SELLWOOD BRIDGE REPLACEMENT PROJECT

Eric Rau, PE

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BIOGRAPHY

Eric Rau is a Senior Bridge Engineer for T.Y. Lin International with over fifteen years of experience. He has provided engineering services on a variety of projects ranging in complexity from rural county road bridge replacements to signature transportation structures, with a heavy emphasis on steel structures. Mr. Rau was the Engineer of Record for the steel deck arch component of the Sellwood Bridge Replacement Project.

David Goodyear is the Chief Bridge Engineer for T.Y. Lin International. Mr. Goodyear has worked with public agencies and contractors across the nation during his 43-year career, on small rural projects as well as large urban projects with a particular focus on arch, segmental, and cable-stayed bridge design, foundation engineering, and waterfront structures. This engineering experience includes a full spectrum of bridge design, from small stream and pedestrian bridges to large cable-stayed bridges and major foundation works. Mr. Goodyear served as the Chief Bridge Engineer responsible for the design of the Sellwood Bridge Replacement Project.

SUMMARY

The original 1925 Sellwood Bridge across the Willamette River was the only four-span continuous deck truss highway bridge in Oregon. The busiest two-lane bridge in the state, carrying 30,000 vehicles each day, the bridge provided a vital link to the Portland community. In 2005, the bridge received a National Bridge Inventory sufficiency rating of 2 out of a possible 100. Critical issues included both roadway geometrics and structural deficiencies, many of which were the result of landslide movement at the west end of the project.

Multnomah County, Project Owner, launched a three-year National Environmental Policy Act planning process in 2006 that resulted in the replacement project.

The signature feature of the new bridge is a three-span steel deck arch across the Willamette River. These arch spans have a total length of 1275-ft and are composed of 5,000 tons of structural steel.

T.Y. Lin International was the Prime Consultant for the final design phase and, as Engineer of Record for the steel deck arch bridge, provided engineering services throughout construction. The project was administered by Multnomah County and delivered via the Construction Manager/General Contactor method. The replacement bridge was opened to traffic on February 29, 2016.

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INTRODUCTION

Constructed in 1925 to replace the Spokane Street Ferry, the original Sellwood Bridge was an important east-west link across the Willamette River. With an average daily traffic count of 30,000 it is the busiest 2-lane bridge in the state of Oregon. Figure 1 shows the project site a few miles south of downtown Portland.

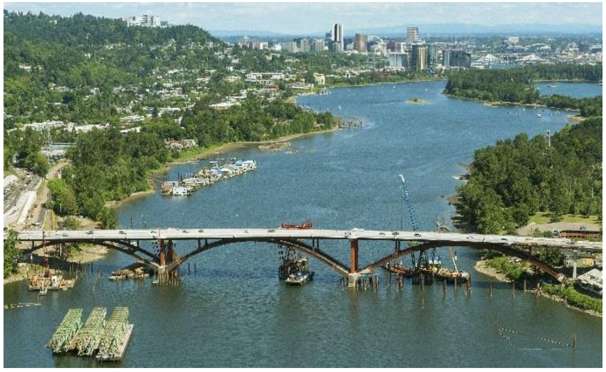

Figure 1: Sellwood Bridge South of Portland

Gustav Lindenthal, a renowned bridge engineer of his era, designed a unique and structurally efficient 4-span continuous 1,091-foot-long steel Warren Truss. The bridge was only 32-feet wide, and unlike other Portland bridges of its time it was not designed for relatively heavy streetcar loads. To minimize costs further, the bridge was located at the narrowest section of the river.

The west end of the project, consisting of concrete approach structures and a truss span foundation, had been constructed in an ancient landslide. Movement resulted in a three-foot segment of bridge deck being removed in 1960 and a complete reconstruction of the west approach structure in 1980. Extensive cracking in the girders of the approach spans was discovered in 2003, prompting the County to reduce the allowed weight limit for vehicles crossing the bridge from 32 tons to 10 tons.

In 2006, Multnomah County (County), Project Owner, launched a three-year National Environmental Policy Act (NEPA) planning process to evaluate rehabilitation and replacement options. The replacement option analyzed numerous structure types, traffic and pedestrian configurations, and roadway and interchange alignments.

Portland is known for its bridges and a commitment to utilizing public engagement to shape its communities. For this project, a Community Advisory Committee (CAC) was formed to represent public interests. The committee included local residents, Willamette River users, and business owners. The CAC scored the alternatives developed by the engineering team using criteria such as cost, aesthetics, environmental impacts, function and configuration, and construction risk. The evaluation resulted in the CAC's recommendation for a steel deck arch bridge on the same alignment as the original bridge, which was reviewed and approved by the County's Board of Commissioners.

Using 5,000 tons of structural steel, the new, 1,976.5-foot-long Sellwood Bridge - 1,275 feet of which comprises the signature steel deck arch- features three arch spans that support the 63- to 90-foot-wide deck of the main river spans. The bridge carries two 12-foot-wide vehicular lanes, two 6.5-foot-wide bike lanes/emergency shoulders, two 12-foot-wide shared-use sidewalks, and is designed to accommodate future streetcar service. As shown in Figure 2, aesthetic treatments such as architectural lighting were a high priority for the project based on public feedback via the CAC.

Figure 2: Completed Sellwood Bridge at Night

Project Delivery

The County selected Slayden/Sundt Joint Venture as the Construction Manager/General Contractor (CM/GC) and the design team of T.Y. Lin International (TYLI), Prime Consultant, Final Design, and subconsultant CH2M. During the NEPA Phase of the project, CH2M was Prime Consultant, with TYLI serving as the Lead Structural Engineer responsible for bridge design alternatives. For Final Design, TYLI served as both Engineer of Record for the replacement bridge and Project Manager with CH2M as a sub consultant. As Project Manager, TYLI oversaw bridge, roadway, architectural, electrical, environmental permitting, geotechnical, and landslide stabilization design teams; led the project's Quality Control program; and performed roadway and traffic design support and construction engineering support services.

The project included the replacement bridge, modernization of the Highway 43 interchange, and stabilization of the hillside located west of the bridge and interchange.

BRIDGE DESCRIPTION

The steel deck arch structure has a span arrangement of 385 ft - 425 ft - 465 ft, which progresses from west to east across the river generally following the profile of the roadway. The cross-section consists of north and south arches, which are welded box sections with a constant web depth of 70 inches, a flange width of 54 inches, and a smooth parabolic curve profile. Each arch span supports four spandrel columns, which coincide with the location of the vierendeel bracing between the two ribs.

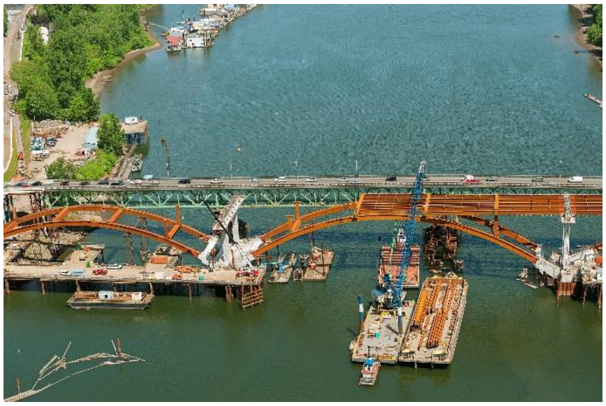

Figure 3: Steel Framing

Both the original truss bridge and new arch bridge have only two through traffic lanes. This was the CAC recommended configuration from the environmental impact statement (EIS) stage, driven by the request from the Sellwood community to restrict traffic to two lanes to match the capacity of Tacoma Street to the east. While the existing bridge had an overall structure width of 32 ft, the new structure provides 6.5-ft shoulders, designated bike lanes and raised 12-ft sidewalks on each side of the bridge. The result is a pedestrian-friendly structure that has a nominal width of 63 ft. The structure width increases on the western half of the bridge to 90 ft, allowing for additional turn lanes to and from Highway 43.

The floor system is composed of welded I-shape longitudinal steel girders and transverse cap beams supported at the spandrel columns. The girders and cap beams have a constant structural depth of 5 ft and are composite with the concrete bridge deck. The girders comprise a 15-span continuous framing system over the 1,275-foot-long arch structure, with five to seven girder lines spaced up to 14 feet, 6 inches. Figure 3 shows the steel framing with the girder system only partially erected.

Based on cost feedback from the CM/GC, welded spice plate transition between cap beams were not used. Flange plate width varied based on structural demand, but was held constant within a spandrel span, and constant plate thickness were used for the entire floor system.

As shown in Figure 4, fixed end girder connections are provided at the transverse cap beams. Girder flanges are connected with continuity plates and a traditional clip angle is provided at the web. The cap beam has an internal diaphragm at the girder line, and the entire connection is bolted. At the request of the CM/GC slotted holes at specific girder locations were used to increase tolerances for fit-up during erection.

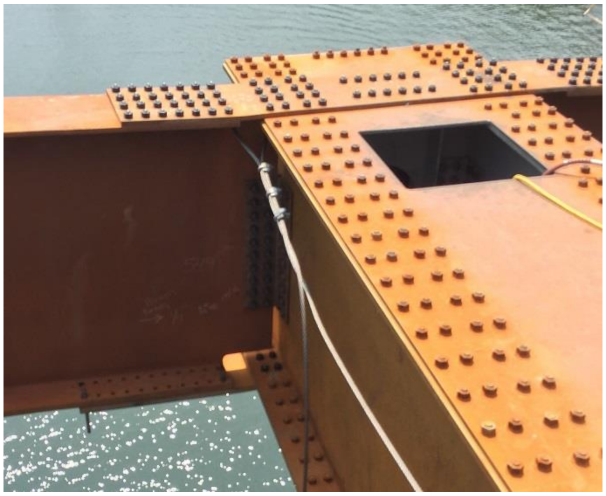

Figure 4: Girder to Spandrel Cap Connection

The transverse cap beams are built-up box-shape members composed of two welded I-girders with top and bottom cover plates. The entire assembly is bolted to eliminate the possibility of crack propagation throughout section, and the design accounts for the loss of either I-shape or cover plate.

Bridge Articulation

Establishing the articulation of the spandrel columns was an important aspect of the design. Design iterations evaluated various configurations of “pinned”, “fixed” and “free” boundary conditions of the twelve column locations, with the primary challenge being to balance structure stiffness and load path during seismic and thermal response. The final articulation provides unidirectional bearings at the top of spandrel columns in the two flanking arch spans and fixed end-plate moment connections for the columns in the center arch span. These fixed columns function similarly to a closed arch crown, while the deck structure is free to move at the ends.

The spandrel columns welded boxes with outside dimensions of 42-inch by 36-inch and plate thickness that varies between 1.25 to 2 inches. The connection of the spandrel columns to the arch rib is a fixed end-plated moment connection that utilizes 1-1/2-in diameter A490 bolts.

Substructure and Springing Connection

Reinforced concrete Y-arms extend from the pier and footing substructure to locate the steel arch rib springing connection above the 100-year flood stage. Figure 5 shows the Y-arms at an interior bent, where extensions are up to 36 feet long and follow the curved geometry of the arch.

The fixed springing connection consists of ten 4-in.-diameter ASTM A354 Gr. BC high-strength steel. The rods are anchored 15 feet into the Y-arms, and rods are post-tensioned to service level demands and grouted for corrosion protection.

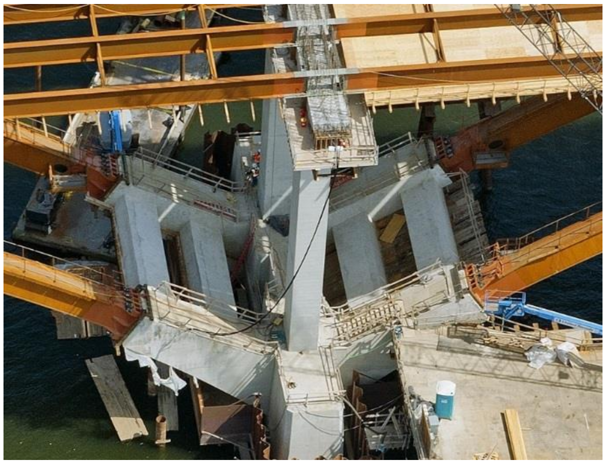

Figure 5: Y-Arm Extensions from Substructure

For the two in-water piers, TYLI developed an innovative “perched foundation.” Drilled shafts frame directly into the pier walls, which were constructed in a box caisson “perched” 15 feet above the riverbed. The general configuration during construction is shown in Figure 6. Eliminating the need for larger conventional footings and the associated cofferdams, this modification significantly reduced cost and construction risk associated with river bottom conditions and enabled year-round construction, thereby avoiding limited in-water work windows. The environmental footprint of the foundation was also minimized and a no-net rise hydraulic condition was achieved.

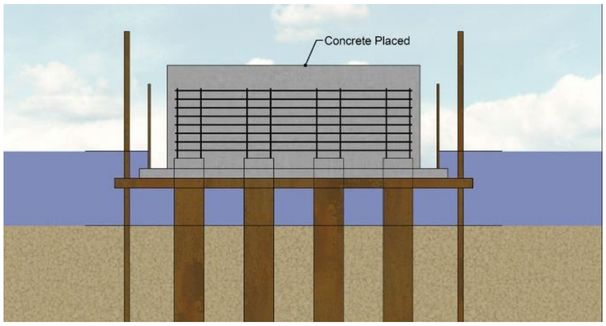

Figure 6: Perched Pier and Cofferdam Schematic

The steel deck arch structure is supported by a total of twenty-two 10-foot diameter drilled shaft spread over the four foundations. Shaft are founded in bedrock with tips located up to 155-feet below the riverbed. Drilled shaft reinforcing is A706 Grade 80, with two layers of #18 vertical bars required to meet demand levels.

Arch Structure Geometry

Bridge geometry was established to meet local site conditions. The replacement bridge had to provide a horizontal and vertical navigational opening that met or exceeded that of the old structure. The arch layout had to provide uninterrupted river navigation during construction with the existing truss bridge foundations, temporary detour structure foundations, and anticipated temporary works for the Contractor in-place. These considerations established the horizontal location of the new foundations, while vertical arch geometry was limited by the necessity to provide a similar roadway profile as the existing bridge in order to limit project extents at west and east connections to existing infrastructure. The required roadway profile ascended from west to east, which combined with varying roadway width meant that arch spans could not be in balance geometrically. The three arches have a rise-to-span ratio that varies from 1:7.7 (0.13) in the west to 1:6.4 (0.16) in the east, which is evident in Figure 7. Arch framing was scaled to trend with the profile, which provided needed balance for the differential thrust across interior piers.

This same geometry for a deck arch resulted in rather shallow arches, shallower than structurally optimum for a deck arch. Bending moments from dead load for fixed arches would have dominated the arch size, creating a heavier arch profile. Through an innovative use of advanced UHMW plastic hinges, TYLI designed the arch ribs to be pinned during construction, allowing rotation of the rib springing. Springing connections are bolted and grouted at completion of the construction to provide continuity for live and seismic loadings.

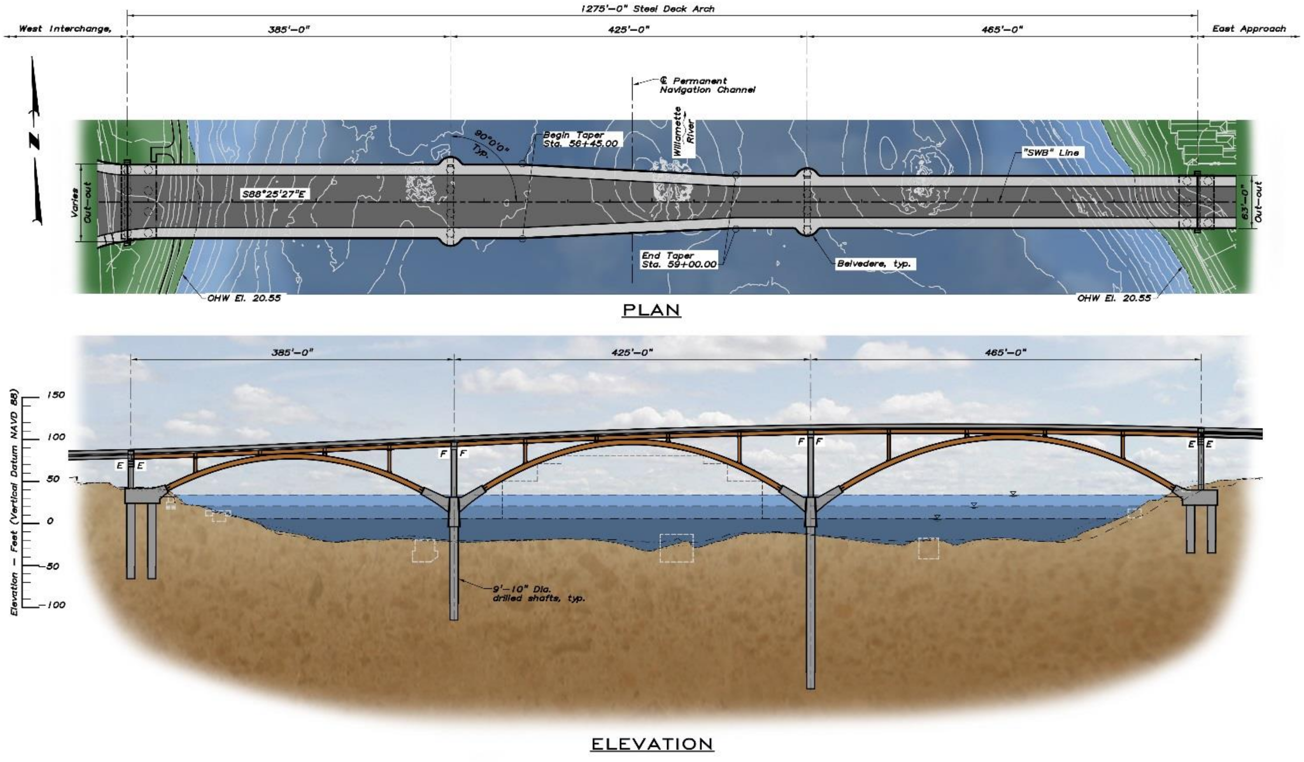

Figure 7: Plan and Elevation Views of Three Span Steel Deck Arch

Future Streetcar Design Basis

The project was designed to accommodate the future addition of streetcar service. To accept future track installation, streetcar alignments were established across the project site and the concrete bridge deck was locally thickened up to 22 inches. This additional thickness provides an upper portion that is removable and a lower structural zone that remains in place. The anchorage of the bridge luminaire poles is designed for larger demand levels of the streetcar's Overhead Catenary System. Other features include an enhanced stray current grounding system and blockouts for future system conduit routing. The bridge design included streetcar vehicles in addition to the full suite of AASHTO-defined live loads.

Landslide Mitigation and Seismic Design

The design team developed an innovative approach to landslide mitigation, combining geotechnical design with a foundation design that provided the stability needed to support the deck arch against the west hillside. Using advanced imaging systems and 3D modeling, the design team analyzed the ground slide area, which measured 800 feet from the hillside down to the water level, 500 feet wide, and 50 feet deep. The solution, a slope stabilization anchored shear pile system, included boring 40 six-foot-diameter shafts vertically to depths of 56 to 88 feet and using 70 prestressed ground anchors drilled diagonally to depths of 85 to 110 feet into bedrock. The stabilization system interacts with the 10-foot-diameter drilled shafts of the arch foundations to counteract any further slide movement. A model view of the mitigation system, along with foundations for the interchange and arch bridges, is shown in Figure 8. While other landmark projects around the world have dealt with landslide movements, few if any others include a true arch bridge design solution in addressing landslide movement.

The new Sellwood Bridge was also designed to be able to operate through a 500-year earthquake, where the bridge must remain in service with only moderate repairs, and to withstand a 1000-year earthquake, where the structure must have the strength to survive an extreme earthquake with acceptable damage. The design included multiple seismic events, including a moment magnitude scale (MMS) 9.0 Cascadia Subduction Zone earthquake, to define the seismic hazard.

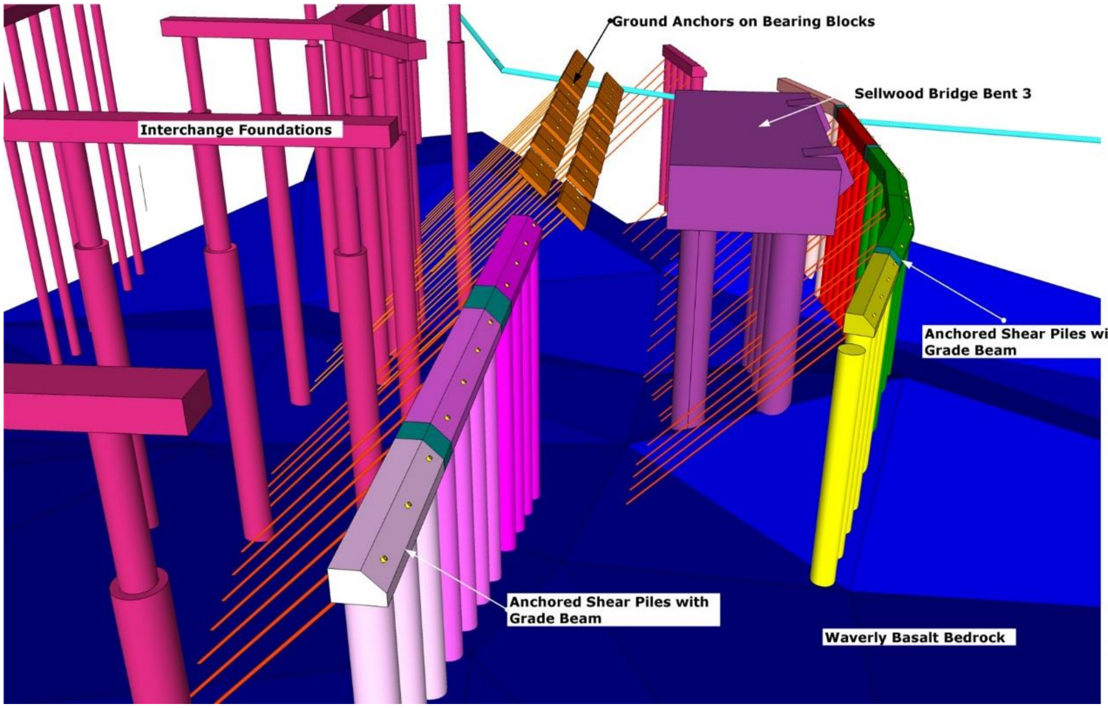

Figure 8: Landslide Mitigation System

Steel Erection

The Vancouver, Washington-based steel fabricator, Thompson Metal Fab, proposed piece-by-piece stick erection for the steel deck arch, with arch ribs placed on shoring towers rather than the float-in system originally considered in design for arch erection. Each rib span contained two bolted field splices to match the optimum weights chosen by the CM/GC for fabrication and erection. This resulted in three segments per span, with segment lengths of up to 148 feet and weights of up to 146 tons each. Steel was transported to the site on barges and placed with cranes operating from work bridges and barges.

Shoofly Detour

A significant challenge for the project team was to replace a major transportation route with minimal traffic disruption. The original plan was to build the replacement bridge in two halves, using the existing span for traffic while the southern half of the new bridge was built first. Once the southern half was completed, traffic would shift onto it, allowing demolition of the old bridge and construction to begin on the northern half of the new bridge. Drawbacks for the split staging included the need for additional arch ribs for each stage, extensive staging to keep traffic moving and increased construction time and costs.

Figure 9: Detour Alignment During Construction

An alternative solution was developed by the design team and the CM/GC. Once temporary piers were erected north of the existing bridge piers, the entire 1,091-foot-long steel deck truss of the old bridge, comprising four continuous deck truss spans, was slid over on rails to a detour alignment using hydraulic jacks. The horizontal distance of the move was 66 feet at the west end and 33 feet at the east end. Temporary approach spans at both ends of the truss were also constructed. The existing bridge in its shoofly alignment is shown in Figure 9.

This innovative solution enabled the replacement bridge to be built in one phase on the original bridge footprint. Benefits included eliminating the need for staged construction; reducing the number of arch ribs from four to two; freeing up the existing alignment for work crews; enhancing public safety by removing traffic from the construction zone; and reducing bridge closure time to only six days. The County also saved up to a year in construction time and as much as $10 million in project costs.

CONCLULUSIONS

Featuring the noteworthy use of fabricated structural steel, the Sellwood Bridge was successfully delivered under a compressed timeframe for a CM/GC contract. The Sellwood Bridge is the first steel deck arch bridge in the City of Portland. Bridge architecture satisfies the public’s desire for a clean, aesthetic signature crossing, with multiple belvederes offering scenic views from the river spans. The final design features two travel lanes, based on public demand for a structure that reflects the scale of the Sellwood neighborhood and matches the capacity of Tacoma Street to the east. The new bridge also underscores local communities’ commitment to sustainability and alternative modes of transportation, providing efficient connections for bicyclists and pedestrians and restoring bus traffic. The Sellwood Bridge opened on-schedule to great public fanfare on February 29, 2016.

Figure 10: Completed Bridge