SCANNING, PLATING, AND HEAT-STRAIGHTENING, OH MY! (REPAIRING AND STRENGTHEN-ING MEDIUM SPAN TRUSSES)

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BIOGRAPHY

Steve Olson is the Principal Bridge Engineer and President of Olson & Nesvold Engineers, P.S.C. (O.N.E.) in Bloomington, Minnesota. He received his engineering degrees from the University of Minnesota.

Prior to starting O.N.E. in 2009 he held engineering positions with: Burgess & Niple, Limited (Columbus, OH), The National Steel Bridge Alliance (Minneapolis, MN), HNTB Corporation (Minneapolis, MN), and the MAST Laboratory at the University of Minnesota.

He has 30 years of bridge engineering practice in addition to adjunct teaching. For 14 years he taught a graduate school course on *"Bridge Management, Maintenance, and Rehabilitation"* at the University of Minnesota

SUMMARY

Tools for designers to use as they approach truss rehabilitation projects are presented through a series of case studies. Tools or approaches include, large distortion heat-straightening, laser-scanning, repair plate integration into gusseted connections, and a pair of tight space repair details (lower-chord "U" fixtures and upper-chord "mill-to-bear" external plating.

The case studies are presented in the context of 125 year old design principles presented in J.A.L. Waddell's 1890 book "De Pontibus: A Pocket-Book for Bridge Engineers"

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Introduction

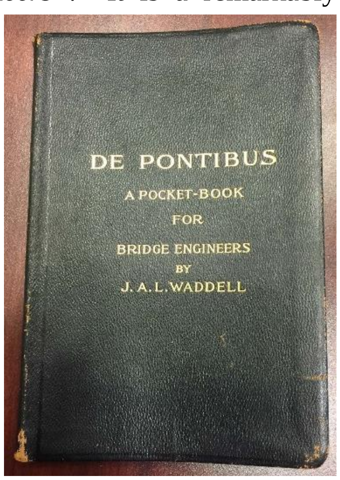
While rarely constructed in the 21st century for new highway bridges, the 2014 dataset for the National Bridge Inventory has nearly 10,000 truss bridges in service on highways in the U.S.A. Many of these bridges are 50, 60, 70, or even 100 years old. The longevity of these structures is testament to the skill of the designers and constructors of the past.

One of the more esteemed engineers of the late 19th and early 20th century was J.A.L. Waddell. He would receive several patents associated with bridges and his consulting practice would spawn the engineering firms we know today as HNTB and Hardesty & Hanover.

Figure 1 – J.A.L. Waddell (image from Wikepedia)

In 1890 he authored, *"DE PONTIBUS: A Pocket-Book for Bridge Engineers"*. It is a remarkably relevant document.

It contains some of the earliest proposed specifications for highway bridges and railroad bridges. It also contains design guidelines and principles that are pertinent to the topic of this paper.



Waddell Principle V

There are no bridge specifications yet written and there probably never will be any which will enable an engineer to make complete design for an important bridge without using his judgment to settle many points which the specifications cannot properly cover or as Mr. Theodore Cooper put it, the most perfect system of rules to insure success must be interpreted upon the broad grounds of professional intelligence and common sense.

While today's AASHTO and AREMA Design Specifications contain enormous amounts of technical information and guidance, 125 years after Waddell's text was published it is still true that professional intelligence and common sense need to be brought to bear in the development of all bridge projects.

This is particularly true for projects that contemplate the rehabilitation of medium span trusses. Engineers approaching these projects need to have an understanding of the changes in materials and fabrication practices of metal bridges over time. Iron bridges gave way to steel structures. Pin connected structures gave way to riveted and bolted trusses and in some cases welded trusses.

Professional intelligence and common sense allow todays engineers to strengthen, rehabilitate, and repair older trusses with modern materials and details to extend the service life of these bridges.

The purpose of this paper is to describe a handful of approaches to strengthening or repairing trusses that designers might consider as they develop their projects.

CASE STUDY 1

THE SALISBURY BRIDGE

Figure 2 – Damaged End Post

An errant vehicle on a snowy, icy road impacted the end post of this 1899 through truss over the North Fork of the Crow River near Kingston, Minnesota. The vehicle nearly collapsed the pin connected truss. With only a single traffic lane on a timber deck and a three ton load capacity, the truss is composed of relatively light members.

Waddell Principle I

Simplicity is one of the highest attributes of good designing.

Originally, we felt that the lower portion of the end post would need to be replaced to put the bridge back in service, However, the contractor suggested using heat straightening to return the end post to its original geometry. We agreed to see how the heat straightening progressed. After shoring the hip joint and a week of field work, the heat straighteners were somewhat amazingly able to return the end post to its original alignment.

Figure 3 – Heat straightening operations underway

However, longitudinal cracks were observed in the web of the primary channels after heat straightening operations. Due to the cracking and because we were uncertain of the impacts of heat straightening on the chemistry of the 19th century steel, supplementary plates were bolted to the web of the channels to carry the entire end post load. As a result of this decision, the heat straightened portion of the end post just needed to brace the new supplementary web plates. We didn't need to develop an end post splice near the lower chord. Consequently it was a simpler solution to plate the web compared to replacing portions of the channels and splicing new material to original.

Figure 4 – Straightened end post with strengthened channels.

CASE STUDY 2

QUARRY HILL NATURE CENTER BRIDGE

The Quarry Hill Nature Center bridge currently carries a trail over Silver Creek on an abandoned township road. The bridge consists of a pair of pony trusses. The City of Rochester eventually acquired the bridge and wrapped it into the trail system at the nature center.

However, by 2011 the structure was showing its age with extensive deterioration of the floor system, the lateral bracing, and the knee bracing.

Figure 5 – Deteriorated components on the north truss.

One of the challenges faced by owners of older bridges is to assess the costs and risks associated with bridge rehabilitation versus bridge replacement. A replacement project is often seen as a low risk choice. Owners often understand that it might be a bit more expensive, but at least they won't be caught expending a large sum of money on rehabilitation only to find out later that the rehabilitation wasn't feasible. Owners are rightfully concerned about unforeseen issues that might be discovered during a rehabilitation project that can increase project costs and delay the project schedule.

Another challenge for rehabilitation projects is having accurate geometric information in hand to work with. Many times original plans are not available - and in the cases in which plans are available, it is likely that any alterations to the bridge over the past 50 to 100 years have not been well documented in as-built drawings, inspection, or maintenance files.

Waddell Principle XII

Before starting a design, one should obtain complete data for same.

Laser scanning is an extremely efficient and cost effective way to collect information. We have used static laser scanning data for our rehabilitation projects for seven years. Not only can member geometry and member sizes be determined, alterations such as railing updates, lighting, and signing can readily be identified. In addition, it is not unusual to have older structures impacted by vehicle hits - or to have substructure units settle and shift with time. These movements can be quantified and extracted from the scan data and included in the design.

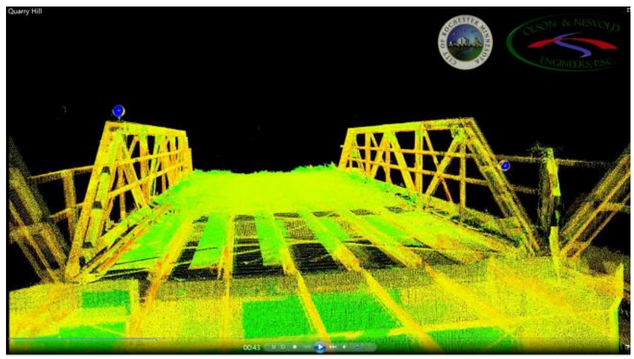


Figure 6 – Point cloud for the bridge

We have found that collecting scan data for medium sized bridges can usually be accomplished with one day in the field (by a two-person crew) and another day to register the scans into a point cloud. One of the side benefits of scanning is the ability to collect more information than what is initially expected. It is not unusual to have additional questions or requests arise during design. With scanning, it is likely the geometric information is already available, eliminating the need to conduct multiple follow up trips to the site.

The floor system for the Quarry Hill Nature Center Bridge was rehabilitated by removing the old deck and stringers and lateral bracing. The new floor system included a cast-in-place slab spanning from floor beam to floor beam. The floor beam deterioration at the ends of the beams was addressed by sandwiching supplemental web plates on both sides. The new plates arrived at the site with a shop applied zinc primer and were placed against the original web after it was blast cleaned and primed in the field.

Figure 7 – Supplemental floor beam web plate prior to final paint coats

The new structural deck with a low profile grade and curb detail will minimize the amount of deicing agents and water seepage that contributed to the deteriorating floor components below.

Figure 8 – Painted pony truss being moved back onto the substructure units

CASE STUDY 3

THE STILLWATER LIFT BRIDGE

The Stillwater Lift Bridge is a heavily traveled two lane bridge over the St. Croix River between Stillwater Minnesota and Houlton, Wisconsin. The vertical lift span and steel truss approach spans were designed by Waddell's firm in 1931, and the bridge has been rehabilitated several times since then.

Figure 9 - Looking northwest at the lift span

It is not unusual for below deck truss chords to exhibit corrosion and section loss. Chloride contaminated runoff can readily seep down verticals and diagonals to reach the lower chord. Once at the lower chord, it can readily seep through the connection and deteriorate adjacent components. As part of a 2012 rehabilitation project, structural steel repairs were required at several locations.

Figure 10 – Lower chord panel point

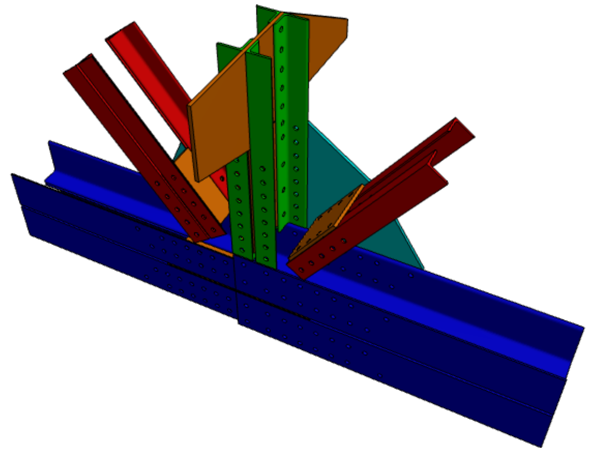


Figure 11 – 3D PDF model of connection with inside gusset plate removed.

Here again it is appropriate to cite one of Waddell's principles.

Waddell Principle XLII

There is but one correct method of checking thoroughly the entire detailing of a finished design for a structure, viz.: "Follow each stress given on the stress diagram from its point of application on one main member until it is transferred completely to either other main members or to the substructure, and see that each plate, pin, rivet or other detail by which it travels has sufficient strength in every particular to resist properly the stress that it thus carries; check also the sizes of such parts as stay-plates and lacing, which are not affected by the stresses given on the diagram, and see that said sizes are in conformity with the best modern practice.

When we develop rehabilitation plans, they are often based on 3D models of joints, connections, and members. This approach allows us to readily check for interference issues. It also allows us to readily visualize the flow of forces through the connection.

Once the 3D model is created in Microstation it can readily be exported to a 3D PDF file where different plates and components are turned on and off to visualize the fit up of different components.

Waddell's principle was intended to encourage engineers to follow for the flow of forces for primary truss members. Today's analytical tools allow engineers to follow the stress into and out of connections.

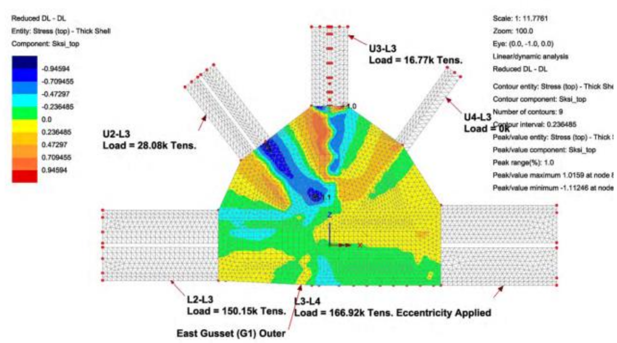


Figure 12 – Lusas model of Joint L2

One of the concerns associated with rehabilitating the Stillwater Lift Bridge was for the lower chord repairs to engage the gusset plates for proper load transfer. The lower chord members had the largest amount of section loss just outside of the gusset plates. Because of the way the original joint was detailed, it would be possible to "leapfrog" the joint itself and simply detail repair plates that engaged the lower chord outside of the gusset plates. This would likely function adequately for the short term. Eventually, the original members could lose additional section and have too little capacity at the gusset plate locations to properly transfer loads into the diagonal member. To address this concern, additional fasteners and fill plates were detailed to properly connect the repair plates to the gusset plates.

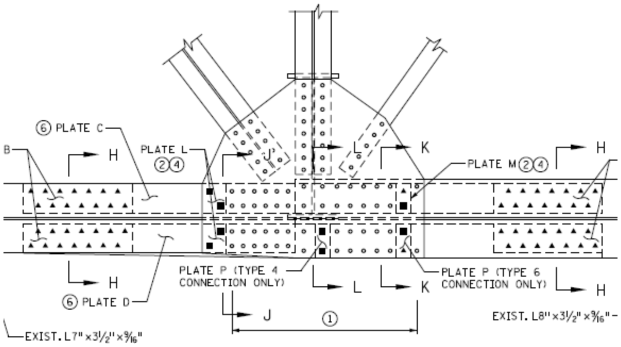


Figure 13 – Plan detail with gusset plate fills and fasteners to engage the repair plates

CASE STUDY 4

THE OSLO BRIDGE OVER THE RED RIVER

The Oslo Bridge carries Minnesota Trunk Highway 1/North Dakota State Highway 54 over the Red River of the North. The two main through truss spans were constructed in 1959 at a length of 220 feet each.

Figure 14 – Looking west along the north face of the bridge

The objective of the design was to improve the load carrying capacity of the bridge, address some minor deterioration and paint the superstructure. The bridge deck was in good condition and was not to be removed as part of the project. The rehabilitation design was to follow current AASHTO LRFD specifications and include HL93 loading. The 220 foot main spans were originally designed with the AASHO Standard Specifications where truck and lane loadings were considered independently. The simultaneous application of truck and lane loadings as part of the HL93 loading significantly increased the live load demand on the bridge, which in turn required the strengthening of the floorbeams, select gusset plates and both the upper and lower chords.

Waddell Principle XXVII

The bridge-designer should never forget that it is essential throughout every design to provide adequate clearance for packing, and to leave ample room for assembling members in confined spaces.

The installation of shoring below the bridge to rebuild the members and connections was cost prohibitive. In addition, there was little desire to break apart the floor beam connections to allow a "symmetric" plating solution to be deployed for the bottom chords. The solution we arrived at to strengthen the lower chord was to deploy conventional plating up to the gusset plates and then install "U" shaped transfer fixtures inside the connections. At a location convenient for the contractor to drill holes, the transfer of force could take place from the outer plates to the inner plates. A handful of bolts would connect the two fixtures together and sandwich the existing diaphragm as shown in Figure 15.

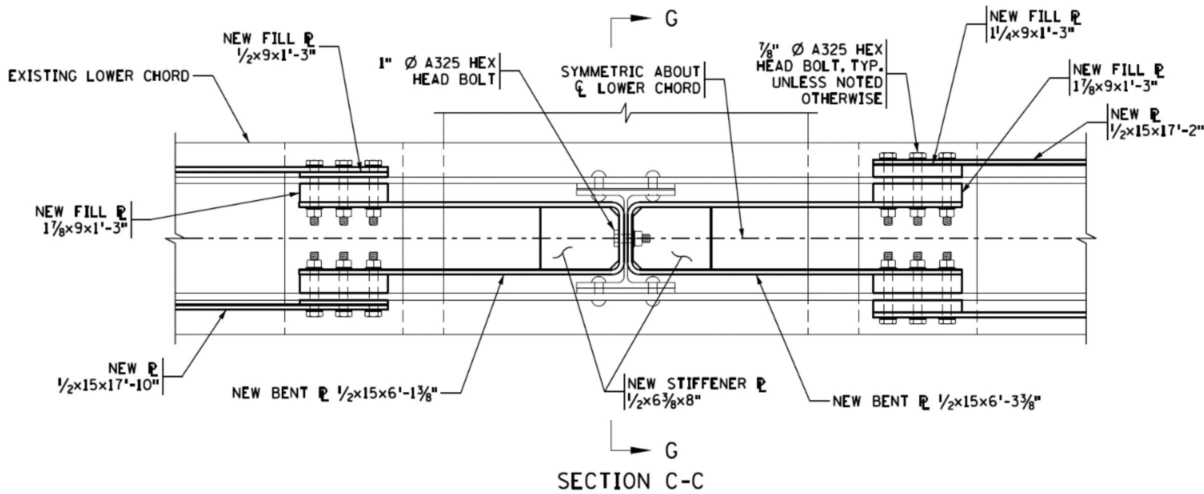


Figure 15 – “U” shaped bent plate fixture detail to strengthen the bottom chord

Similar challenges were present on the top chord. The installation of temporary bracing and removing the portals to install supplementary web plates was not an option due to cost Our solution was to detail plates that would enter the hip joint from each side and meet at the joint and have a mill to bear surface to carry the additional live load compression force. This would allow the contractor to handle smaller straight p[illegible] behind the existing portal elements.

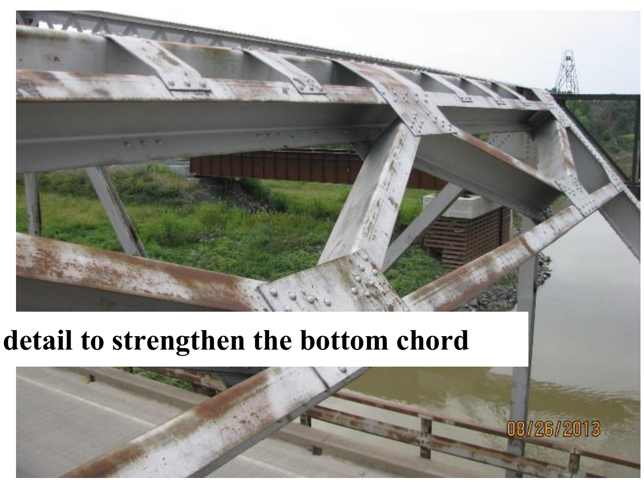


Figure 15 – Portal end post details

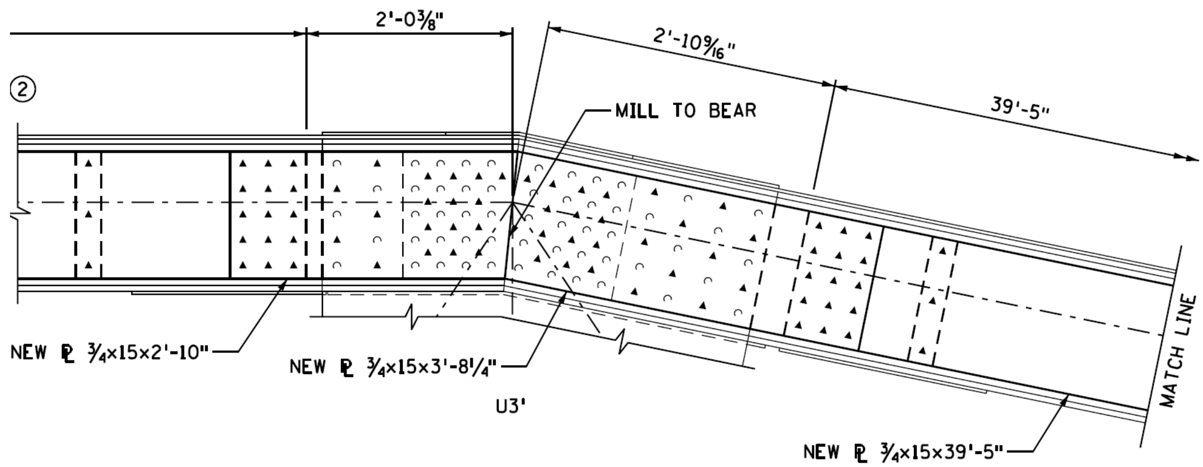


Figure 16 – Top chord strengthening detail with mill to bear surface

Conclusion

Truss bridges have been, and will continue to be, key elements of our transportation network. Engineers tasked with rehabilitating trusses need to use professional intelligence and common sense in concert with available codes and specifications to deliver quality projects. It has been this way for over 125 years.

Reference

1. Waddell, J.A.L., *DE PONTIBUS: A Pocket Book for Bridge Engineers,* First Edition, The Scientific Press, Robert Drummond and Company, New York, 1890, Second Edition, John Wiley & Sons, New York 1908, Six thousand copies.