Innovative Rehabilitation Gives new Life to a 100-Year-Old Steel Truss Bridge

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Abstract

Dawson Bridge over the North Saskatchewan River has served the people of Edmonton for nearly 100 years. A five-span riveted steel through-truss, it was originally constructed to carry electric trains to a coal mine located on the east bank. Later converted to carry highway vehicles, the bridge currently accommodates 17,000 vehicles per day along with significant pedestrian and cyclist traffic.

In 2007, a bridge condition assessment revealed that the superstructure was in need of significant repair, including bridge deck replacement and truss repainting. Field inspection and structural analysis also identified numerous truss members requiring strengthening or replacement to provide an appropriate level of safety and extend the service life of the bridge.

Presented as a case study, the paper includes the rationale for selecting the rehabilitation strategy for the bridge. The paper will focus on an innovative strategy for replacing the existing concrete deck with a proprietary composite steel plate and elastomer lightweight deck system. This system, known as SPS™ makes use of two relatively thin steel face plates connected by an injected thermosetting elastomer core. The final product is a composite panel with high stiffness and strength, but relatively low weight. Dawson Bridge is the largest project in the world to incorporate this innovative deck system.

The paper also discusses the importance of a structured risk control plan in the implementation of new technologies. Perceived risk—and its associated liability—often dissuades engineers from trying innovations that might advance the state of the art for the long-term benefit of society. Striking the right balance between innovation and risk control is the key to success.

1. Background and Historical Context

Originally named the East End Bridge, Dawson Bridge was constructed in 1912 to carry electric trains and horse-drawn wagons to a coal mine located on the east bank. With five simply supported riveted steel through-truss spans—43.3 m, 43.3 m, 43.3 m, 76.2 m, and 30.5 m from west to east—the bridge has an overall length of 236.5 m and a clear width of 8.1 m. Refer to Figure 1.

When originally constructed, the bridge had a timber deck supported on structural steel stringers. Loading data from the original construction drawings show that the trusses were designed to support a train on the south lane and vehicular traffic on the north lane. Because the rail tracks were on the south half of the deck, the south truss has members that are approximately 10% heavier than the north truss. The trusses are built up from structural steel angles, cover plates, gusset plates, and lattice members. Abutments at the banks and four concrete piers founded on concrete spread footings in the river support the trusses.

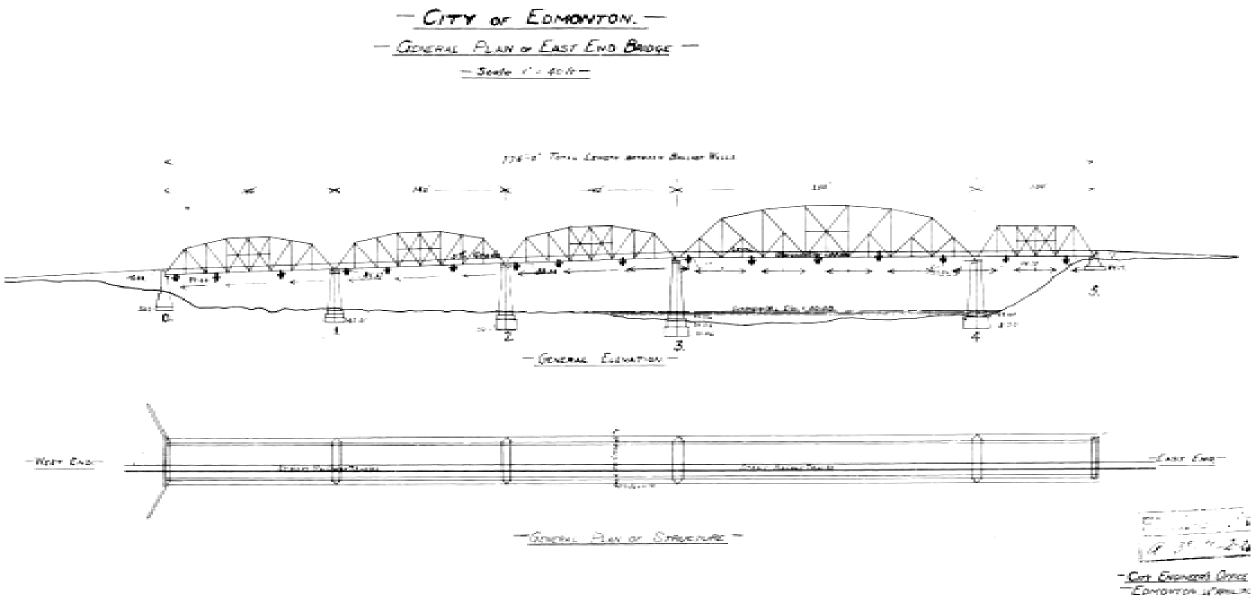

Figure 1: Original general arrangement drawing of Dawson Bridge.

Modifications and rehabilitation work has taken place numerous times over the years. A drawing dated January 1926 indicates that the original deck was replaced with a new timber plank deck with an asphalt wearing surface. A drawing dated January 1942 shows that the deck was again replaced, this time with reinforced concrete cast on top of creosote-preserved planks.

Prior to the rehabilitation discussed in this paper, the last significant work on the bridge occurred in 1986. Major repairs were done to the structural steel trusses, including member strengthening, selected member replacements, and painting. The concrete abutments were rehabilitated and the original expansion bearings were replaced with modern, pot-type bearings. A new semi-lightweight concrete deck was cast on top of the existing 50-mm-thick preserved wooden deck. The concrete deck was only 165 mm thick with epoxy-coated reinforcing, steel fibre reinforcing, and an epoxy membrane wearing surface.

Dawson Bridge is listed on the Inventory of Historic Resources in the City of Edmonton. This designation means that any modifications to the bridge must be carried out in a manner that respects historical aspects of its appearance.

2. Condition Assessment

In 2007, the City of Edmonton commenced a condition assessment of Dawson Bridge along with preliminary design of recommended rehabilitation measures. The goals of the condition assessment were to establish the structural reliability of the bridge, including evaluation of its strength, serviceability, and fatigue life expectancy.

The scope of work associated with the condition assessment included extensive review of bridge file information and the original design drawings, along with a detailed field inspection of the bridge. The inspection work included deck concrete sampling and testing, a deck delamination survey, paint testing, a truss member condition survey that included visual and ultrasonic inspection of selected truss members for fatigue damage, and measurements of section loss resulting from corrosion. The objective was to develop and compare preliminary design options for the rehabilitation of Dawson Bridge.

2.1 Substructure and Floor System

Field inspection revealed that the concrete piers and abutments were in relatively good condition. Some minor concrete repairs to the substructure were recommended as part of the rehabilitation program.

In general, the deck concrete evaluation indicated that effects of chlorides and corrosion were not significant. However, major deck serviceability problems were arising from detailing problems at the floor beams and from excessive deck flexibility.

Figure 2: Deck deterioration over floor beams on each side of expansion joint.

Though its relatively light weight was beneficial for limiting overall dead loads, the 165 mm concrete deck was too flexible to resist cracking. In particular, where the concrete deck passed over the existing transverse floor beams, the deck section was reduced to only 65 mm thick, creating a stress concentration in the concrete and making it nearly impossible to control cracking. Figure 2 shows severe deterioration of the thin traffic deck membrane at floor beams on each side of an expansion joint.

Generally speaking, the steel floor system was judged to be in good condition with the exception of corrosion concentrated in the vicinity of the expansion joints, a result of water leakage. Ends of all floor beams were also corroded from exposure to saturated wood decking and from road spray. Most of the floor members have sizeable thickness, so corrosion losses appear not to affect member capacity significantly, and paint recoating was the only rehabilitation work required in most cases.

2.2 Steel Truss Superstructure

Field inspections revealed that paint on the steel trusses was in fair to good condition except within the splash zones (1 m below to 3 m above the deck). Within the splash zones, the paint had deteriorated to an extent that it provided little or no protection against further corrosion. Repair of the existing coating system was past the point of economical rehabilitation by overcoating, necessitating complete recoating. The team determined that the entire bridge structure should be gritblasted clean to base metal and repainted with a three-coat zinc-epoxy-polyurethane system.

Inspection of the upper portions of the trusses—above the splash zone—revealed that they were in good condition with minimal corrosion. Several upper locations showed damage as a result of high load impacts.

Lower portions of all trusses—within the splash zone—suffered from the effects of corrosion, including general surface corrosion, pitting, and pack rust between connected elements.

As part of the assessment work, a load rating of the Dawson Bridge superstructure was completed in accordance with the Section 14 “Evaluation” of the Canadian Highway Bridge Design Code (CHBDC) (Canadian Standards Association, 2006). The rating analysis was conducted using the Alberta Transportation rating vehicle models, CS1, CS2 and CS3. The Alberta CS3, 4-axle, 613 kN rating vehicle represents the largest vehicle that might practically access the bridge considering its vertical clearance restrictions and location. The assessment concluded that numerous truss members must be strengthened or replaced in order to provide an appropriate level of safety and to extend the lifespan of the bridge. More details regarding consideration of corrosion and fatigue life expectancy are provided below.

2.2.1 Fatigue Assessment

The results of the fatigue assessment concluded the fatigue life of many of the riveted connections on the bridge had theoretically been consumed. Fortunately, the steel inspection carried out as part of the field inspection did not reveal any fatigue cracking.

Figure 3: Rivets replaced by high-strength pretensioned bolts at all critical tension connections.

To counter the risk of future fatigue crack growth, the design team implemented a simple and economical fatigue strengthening strategy: replacement of all rivets at critical connections with high-strength pretensioned bolts. High-strength bolts have a higher fatigue stress range threshold (Category B, 110 MPa) than riveted connections (Category D, 48 MPa). The improvement in performance is primarily attributable to local compressive stresses generated by the bolt tensioning, which retard fatigue crack growth.

During rivet replacement operations, close visual inspections were conducted for fatigue cracking at the rivet holes. With these strengthening and inspection measures, no fatigue cracking problems are anticipated within the remaining service life of Dawson Bridge.

3. Rehabilitation Options

Several options for the rehabilitation of Dawson Bridge were assessed, each providing a different level of cost, service life extension, and functional improvement. The options ranged from a low-initial-cost rehabilitation that provides a 10-year service life extension, full rehabilitation options that extend the service life by 50 years, and total bridge replacement.

After extensive cost-benefit analysis and discussion with representatives from the City of Edmonton, it was judged that rehabilitation—not replacement—of Dawson Bridge offered the best value to the City. Taken into account in that assessment were the comparatively low cost of rehabilitation, the historical significance of the bridge, potential effects on surrounding communities, and the advice of local bridge contractors and steel fabricators.

As options for rehabilitation were developed, it became clear that the bridge could be rehabilitated economically only if a lightweight deck replaced the existing deteriorated concrete deck. A traditional concrete deck would require costly replacement or strengthening of many truss members, along with difficult upgrading of existing connections. By replacing the existing concrete deck with a lightweight steel deck, the design team concluded that the dead load savings could be applied to carrying additional live load and widening the sidewalk. Only steel offered viable lightweight deck options: grating, orthotropic deck, or an innovative composite steel plate and elastomer system called the Sandwich Plate System (SPS™) patented by Intelligent Engineering (Canada) Ltd.

Grating was quickly eliminated as an option for the deck because increased road noise would be detrimental to the nearby Riverdale community. Orthotropic steel deck was judged a suitable option, but detailing would be challenging where the deck had to clear the tops of the floor beams without raising the grade line, and orthotropic deck may be susceptible to fatigue cracking. After considerable research, the design team recommended SPS to The City of Edmonton, judging that SPS technology offered the best combination of light weight, thin profile, and ease of erection for the Dawson Bridge Rehabilitation project.

In addition to replacement of the existing deck, the overall scope of work for the project included repair or replacement of damaged and under-strength truss members; replacement of rivets at fatigue-critical connections with high-strength pretensioned bolts; replacement of all bridge deck expansion joints; construction of new sidewalk support brackets; construction of new, widened wooden sidewalks (2.65 m clear width); replacement of traffic and pedestrian barriers; replacement of bridge bearings; and complete blast cleaning and painting of the entire bridge with a three-coat zinc-epoxy-polyurethane system.

With these repairs, it is anticipated that the service life of Dawson Bridge will be extended for 50 years, with only relatively minor maintenance required for the truss superstructure during that time.

3.1 SPS Deck: Innovation and Risk Control

The SPS composite steel plate and elastomer system was originally developed by Intelligent Engineering Ltd. for ship hulls and decks in the marine industry. Application of this technology began about a decade ago in the bridge industry, and SPS has been installed on several bridges worldwide. The technology is gradually gaining acceptance by bridge engineers.

The composite steel plate and elastomer decking makes use of two relatively thin steel face plates—10 mm thick, in the case of Dawson Bridge—connected by an injected elastomer core. The final product is a composite panel with high stiffness and strength, but relatively low weight.

Deck panels are fabricated in the shop using conventional steel fabrication techniques. First, solid "perimeter bars" are welded along each edge of the bottom plate using a continuous fillet weld. The top plate is then lowered onto the perimeter bars and fillet welded all around forming a panel with a sealed void. The liquid elastomer, which cures into solid form within an hour, is injected through a port to form the core. For Dawson Bridge, the 10 mm steel face plates sandwich a 25 mm elastomer core, forming a composite deck panel with a total thickness of only 45 mm. These prefabricated panels on the Dawson Bridge are typically 1.90 m wide and 8.6 m long.

Risk is inherent in the application of all new technologies in all industries. Perceived risk—and its associated liability—often dissuades engineers from trying innovations that might advance the state of the art in their area of practice. Potential liability places a constriction on the pace of innovation that, in the long run, is most often a disservice to society. Striking the right balance between innovation and risk control is the key to success. Thus, when DIALOG recommended SPS—a relatively new technology—to the City of Edmonton, that recommendation came with the provision that an intensive risk control program must be implemented, especially since Dawson Bridge is an important and expensive asset. The City of Edmonton is a progressive bridge owner that welcomes innovation, and they directed the design team to proceed with SPS as the basis of design for the deck.

The risk control plan developed for the deck comprised six key elements:

- Extensive background research in the available literature;
- Site visits by the design team to other bridges with SPS decks, and interviews with the bridge authority managing those structures;
- Development of improved connection details in consultation with Intelligent Engineering;
- Fatigue testing of full-scale sample connections in the laboratory;
- Enhanced quality control and quality assurance programs during deck fabrication and erection; and,
- Monitoring of deck performance over the lifetime of the bridge as part of the City of Edmonton's bridge maintenance program.

The design team judged the most important aspect of the risk control plan to be the development of new connection details between adjacent SPS deck panels. Of the handful of bridges around the world built using SPS technology, all have involved significant field welding—a method that is costly and makes quality control difficult. Risks associated with field welding include fit-up, out-of-tolerance, the potential for excessive heat input that might debond the elastomer from the steel, and undesirable weld flaws that might inadvertently result in premature fatigue cracking.

Taking to heart the golden rule "shop weld and field bolt," the design team developed unique bolted details for connecting the SPS deck panels. These details completely eliminate the need for field welding. The new details make use of splice plates to connect adjacent deck panels with countersunk ASTM A325 bolts, as illustrated in Figures 4 and 5. Bolted connections drastically increase speed of erection, significantly reduce cost, and improve fatigue performance from Detail Category D (depending on the specifics of the weld geometry) to Detail Category B when using slip-critical connections.

To connect adjacent composite steel plate and elastomer decking panels, a top splice plate is fastened to each panel by a single row of countersunk pretensioned ASTM A325 bolts. Countersunk bolts provide a flat surface for the finished deck, except for the thickness of the splice plate itself. This surface, once grit blasted, is prepared to receive a waterproofing membrane and asphalt wearing surface.

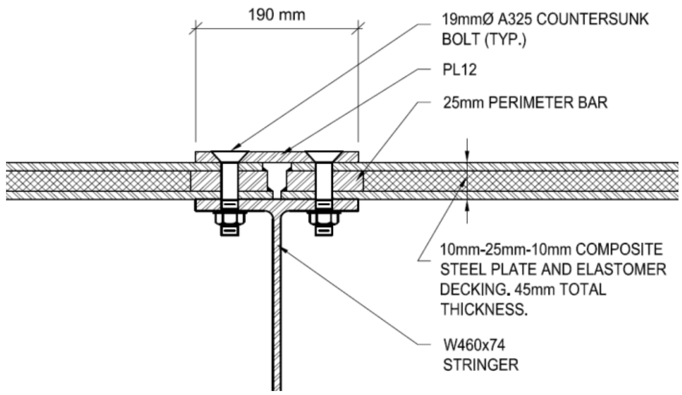

Figure 4: Design drawing of bolted connection of composite steel plate and elastomer decking panels at longitudinal stringer.

Longitudinal deck splices are designed to align with floor stringers below. This arrangement enables the top flange of the stringers to act as the bottom splice plate for The connection, saving both weight and complexity The new stringers chosen for Dawson Bridge—W460x74—are larger than required for flexural strength, but offer a flange wide enough to accept a row of bolts on each side.

Figure 5: Laboratory prototype of bolted connection of composite steel plate and elastomer decking panels at longitudinal stringer.

At transverse deck joints—located away from the floor beams to avoid geometric clashes—bolted splice plates are used both top and bottom. In all cases, the bolt pattern is arranged to meet sealing requirements and provide negative moment transfer across the supporting stringers.

Using similar bolting details, the traffic barriers along the length of the bridge are also bolted down through the deck to the edge stringer.

3.1.1 Assessment of Deck Connection Fatigue Performance

To assess fatigue life of the new bolted longitudinal deck connections, it is first necessary to estimate the stress range at critical locations. This estimate can be based on measured strains or can be calculated analytically.

A structural model using the finite element method of analysis was developed to determine the predicted stresses induced in the bridge deck at longitudinal bolted splice connections. The model was a scale representation of a travel lane on the bridge, including three lines of support representing the longitudinal stringers. Constructed from three-dimensional solid elements, the model includes the composite steel plate and elastomer decking deck system, the splice plate, and the top flange of the longitudinal stringer. Loading representing the wheels on the rear axle of the CS2 Alberta Transportation load rating truck—the largest axle load of the load rating trucks considered—was applied to the model.

Live load stress ranges induced in the top splice plate and plate parent material were calculated from the model. The location of the governing fatigue stress detail was identified in the plate parent material near the interface of the perimeter bar and the elastomer core, which is an abrupt change in stiffness of the composite panel. The maximum calculated fatigue stress range in the plate parent material does not exceed the constant amplitude fatigue limit stress range, thus it is anticipated that the bridge deck will have an unlimited fatigue life for the design truck considered.

To support the results of the analytical analysis, three proof-of-concept samples of the longitudinal bolted deck connection detail were built at 1:1 scale and tested under fatigue loading at the University of Alberta. The goal of the test program was to observe the fatigue behaviour of the deck panel and the longitudinal bolted connection, and to conservatively estimate the fatigue category of the connection. Those tests demonstrated that the new connection detail can withstand fatigue loads nearly double in magnitude to those expected in actual in-service conditions.

4. Deck Installation

After removal of the existing concrete deck, wood sub-deck and original steel stringers was complete, five new lines of longitudinal structural steel stringers were installed between existing floor beams, matching the 1.9 m deck panel width. All stringer flanges were pre-drilled with holes to accept the composite steel plate and elastomer deck panels, which were hoisted into place and bolted to the stringers using countersunk pre-tensioned ASTM A325 bolts (Figure 6).

As the deck panels were placed they became the working platform for installation of the next series of panels. Deck installation began on the west abutment and moved eastward across the bridge.

Figure 6: Installation of composite steel plate and elastomer decking panels.

Figure 7: Deck construction sequence: A) panel bolting; B) grit blast surface; C) apply multi-coat waterproofing membrane; D) polymer-modified asphalt wearing surface.

In order to make deck detailing and construction simpler, the deck in each span is planar with no cross-fall. Deck steel is protected by a multi-coat waterproofing membrane and has an asphalt wearing surface. To achieve positive drainage, the asphalt has cross-fall and varies in thickness from 40 mm at the edges to 100 mm along the deck centreline. Polymer-modified asphalt (PMA) was specified to reduce the probability of cracking at the splice plates atop the deck panels. Figure 7 illustrates the construction sequence used to achieve the finished deck surface.

5. Summary, Conclusions and Recommendations

Rehabilitation of Dawson Bridge involved strengthening or replacement of about 40% of the main truss members, repainting of the bridge, replacing the existing concrete deck with a new lightweight composite steel plate and elastomer decking system complete with a polymer modified asphalt wearing surface, rebuilding new wider sidewalks and installation of new precast concrete barriers. Over 17,500 rivets were removed and over 37,500 new bolts were installed.

The bolted connections developed for the steel plate and elastomer decking system are an effective way to connect adjacent panels. Laboratory testing was performed to measure the fatigue behaviour of the deck panel and longitudinal bolted connection, and to estimate the fatigue category of the connection. Those test results support the analytical analysis that the bolted connection detail used on the Dawson Bridge project can withstand fatigue loads nearly double in magnitude to those expected in actual in-service conditions. Before general design guidelines can be established for the newly developed bolted connection, additional laboratory tests are required in order to establish statistically significant fatigue performance baseline data.

Because the composite steel deck panels could be fabricated entirely in the shop and bolted quickly into position on the bridge, erection of the deck was finished in only six weeks. This speed allowed all main construction activities to be completed in approximately 12 months, with the bridge closed to traffic on January 4, 2010 and reopened on December 20, 2010. If a traditional concrete deck had been used, the difficulty and expense of strengthening truss members would have been far greater and the construction schedule would have taken at least 18 months.

The Dawson Bridge project has successfully advanced the state of the art in bridge technology and has achieved cost savings for the City of Edmonton. Today, Dawson Bridge is fully rehabilitated with the world's largest steel plate and elastomer deck and is the only installation built entirely without field welding. The bridge has adapted many times over the past century to meet the changing needs of the City of Edmonton, and is now prepared once again to serve Edmontonians for generations to come.

6. Acknowledgements

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