PENNSYLVANIA'S EXPERIENCE AND FUTURE PLANS FOR HIGH PERFORMANCE STEEL BRIDGES

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Abstract

Pennsylvania has designed, constructed and opened to traffic a long span bridge constructed with HPS485W steel. Pennsylvania has several HPSteel bridges currently under construction and additional bridges under design. Innovative techniques have been used, optimized welding and innovative designs are planned to be used, including corrugated web I-girders. Descriptions of projects, selection of the use of HPSteel, research conducted in association with these projects and contracting methods are presented.

Introduction

The Pennsylvania Department of Transportation (PennDOT) has completed a bridge project that uses HPS485W material and is sponsoring a research project to design, fabricate and build an innovative superstructure type with HPS485W material. PennDOT is striving to optimize the benefits of this new steel with a multifaceted approach:

- research and development
- quality assurance quality control testing
- traditional design, award, construct project
- modified design-build turnkey projects

To date the most significant project has been The Ford City Bridge, a 3 span continuous steel plate girder structure that carries state route 128 over the Allegheny River approximately 60 km north east of the City of Pittsburgh, Pa. The bridge was opened in July 2000. This high performance bridge project involved full-scale tension and fatigue testing, extensive material testing and extensive weld testing and inspection. The Ford City Bridge has homogenous HPS485W sections at the piers and homogenous Grade 345W sections for the remainder of the bridge.

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A basis to evaluate the economic aspect of this HPSteel in the bridge market is to advertise and award a design-build bridge project. The ability to compete and win against prestressed concrete or conventional Grade 345W will be determined for the medium span range. PennDOT will be advertising a design-build bridge project with an estimated cost between $25,000,000 and $30,000,000.

The Ford City Bridge has proven the cost effectiveness and benefits of HPSteel for use in long span bridges. PennDOT is in the preliminary design phase for a three span steel bridge with a main span greater than the Ford City Bridge. It will also have homogenous HPS485W sections at the piers and homogenous Grade 345W sections for the remainder of the bridge. The estimated cost is $20,000,000 to$25,000,000.

To realize additional benefits of HPSteel, a research project is in progress to develop an innovative superstructure type, specifically, a corrugated web I-girder bridge. This is not purely an academic oriented project but a practical results oriented project. Some main aspects of the research include development of optimum corrugation shape, shear, flexure and fatigue testing, development of design equations, fabrication of corrugated plates and welding of corrugated shapes to make bridge members. After this research project is completed, PennDOT intends to design and construct a corrugated web I-girder bridge.

The Pennsylvania Turnpike Commission is constructing a dual, nine span continuous plate girder bridge in western Pennsylvania with HPSteel, the Mingo Creek Bridge, and has upcoming projects that will use HPSteel. The Mingo Creek Bridge, like the Ford City Bridge, has homogenous HPS485W sections at the piers and homogenous Grade 345W sections for the remainder of the bridge.

The Pennsylvania Department of Transportation Ford City Bridge

The Ford City Bridge replaces an existing 3 span camel back truss bridge built in 1914 with an open steel grid deck and wooden sidewalk that was structurally deficient and functionally obsolete. Some of the key features of the replacement bridge are:

- 3 span continuous steel plate girder with spans of 98m – 127m – 98m
- Horizontally curved structure with a 155m radius in span 1, other spans on tangent alignment
- Constant depth webs 4.26m, longitudinally and transversely stiffened
- 4 girder cross section with 4.1m girder spacing
- Longitudinally hybrid girders, HPS485W in negative moment region, Grade 345W elsewhere
- Optimized/undermatched butt welds for the webs and flanges with the L61/AXXX-10 electrode/flux combination
- Undermatched flange to web fillet weld
- 474,738 kg (523 tons) of Grade HPS485W fabricated structural steel and 1,768,175 kg (1949 tons) of Grade 345W

This replacement structure is the longest span bridge built with HPS485W material in the United States, and the longest curved girder bridge in Pennsylvania. The bridge was opened to traffic August 2000.

An extensive bridge study was performed to select the most economical and appropriate bridge for the site. From this study the longitudinally hybrid structure was selected. The study revealed many advantages for using the HPS485W material besides the promoted aspects of high strength and toughness, improved weldability and weathering properties. The advantages included significant reduction (20%) in structural steel weight due to higher strength. The higher strength enabled the girder sections to be constant depth instead of a haunched girder. By eliminating the variable web depth, a costly longitudinal bolted web splice was avoided. This reduced the number of pieces to fabricate, ship and erect, thus providing additional savings while improving construction safety.

The selection to fabricate the HPSteel girder sections with optimized/undermatched welds was to overcome the difficulties of using higher strength weld metals. The use of weld metal consumables traditionally used in bridge fabrication is advantageous in producing high quality welds. We did not select the traditional weld metal for economic reasons, only a means of bypassing the use of high strength weld consumables. To validate the use of optimized welds, a research program was conducted by Lehigh University (1) for the Department. The scope of the research and results are described further in the paper.

Since this bridge was the first use of HPSteel by PennDOT and the innovative use of optimized butt welds, additional requirements were specified in the construction documents. These requirements included a list of pre-approved fabricators that were experienced in welding Grade 485W steel and/or welding HPS 485W, sending plate samples to Lehigh University for independent mechanical property testing and chemical analysis (1), and additional shop and field inspection of the full penetration groove welds and the fillet welds.

Optimized Weld Research Testing Program

A primary goal of the research program was to study the feasibility of using weld metals used to fabricate Grade 345W steel to fabricate HPS485W steel. The research program demonstrated that optimized/undermatched weld metals can successfully be used to provide bridge members of acceptable strength and fatigue resistance for 485 MPa yield strength design criteria. The participants in conducting this research were:

- Federal Highway Administration
- Pennsylvania Department of Transportation
- ATLSS Center at Lehigh University
- American Iron and Steel Institute
- High Steel Structures, Inc.

The research program consisted of two components: 1) wide plate tension tests to characterize the strength and ductility of closely matched or undermatched HPS485W steel weldment, and 2) full scale girder tests to characterize their fatigue resistance.

Wide Plate Tension Tests – The wide plate tension tests consisted of a specimen with typical dimensions of 610mm wide and 1500 mm in test length. The specimen size was selected to provide constraint conditions (plane strain) for the steel. A full penetration groove weld in the center of the specimen was used to fabricate the specimen. These full scale tests demonstrated the overall strength and ductility of the weldments compared to the base metal. Four wide plate tests were performed: two specimens were fabricated with the L61/AXXX-10 and one specimen with E7018 electrode and the remaining specimen with a LA100 submerged arc wire with M800-H flux weld material.

Full Size Girder Fatigue Tests – The full size girder fatigue tests were consistent with designs of prior fatigue tests. This allowed comparison of this data to the existing database. The girders included two each of the two undermatched conditions with L61/AXXX-10 submerged arc weld metal and E7018 shielded metal arc (4 fatigue tests) for the flange butt welds. The longitudinal web to flange fillet weld was made with the submerged arc process and L61/AXXX-10 electrode/flux combination.

Optimized Weld Test Results

The wide plate tension tests demonstrated that butt tension splices fabricated with L61 submerged arc weld process made with AXXX-10 flux, a shielded metal arc process made with E7018 electrodes and a LA100 submerged arc wire made with M800-H flux achieve the strength of the base metal. The ductility of the specimens fabricated with the L61 AXXX-10 combination and the E7018 electrode was reduced, only achieving strains at fracture of 5-7%. The overmatched specimen achieved gross yielding of the cross section with strains greater than 10%. The undermatched weld specimens were loaded to fracture with failure in the weld metal, while the overmatched weld specimen was not loaded to fracture.

The results showed that if the undermatching of the weld metal strength to the plate was no more than 12-15%, the weldment achieved adequate strength. The L61 weld metal tensile strength was 14% undermatching of the HPS485W material and the E7018 weld metal was 13% undermatching.

The fatigue test specimens fabricated with full penetration butt flange splice welds demonstrated the fatigue performance to be consistent with the AASHTO Category B. The fatigue resistance of the web to flange fillet web fabricated with the undermatched weld metal was also consistent with AASHTO Category B.

QA/QC Bridge Material Testing Program of HPS485W

An extensive independent QA/QC testing program was performed by Lehigh University for PennDOT using steel manufactured for the bridge. The testing included chemical composition, tensile properties and Charpy V-notch. The objectives of testing program were to verify that the material met the contract specifications and to obtain independent data on this new grade of steel.

The number of specimens tested was dependent on the manufacturing process. For slab cast steel only one 200 mm x 150 mm full plate thickness block was required. For plates rolled from ingots samples from each end of the plate were required. A total of 60 plates were rolled for this bridge, with thickness ranging from 20 to 80 mm.

The material testing revealed that the chemical results were good. The Charpy results were tremendous with a mean of 237 J @ -23C (1). The required Charpy V-notch value per the specification was 34 J @ –23C.

Tensile tests indicated the material generally met the specifications with some thicker plates (55-80mm) slightly below the minimum specification requirement. The mean yield strength was 541 MPa and mean tensile strength was 642 MPa with a mean yield to tensile ratio of 0.84 (1).

Weld Inspection Testing

The construction documents required 100% of all complete penetration groove welds for HPS485W to be both radiographic and ultrasonic tested. All stiffener fillet welds were magnetic particle tested within 48 hours of weld completion. All fillet and groove welds were magnetic particle tested 10 days prior to shipping from the fabrication plant and again in the field immediately prior to erection of the steel. The Grade 345W steel was inspected in accordance with normal fabrication inspection requirements.

The magnetic particle testing revealed numerous cracks in the connection plate to flange fillet welds of the HPSteel and some in the conventional grade material. The majority of the cracks were found during the inspection just prior to shipping the girders from the fabricator. The cracks were along the length of the weld, from the root through the weld throat and are within the weld metal. The welds were 5/16" fillets made with an E8018-C electrode.

An investigation of the cracked fillet welds was conducted by Valley Forge Laboratories and Lehigh University (2). The cracked surface was oxidized, thus indicating the crack was exposed to an elevated temperature and not a hydrogen induced crack. The fillet welds were made in two passes, with the crack developing in the root pass and propagating through the second pass due to joint constraint. The HPSteel with higher strength provided more constraint than the 345W material, therefore the tendency to have more cracking in the HPS material.

The cracked fillet welds were corrected by gouging to completely remove the fillet weld, testing the base metal to insure removal of all discontinuities, preheating to minimum temperature, welding in a single pass and post heating for one hour. Depositing the weld in a single pass and post heating were not used in the original fabrication, only for repairing the cracked welds.

As a measure to verify that additional weld cracks were not induced during erection or placement of the deck slab, a hands on, visual and dye penetrant testing of the fillet welds in the regions of the bridge with HPS material was conducted. The first inspection occurred after steel erection was complete; no cracked welds were found. The inspectors indicated that the top flange connection plate welds would be difficult to dye penetrant test after the deck was placed. The Department therefore elected to use SmartPaint in the top flange connection plate areas to facilitate inspection of the welds for cracking after deck placement and the long term in service NBIS inspections. These fillet welds were inspected shortly after the bridge was open to traffic and no cracked welds were found.

Pennsylvania Turnpike Commission Mingo Creek Bridge

The Pennsylvania Turnpike Commission is currently constructing a dual, nine span continuous, deck steel plate girder bridge in western Pennsylvania. The structure, known as the Mingo Creek Bridge, is located on the Pennsylvania Turnpike Commission's Mon/Fayette Expressway, State Route 43, crossing State Route 88 in Union Township, Washington County. Each bridge of this dual structure has four girders with 2895 mm deep webs spaced at 3660 mm. The web thickness is 14 mm and is stiffened both transversely and longitudinally. The out-to-out dimension of the cast-in-place concrete deck of each bridge of this dual structure is 13,280 mm. The northbound bridge is 701 m long with spans of 67m-76.2m-76.2m-91.4m-91.4m-76.2m-76.2m-76.2m-70.1m. The southbound bridge is 762 m long with spans of 76.2m-6@91.4m-76.2m-61m. The height of this structure is approximately 76.2m above the valley and the structure spans 15.2m above a Wheeling and Lake Erie Railroad trestle.

During preliminary design, several steel structure types were considered for this site, including a truss bridge, two types of "delta" frame structures and steel box girders. The truss alternative was not economical because the Commission wanted to keep the highway divided by the 18.3m median for its entire length from I-70 to State Route 51. By keeping the highway divided, four truss lines were needed, which made this alternative cost prohibitive. In addition to the steel bridges, the Pennsylvania Turnpike Commission also studied two segmental concrete box girder structures for this crossing. As a result of the concrete bridge studies, a dual nine span, continuous, precast segmental concrete box girder structure was included in the bid package as a concrete bid alternative.

Once it was decided that steel plate girders were the most economical and feasible framing for the steel alternative for the Mingo Creek Bridge, the next step was to determine the web depth. Gannett Fleming, Inc., the designer, wanted to keep the girder sections as light as possible to aid in erection of this 76.2m high bridge. Because of the 91.4m long spans, haunched

steel plate girders were estimated to be more economical over parallel flange, steel plate girders when using all ASTM A709, Grade 345W steel. The construction cost of the haunched steel plate girder structure was estimated to be approximately $34.04 million or $1680 per sq. m versus $34.6 million or $1710 per sq. m for the parallel flange steel plate girder structure. This resulted in an estimated saving of approximately $0.56 million for the haunched steel plate girder bridge. When a construction cost estimate was formulated for a hybrid, haunched steel plate girder structure using ASTM A709, Grade HPS485W steel for the flanges and ASTM A709, Grade 345W steel for the webs, this estimate came out to be $33.16 million or $1640 per sq. m. A hybrid, parallel flange, steel plate girder structure was estimated to be $33.33 million or $1650 per sq. m. But these hybrid structures had one drawback; to be economical the live load deflections had to be greater than the L/800 ratio allowed by the AASHTO Specifications.

Due to the extreme height of the Mingo Creek Bridge, several erection schemes were studied during preliminary design to ensure that the design would be economical to erect. Balanced cantilever construction was determined to be the most feasible method for the precast, segmental concrete alternative. As previously mentioned, the weight of the steel girders was kept to a minimum to accommodate erection by the conventional method of using cranes to lift the girders from below. However, so as not to limit a contractor's ingenuity, the designer demonstrated to the Turnpike Commission that it could be possible to incrementally launch the steel girders, two at time, across the valley. To accomplish this, the use of haunched steel plate girders had to be ruled out. With this in mind, and with the limits placed on deflections by the AASHTO specifications, a new cost estimate for a parallel flange steel plate girder comprised of all ASTM A709, Grade HPS485W steel in the negative moment regions and ASTM A709, Grade 345W steel in the positive moment regions was prepared. Hybrid construction in the negative moment regions was not considered in order to simplify design and fabrication. The cost estimate for this steel structure was approximately $34.2 million or $1690 per sq. m. This estimate was approximately $0.16 million or 0.5% more than the all ASTM A709, Grade 345W haunched steel plate girder structure. Because this was only a cost estimate at the Type, Size and Location (T.S.&L.) study phase of the project, this difference in cost was considered negligible. But the benefit of achieving two possible construction methods by using a parallel flange, steel plate girder over a haunched steel plate girder was too good to ignore. It was also determined that it would be much safer and more cost effective to erect parallel flange, steel plate girders with cranes at heights reaching 76.2 m feet than it would be to erect haunched steel plate girders by the same method at this height.

The specifications for the Mingo Creek Bridge steel alternate included the special provision recommended by the "Guide for Highway Bridge Fabrication with HPS485W Steel," which was later adopted at the May 16-20, 1999 Annual Meeting of the AASHTO Subcommittee on Bridges and Structures. This special provision required the flange-to-web fillet welds to be "undermatched," specified the consumables to be used for all groove welds, and specified the minimum preheat and interpass temperatures. In addition, the Turnpike Commission's special provision allowed only fabricators having Category III, Major Steel Bridges, with Certified Fracture Critical certification to fabricate the bridge components composed of Grade HPS485W. The Commission also required 100% testing of all complete penetration groove welds in butt

joints and "T" joints by both radiographic and ultrasonic testing. All fillet welds required full-length inspection by magnetic particle testing.

Dick Corporation successfully bid the Mingo Creek Bridge steel alternate in April, 1999 at a dual structure cost, including foundations, of approximately $32.40 million or $1610 per sq. m. In the component item schedule for the lump sum bid price for the bridge, the contractor indicated a price of $2.64 per kg for 1,584,350 kgs (1,746 tons) of Grade HPS485W steel. As of this writing, there have been no weldability problems or weld cracks reported by the fabricator.

Pennsylvania Department of Transportation Future Projects

Carey Avenue Bridge

In late 2000, the Department is scheduled to let a major river-crossing project through a Modified Turnkey contract. The Carey Avenue Bridge, located in PennDOT's Engineering District 4-0, carries S.R. 2005 over the Susquehanna River and Richard Island in Luzerne County. The new structure will replace a 579 m long seven-span riveted steel through truss constructed in 1948.

The proposed crossing will be positioned on a new alignment slightly upstream from the existing bridge and span 732 m from abutment to abutment. The 28 m out to out bridge width will carry two lanes of traffic in each direction and provide for a sidewalk on the east side. The structure has a horizontal alignment and a constant 1.18% grade.

The Modified Turnkey contracting method slated for this project is similar to a conventional Design-Build process. The Department will furnish preliminary structure plans and contract specifications and the contractor is responsible for the final design and construction. The design and plan preparation will conform to the same requirements used for standard contracts using the Department's Design Manual Part 4, Structures.

Two alternatives have been developed for the preliminary structure design, one utilizing prestressed concrete I-beams and one using welded steel plate girders. The successful contractor will have the option to design and construct either of the two alternatives or propose another bridge configuration that meets environmental requirements. This contracting method will allow the contractor to design and construct the most economical bridge type while meeting project requirements. Load and Resistance Factor Design (LRFD) methodology will be used for the entire structure design.

Preliminary engineering studies indicate that a 10-span structure will be the most economical steel alternative. Span lengths ranging from 61.6 to 81.7 m are proposed with a cross section comprised of eight girders (four girders in each of the northbound and southbound dual sections). Constant web depths of 2.36m and 2.51 m are anticipated for the northbound and southbound units, respectively.

Grade HPS485W weathering steel will be permitted for the new structure. The preliminary engineering studies indicate that HPSteel will be most cost effective in the negative moment regions with Grade 345W more economical in the positive moment regions and for all other fabricated structural steel. HPSteel plates produced using thermo-mechanical controlled processing (TMCP) will be permitted for plates up to 50 mm thick. TMCP allows production of plates to over 35 m in length, which far exceeds the 15 m length restriction for plates treated using a conventional quenching and tempering process. It is expected that the use of TMCP plates will be most beneficial for use in the girder webs where costly splices can be eliminated. Welding for HPSteel will generally conform to the ANSI/AASHTO/AWS D1.5-95 Welding Code. Undermatched filler metal will be permitted for web-to-flange welds only.

Wintergreen Gorge Bridge

The Wintergreen Gorge is a new structure part of a four lane controlled access facility near the city of Erie. Various bridge types were studied for this location including steel tied arch, steel thru arch, three span steel deck truss, three span concrete segmental bridge and a three span steel plate girder bridge. Some of the key features of the selected alternate are:

- 3 span continuous steel plate girder with spans of 77m – 142m – 115m
- Tangent alignment
- Constant depth webs 4.30m, longitudinally and transversely stiffened
- 6 girder cross section with 4.5m girder spacing
- Longitudinally hybrid girders, HPS485W in negative moment region, Grade 345W elsewhere

The final design of the bridge is scheduled to be completed by summer 2001. This project will be the conventional design, bid, and construct process. The contract documents will permit contractor's design alternates (steel or concrete), but with restrictions on span lengths, structure depths and pier configurations to satisfy the objectives of the Final Environmental Impact Statement.

Corrugated Web I- Girder Bridge

Innovative bridge member configurations have been studied that maximize the benefits of HPSteel. One of these innovative configurations is an I-girder with a corrugated web that has increased web stability a benefit during fabrication and erection plus fatigue performance due to fewer attachments to the web and flange. PennDOT is planning to design and construct a HPSteel demonstration corrugated web I-girder bridge.

Due to the innovative concept of an I-girder with a corrugated web, a project team has been assembled to develop design equations, design details, FEM analysis, fabrication studies and applied laboratory research. The project team consists of ATLSS Center at Lehigh University, Modjeski and Masters, Inc., High Steel Structures, Inc., Drexel University, Federal

Highway Administration and PennDOT. A significant effort, both engineering and financial (in excess of $750,000), is being expended for the research program that includes:

- Selecting the optimum corrugated shape (trapezoidal or sinusoidal) considering structural performance, fabrication, manufacturing processes
- Conducting shear and flexural tests to verify design capacities this includes tests of bolted splices
- Conducting fatigue tests

Results to date of this program are selection a trapezoidal web configuration, development of preliminary bolted splice details and fabrication of the test specimens.

Once this research program is completed, PennDOT will design and construct a demonstration bridge. The demonstration bridge will have a span length greater than 48 m, 4 girder cross section, and a bridge width greater than 12 m. The final site for the demonstration bridge and the construction cost have not been determined. The construction of the demonstration bridge is anticipated for the 2002 construction season.

Pennsylvania Turnpike Commission Future Projects

At present, the Pennsylvania Turnpike Commission is in the final design stage of the PA 60 to US 22, otherwise known as the Findlay Connector, of the Southern Beltway Transportation Project near the Greater Pittsburgh International Airport. This 8.9 km stretch of highway will include 22 new bridges and the section designers have been instructed to consider the use of ASTM A709 Grade HPS485W steel where feasible. The Commission is also on the verge of beginning the final design of the Uniontown to Brownsville portion of the Mon/Fayette Expressway. Included on this section of highway will be a major river crossing over the Monongahela River near Brownsville. It is estimated that this structure will be approximately 1128 m long with a main channel span approaching 274 m. Although a structure type has not yet been determined for this crossing, it is very likely that ASTM A709 Grade HPS485W steel will be used in a steel structure. Grade HPS485W steel would also be the ideal choice for the tension members of a truss structure or for the tie member in a tied-arch structure.

Conclusions

Pennsylvania Department of Transportation has used HPS485W steel for major river crossing bridge which shows the viability of this new material for long span steel plate girder structures. Pennsylvania Department of Transportation is designing another plate girder bridge with an even greater span length over an environmentally sensitive gorge. A design-build project will demonstrate the competitiveness of this new material against conventional steels and/or prestressed concrete. To assist further advances with this new material the Pennsylvania Department of Transportation is committed to an extensive research program and intends to construct a demonstration bridge with innovative corrugated web I-girder.

The Pennsylvania Turnpike Commission remains optimistic that this new material, ASTM A709, Grade HPS485W, will indeed reduce bridge construction costs in the future.

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