

Existing Simple Steel Spans Made Continuous: A Retrofit Scheme for the I-476 Bridge over the Schuylkill River

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Abstract

The rehabilitation of the SR 476 Bridge over the Schuylkill River near Philadelphia, Pennsylvania, converted existing steel multigirder simple spans into three- and four-span continuous units. Employing a design method typically used for construction of new simple-span-made-continuous (SSMC) steel girder bridges, it is believed to be the first bridge rehabilitation project in Pennsylvania to use such a scheme. The rehabilitation design upgraded load capacity of the girders to meet current LRFD code requirements. The SSMC design, coupled with other deck joint elimination techniques, was able to reduce the combined number of deck joints on the northbound and southbound structures from 25 to 8. With nearly all previous steel deterioration occurring at deck joints, this substantial reduction in deck joints will aid in extending the remaining life of the bridge. This paper will illustrate the construction methods employed for conversion of the bridge from multiple simple spans to continuous spans. The paper will also provide detailed insight into the many design requirements for this structural conversion, from substructure retrofits and sequential bearing replacements to superstructure continuity and full-depth concrete diaphragm details.

Keywords: simple-span-made-continuous (SSMC), bridge rehabilitation, modified fixity conditions, steel wedge plates, bolted steel splice plates, full-depth concrete diaphragm, staged construction, sequential bearing replacement, steel bolsters.

INTRODUCTION

AECOM was tasked by the Pennsylvania Department of Transportation (PENNDOT) District 6-0 to perform the rehabilitation design for the Schuylkill River Bridge (Figure 1) as part of the SR 476, Section RES Project. The bridge rehabilitation included the removal of the existing noncomposite concrete deck and replacement with a new composite concrete deck (see Figure 2). The rehabilitation also included the repainting of all structural steel and structural steel repairs required to upgrade the structure to meet current design code requirements. The rehabilitation of the southern approach spans of both the northbound and southbound structures is the focus of this paper.

DESIGN REQUIREMENTS

PENNDOT District 6-0 requested that AECOM investigate eliminating deck joints by providing continuity in the steel multistringer approach spans on the northbound and southbound structures. Several state bridge departments

have begun utilizing SSMC construction techniques for new steel bridges over the past several years. The techniques were developed in an effort to make medium-span (100-ft to 140-ft) steel bridge designs cost competitive against prestressed concrete simple-made-continuous bridges. The cost advantage for SSMC construction is often realized in the speed and simplicity of girder erection (Azizinamini, 2004; Talbot, 2005; NSBA, 2006).

The techniques developed simplify the formation of continuous structures by eliminating the need for conventional bolted field splices, but also work to improve structural efficiency and long-term durability as compared to simple-span construction with numerous deck joints. While the SSMC concept has been used for the design of new steel bridges, its use as a rehabilitation strategy is a relatively new concept to the bridge industry. While the concepts may appear to be relatively simple on the surface, numerous design checks were required to accomplish this bridge rehabilitation scheme.

SUBSTRUCTURE ANALYSIS AND REVISED FIXITY CONSIDERATIONS

The first step in assessing the feasibility of making the simple-span approach spans continuous was to perform an analysis of the existing substructures and foundations to determine their capacity to resist the new loading and fixity conditions created by making the simple spans continuous.

The southern approach spans for the northbound bridge include three 119-ft simple spans, and the southbound

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southern approach spans include four 103-ft simple spans in their existing configuration (see Figure 3). In an effort to eliminate as many deck joints as possible, AECOM began by investigating a four-span-continuous unit and a three-span-continuous unit for the southbound and northbound approach spans, respectively. In each case, an arrangement

that restrained the superstructure in the longitudinal direction at a single “fixed” pier was analyzed: pier 1 southbound and pier 1 northbound. Note that pier 1 southbound is actually the second interior support within the southernmost proposed four-span unit.

Analysis of the existing piers and foundations was



Fig. 1. I-476 northbound and southbound over the Schuylkill River.



Fig. 2. Approach spans: seven-stringer cross-section during half-width redecking.

performed using AASHTO design criteria (AASHTO, 2004). Seismic analysis and retrofits were not part of the scope of this project; therefore, load cases III through VI were the critical load combinations for verifying the structural adequacy of the existing piers under the new proposed loading conditions. Continuity resulted in redistributed longitudinal braking forces to the fixed piers and new thermal loading conditions to all of the substructure units. These increased longitudinal forces, combined with increased vertical loads at the interior supports of the continuous units, were used for the analysis of the existing piers.

Analysis of the piers proved to be an iterative process between bearing design and pier analysis. Because the proposed northbound fixed pier was not centered within its multispans unit, unequal thermal forces induced at the ahead-station and back-station expansion bearings were resolved at the fixed pier. Elastomeric bearings were designed for all of the supports along the three-span northbound unit. In order to reduce the thermal forces to an acceptable level at the fixed piers, low friction bearings were provided at pier 3 northbound. Elastomeric bearings equipped with PTFE/stainless steel sliding surfaces were utilized for this application. Standard reinforced elastomeric bearings were designed for the remaining substructure units. Once the bearings were designed, substructure analysis was then begun; the analysis

demonstrated that the existing substructures and foundations could support the new load conditions.

STEEL STRINGER ANALYSIS AND CONTINUITY DESIGN

The analysis of the existing stringers and the continuity design also required a multistep process. The first step included investigating various alternatives for continuity details over the interior supports for the bridge rehabilitation project. The design requirements associated with making simple steel beams continuous are similar to the design requirements associated with field-splice design—moments and shears must be carried through the detail. The SSMC design must ensure that forces can be adequately carried through the joint without overstressing elements, particularly the concrete elements. Three alternatives for achieving these design requirements were investigated.

The first alternative investigated a Colorado Department of Transportation detail. In this detail, the compressive forces in the stringer bottom flanges are taken by two mated trapezoidal plates, called wedge plates, through the joint between the bottom flanges of the two adjacent beams (see Figure 4). The wedge plates are at least the thickness of the stringer bottom flanges and are installed in the gap to



Fig. 3. Southbound approach spans: existing simple-span condition.

provide a tight fit connection between the bottom compression flanges of the adjacent-span stringers. As dead loads are added to the bridge, bottom flange compression is transmitted through the wedge plates, locking the system in place and establishing a continuous steel bottom flange.

The longitudinal reinforcing bars in the deck slab are then designed to take the tensile forces, similar to the practice used for prestressed concrete bridges designed for continuity. If additional tensile capacity is required, a bolted top flange plate joining the adjacent beams is provided. For this detail, the deck slab must be designed to carry any net shear force across the gap in the beams. The net shear force is any shear that is not directly transferred from the webs of the steel girders into the bearings.

The second alternative was a variation of a continuity detail used by the Tennessee and Nebraska Departments of Transportation. The detail is similar to alternative 1, but includes the addition of a full-depth concrete diaphragm closing the open gap between the webs of the two adjacent stringers. The concrete diaphragm aids in providing additional rigidity in the detail, as well as transferring net shear through the joint. Similar to alternative 1, steel wedge plates are installed between the bottom compressive flanges of the adjacent beams. The thickness of the wedge plates is sized to carry the steel-beam, bottom-flange compression. The wedge plates also serve to minimize compressive stress in

the concrete diaphragm, thereby preventing crushing of the concrete between the girders. Similar to alternative 1, the longitudinal reinforcing bars in the deck slab, or a bolted top flange plate, would be designed to transfer the tensile force through the continuity detail.

The third alternative considered the use of steel flange and web connection plates to splice over the gap, similar to a conventional steel-field splice. This alternative would require a large number of field-drilled bolt holes, making this alternative very labor intensive and cost prohibitive. This alternative would also require the removal and replacement of the existing bearing stiffeners. The fact that the existing girders are kinked at the centerline of the interior supports would only add to the cost of fabricating and installing this continuity detail alternative. For these reasons, this alternative was eliminated from the investigation early on in the design process.

Based on the results of the alternatives study, AECOM proposed alternative 2 as the continuity detail for final design. Alternative 2 was ultimately selected by PENNDOT due to the inclusion of a full-depth concrete diaphragm, particularly for ensuring the long-term durability and structural performance for this interstate highway bridge. See Figure 5.

Once the continuity detail was selected, the next step in the superstructure design was to analyze the existing stringers for the SSMC condition. This analysis was performed



Fig. 4. Wedge plates between bottom flanges of adjacent-span stringers (Section RES construction photo).

by superimposing noncomposite moments and shears with composite dead load and live load moments and shears. The results of our analysis showed that the stringer flanges alone were inadequate to support negative moments over the interior supports.

The stringers—noncomposite in their existing condition—are proposed to be composite as part of the bridge rehabilitation. The composite girders provided ample positive moment capacity but were insufficient in the negative moment region for the proposed loading condition. AECOM, therefore, proposed the installation of a bottom-flange cover plate between the bottom flange of the existing stringers and new bearing assemblies.

The design for this project required that a top-flange splice plate be used with the longitudinal reinforcing bars in the deck slab to transfer the tensile forces through the continuity detail. The top-flange splice plate used a single-shear, bolted connection to join the stringer from the adjacent span. Similar to the bottom-flange cover plates, the top-flange splice plates were extended as required to function as bolted cover plates. The detailing of the flange splice plates required another unique design for this project. The approach spans lie within a curved horizontal alignment, with the existing straight stringers chorded to frame the stringer around the curve. The chorded framing results in the stringers having

a slight kink at their interior supports. In an effort to reduce fabrication costs, the splice plates were detailed as oversized rectangular plates with skewed lines of bolts, eliminating the need for fabrication of unique splice plates for each stringer support location, as shown in Figure 6.

The final continuity elements designed were the full-depth concrete diaphragms over the piers. A combination of transverse reinforcing steel passing through field drilled holes in the girder webs and shear studs welded to each side of the webs provided the way of locking the full-depth diaphragm and stringer together, enhancing continuity, as well as providing the means for transferring shear through the joint, as shown in Figure 7.

BEARING REPLACEMENT

Another unique aspect of this SSMC rehabilitation design was determining the feasibility of bearing replacement, particularly for staged deck reconstruction. This rehabilitation involved half-width re-decking for each direction. The construction specifications required the contractor to replace all bearings prior to first stage deck demolition. This requirement was so that all bearings along any given bearing line would all have the same capacities for load, translation and rotation.



Fig. 5. Formwork for full-depth concrete diaphragm (Section RES construction photo).



Fig. 6. Bottom-flange cover plate with skewed bolt lines.



Fig. 7. Reinforcing and shear studs on stringer webs for full-depth concrete diaphragm.

Another important design consideration is the sequence in which the bearings are replaced. The designer must consider temporary construction conditions, such as the changes in fixity conditions and thermal movement range for the new and existing bearings during sequential replacement of all the bearings within the multispan units, and the contract documents need to include a scheme outlining the order in which each support line would be replaced. This scheme ensured that all bearings would stay within their functional range for stresses and thermal translation during each step of replacement, as shown in Figure 8.

Steel bolsters were designed to maintain the same girder profile as the structure transitions from high-profile rocker bearings to elastomeric bearings, as shown in Figure 9. The use of steel bolsters was selected over reconstruction of the concrete bearing pedestals, enabling the contractor to replace all seven bearings within a given line in one overnight bridge jacking operation.

Steel bolsters also provided an efficient means for transitioning from two bearing lines to one bearing line at interior supports of the multispan units, while maintaining traffic over the structure during construction. The bolsters were designed for upward reactions from the new bearings, as well as for maximum downward shear from each side of

the new interior support. This design was accomplished by detailing the steel bolsters to transmit bearing reaction from the new elastomeric bearing into the girder's existing bearing stiffeners. The bolster was also designed to transmit maximum shear forces from the existing girder-bearing stiffeners (offset from the centerline of the new bearing) into the new bearings, as shown in Figure 10.

CONCLUSIONS

The rehabilitation of the SR 476 Bridge over the Schuylkill River near Philadelphia, Pennsylvania, converted existing steel multigirder simple spans into three- and four-span-continuous units. Employing a design method typically used for construction of new SSMC steel girder bridges, this rehabilitation design upgraded load capacity of the girders to meet current LRFD code requirements.

The SSMC design, coupled with other deck joint elimination techniques, was also able to reduce the combined number of deck joints on the northbound and southbound structures from 25 to 8, as shown in Figures 11 and 12. With nearly all previous steel deterioration occurring at deck joints, this substantial reduction in deck joints will work to significantly extend the remaining life of the bridge.



Fig. 8. Jacking and temporary support of bridge for bearing replacement.



Fig. 9. Elastomeric bearings with steel bolsters.

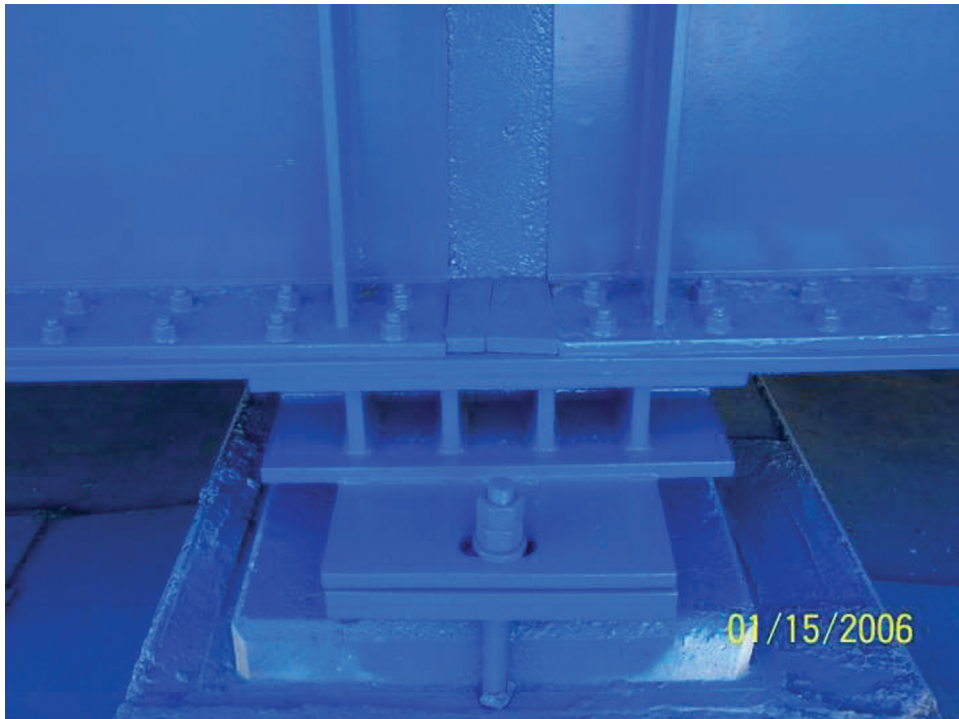


Fig. 10. Bolsters and concrete diaphragms transmit reactions to bearings.



Fig. 11. Completed northbound three-span structure.



Fig. 12. Reduced number of deck joints.

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