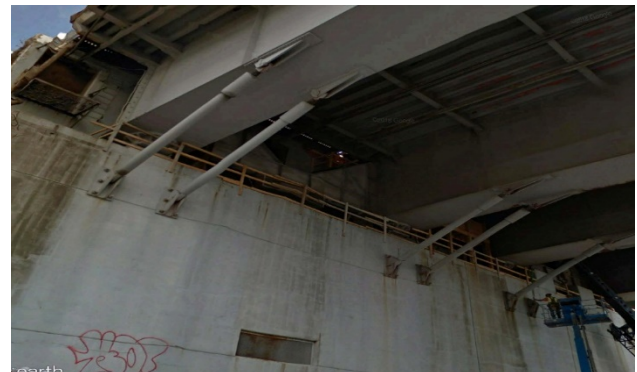
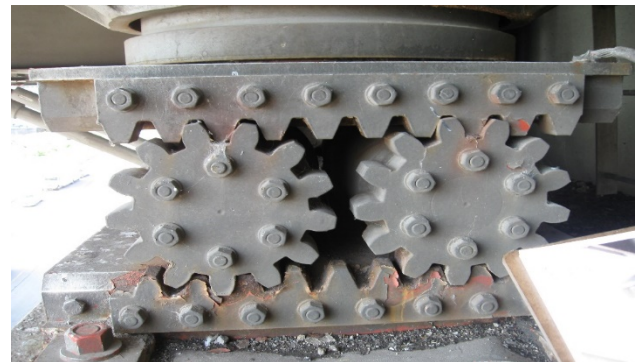


Figure 16: Existing Bearing and STU's

The concern of potential poor performance of the

STU's led MoDOT to remove 4 of the in-service units to send to the manufacturer's lab for verification testing with third party observation. The testing confirmed that 1 of the 4 STU's had leaking fluid and did not pass verification testing resulting in the potential for a lack of adequate response under seismic loading. Figure 17 shows the leaking STU in the lab prior to verification testing.



Figure 17: Existing Leaking STU

There were 64 existing individual STU's on the bridge located at expansion Piers 1, 2, 4, 5 & 6, with two for each girder in each span adjacent to the particular pier. Since 25% of the tested STU's failed verification, there was concern that costly laboratory or field testing of every STU would result in the in-service replacement of 16 units. HDR proposed instead to remove the all of the existing STU's and replace the existing bearings with lead core seismic isolation bearings. The thermal and seismic stiffnesses of the isolation were specified in the contract documents with prototypes developed for verification. The existing pier and foundation capacities were checked for wind, thermal and seismic forces based on the specified bearing stiffnesses.

The existing bearings of the westbound superstructure were replaced under live traffic while the eastbound bearings were installed prior to the slide so they were in place when the girders were moved from their existing location. Figure 18 shows the new seismic isolation bearing under Girder 2 of the westbound bridge at Pier 1. Pier 1 is approximately 1400' from the point of thermal origin of the bridge. This picture was taken in January of 2018 with an air temperature of approximately 5°F. This actual displacement of isolation bearing of

approximately 4.5" matched very closely to the theoretical displacement based on the temperature and bearing stiffness.



Figure 18: Seismic Isolation Bearing

Conclusions

The reconstruction of the I-64/I-55/I-70 interchange was a critical part of the overall MoDOT Mississippi River bridge project in downtown St. Louis. As part of the project the Poplar Street Bridge needed to be widened to improve the operational characteristics of the interchange. In lieu of a conventional widening, the 2165' eastbound structure over the Mississippi River was slid 9' to the south on its modified existing supports to widen the bridge for a critical 5th lane. The eastbound and westbound superstructures were then connected together to transform the separate two girder bridges into a more redundant four girder structure. The bridge slide was the 2nd longest ever in the United States and longest for an existing bridge.

Also as part of the project, the existing overlay on the Poplar Street Bridge was replaced with a 4" steel fiber reinforced lightweight concrete overlay mechanically connected to the steel deck plate via shear studs. This new overlay not only provides a reliable low maintenance riding surface, but also increases the stiffness of the deck system. The stiffer deck system is less susceptible to fatigue cracking in the deck plate to rib weld. A final portion of the project was a major rehabilitation of the Poplar Street Bridge and Illinois approaches. Rehabilitation included new expansion devices, painting, structural steel repairs, bearing replacement, pier repair and total bent replacements. Figure 19 shows a view of the completed Poplar Street Bridge.



Figure 19: Completed Poplar Street Bridge

Acknowledgements

The authors would like to thank the contributions from the following participants involved in the widening and rehabilitation of the Poplar Street Bridge:

Owners: Missouri Department of Transportation (MoDOT) and Illinois Department of Transportation (IDOT)

Lead Contracting Agency: Missouri Department of Transportation (MoDOT)

Engineer of Record (Main Span): HDR

Engineer of Record (Illinois Approach): ABNA

General Contractor: KCI Construction

Slide Contractor: Mammoet

Structural Steel Fabricator (Infill): DeLongs

References

1. Gopalaratnam, V.S. and Chamarthi, R (2012). "Evaluation of Wearing Surface Systems for the Orthotropic Steel Deck of the San Mateo Hayward Bridge", Final Report No.: MU Gopalaratnam 12-02 to the California Department of Transportation (Project 59A0742), 151 pp.