NSBA White Paper

ADVANCES IN HIGH PERFORMANCE STEELS

FOR HIGHWAY BRIDGES

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THE DEVELOPMENT and deployment of High Performance Steel (HPS) for highway bridges originated with a joint effort of the Federal Highway Administration (FHWA), the Navy, and the American Iron & Steel Institute in 1992. This collaboration acted to develop an affordable steel grade with higher strength, improved weldability, and greater toughness while enhancing overall quality and ease of fabrication. The effort was a resounding success. More than 200 HPS bridges now carry traffic in 43 states.

HPS has outstanding potential to decrease costs and increase productivity for building steel bridges. The new steel provides up to 18% cost savings and 28% weight savings compared to traditional bridge design materials. The higher strength plus excellent weldability of this steel are especially advantageous for hybrid girders where it can be used in high-stress regions while using lower strength steels elsewhere. AASHTO has well established steel design codes, and has made adjustments to accommodate these higher strength steels.

The advantages of HPS for bridges include:

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- Longer span lengths and fewer piers
- Lower foundation and superstructure costs
- Wider beam spacing and fewer beams
- Increased vertical clearance without expensive roadway approach work
- Fewer maintenance requirements and longer service life
- Lower initial and life-cycle costs

HPS properties

ACCORDING to the FHWA, HPS offers several beneficial attributes for bridges, including weldability, toughness, ductility, and corrosion resistance. For example, it has low levels of carbon and carbon equivalents to provide good weldability with reduced or no preheat and without expensive welding techniques. HPS also has a high level of fracture toughness to minimize the potential for brittle failure and to improve structure reliability. It provides better than adequate material ductility, and has a much higher tolerance of cracks. HPS has slightly higher atmospheric corrosion resistance characteristics than that of conventional weathering steel.

Strength—Before the development of HPS, the steel grades for bridges had a minimum yield strength of 36,000 and 50,000 lbs per square inch (36 and 50 ksi). In the metric system, these grades translate to 250 and 345 megapascals (MPa). Currently available high-performing steels have minimum yield strengths of 50, 70, and 100 ksi (345, 485, and 690 MPa).

Weathering Capability—Included in this development are HPS formulations with weathering capability that add savings in life cycle costs. These specials grades effectively resist weather and corrosion. Naturally occurring corrosion eventually forms a protective barrier layer (patina) on the steel that greatly reduces further access to oxygen, moisture, and contaminants. This stable barrier layer resists further corrosion, reducing it to a low value. The increased durability and corrosion resistance of these weathering formulations of HPS result in a longer, maintenance-free bridge life.

When the steel has a weathering capability, the letter “W” becomes a suffix to the grade number. Because all HPS is produced with weathering capability, the grades are 50W, 70W, and 100W. Currently, HPS 50W, 70W and 100W steel plates are available in thicknesses up to 4, 4, and 2.5 inches respectively.

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Weldability—High strength levels in steel are usually achieved by increasing the amount of carbon and other alloys. But high carbon levels make welding difficult, often leading to cracking during construction or in service. To avoid cracking, fabricators and erectors must perform carefully controlled techniques. They must often heat the steel before and after welding, precisely control energy input and temperatures, and regulate welding consumables. These requirements increase fabrication and erection costs.

HPS grades, on the other hand, have been developed to greatly improve weldability and to minimize need for pre- and post-heating. The high strength of HPS comes from heat treatment and rolling processes during manufacture rather than from carbon content. HPS contains low levels of carbon, making it easy to weld under a variety of conditions.

Impact Resistance—The ability to resist impact is a function of climate. The United States divides into climatic zones—Zones 3, 2, and 1—that delineate geographical requirements of impact resistance for bridge steels. The more northern climates constitute Zone 3, while the southern climates are in Zone 1. HPS meets the most critical requirements of Zone 3.

Fracture Toughness—High Performance Steel has much higher fracture toughness than the conventional grades of steel used for bridge construction. HPS makes the transition from brittle to ductile at a much lower temperature than conventional grades. So HPS improves reliability by minimizing the chance of sudden brittle failure.

Having greater fracture toughness, HPS better resists cracks in the bridge structure. This property provides more time for inspectors to detect and repair any fatigue cracks that might develop before the structure becomes unsafe.

Fabrication—Standard shop practices of girders of High Performance Steel may require some modification for drilling, reaming, and mill scale removal. For HPS 70W, drill bits and reamers will dull quickly unless the worked area is flooded with lubricants. To remove mill scale, abrasive blasting is the preferred method. Grinding mill scale from HPS grades has proved difficult.

Enhancing HPS performance

WORK continues on improving the capability of HPS grades. For example, the yield strength of HPS 70W, the most widely used of the HPS grades, tends to

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drop off with plate thickness. To compensate, the steel's manganese content can be increased. For HPS 70W plate thicknesses greater than 2.5 inch, specifications now permit increasing the manganese maximum level from 1.35% to 1.50%. This change avoids the need for re-heat treating the plate to maintain minimum yield strength requirements.

Other studies suggest that for special fracture-critical applications improved impact properties of HPS 70W can be achieved. For example, a minimum Charpy V-Notch level of 50 ft-lb may be possible for test temperatures as low as -25ºF. The HPS steering committee is considering such issues for future upgrades of the specification.

HPS 100W—The most recent development of high-performing bridge steels is the HPS 100W grade. Development work is underway to increase toughness for plate thicknesses of this grade beyond 2.5 inches, which may require increasing the plate's nickel content. The steel chemistries being studied are based on the U.S. Navy's 100 ksi grades.

A recent demonstration project in Nebraska represents the first steel bridge that makes extensive use of 100 ksi steel. This bridge, located near Grand Island, NE, crosses over I-80. It's a two-span steel box bridge with equal spans of 139 feet in length.

Original design for the bridge made use of steel box girders in a hybrid arrangement, with bottom flanges of the box sections using 70 ksi High Performance Steel and webs and top flanges using conventional 50 ksi steel. Then designers substituted 100 ksi HPS for all webs and flanges to demonstrate that fabrication and construction would proceed normally.

Use of HPS allowed designers to increase the span length of each girder beyond the traditional 120 feet, while keeping the total weight of each girder below the 30-ton crane capacity of the local fabricators. In addition, the HPS permitted thinner bottom flanges and reduced web depth. The webs of the HPS girders are perpendicular to the bottom flanges rather than sloped. This significantly reduces fabrication time and cost. The fabricator can use equipment and practices typical for I-beam plate girders.

The Nebraska Department of Roads implemented another innovation for this bridge. Designers initially configured each of the HPS girders as simple spans (abutment to pier). They then made the simple spans continuous by connecting

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each of the two in-line girders with a concrete diaphragm at the pier, making the three HPS bridge girders continuous for live and superimposed loads.

The simple-made-continuous technique eliminated bolted field splicing of the girders, which would normally take place away from the pier and over the traffic below. The concrete “splice” significantly reduced the interruption of traffic and accelerated construction time. In this case, the I-80 highway had to be closed for only 90 minutes for placing the three girders for each span.

The bridge opened to traffic in October 2003, becoming the first 100 ksi HPS bridge in the U.S.

Corrugated Webs—New optimized shapes, designed to replace routine box and I-girder shapes, will further realize the full benefit of the strength and weldability of HPS. In the mid-90s the Advanced Technology for Large Structural Systems (ATLSS) Center at Lehigh University and Modjeski and Masters, Inc., with funding by the Federal Highway Administration, began studying non-traditional steel bridge beam configurations.

One candidate configuration studied was an I-girder with a corrugated steel web. The corrugated web increases web stability, allowing a reduced web thickness without the need for web stiffeners. Increased stability benefits fabrication and erection. Fewer attachments to the web and flanges also improves fatigue performance.

Following initial studies, the next step was to design and build a demonstration bridge, based on design equations and details using finite element analysis, fabrication studies, and applied laboratory research. Research for the extended project included:

Selecting the optimum corrugated shape (trapezoidal or sinusoidal), considering structural performance, fabrication, and manufacturing processes

- Conducting shear and flexural tests to verify design capacities
- Testing bolted splices, and determining fatigue properties.
- Production processes tested included robotic welders on full-size test specimens.

Fabricators studied two different robotic systems: one with the robot stationary while the steel girder advanced, and vice versa. This work represents the first step in using robotic welding for bridge girders in the United States.

Bradford County, PA, became the site of a demonstration HPS bridge with a corrugated web, which was designed by Pennsylvania Department of Transportation (PennDOT). According of Tom Macioce, P.E., a bridge engineer with PennDOT, this two-lane demonstration bridge has two spans. The four lines of steel girders for this bridge have corrugated webs with a trapezoidal configuration. HPS 70W constitutes the web, flanges, and splice plates. The bridge opened for service in July of 2005.

The work toward the corrugated web girders in the demonstration bridge represents the successful culmination of a ten-year development project carried out by Lehigh University, Drexel University, Modjeski and Masters, High Steel Structures, FHWA, and PennDOT.

ASTM A1010—In another development, steels with superior corrosion resistance are being evaluated for challenging bridge applications. ASTM A1010 steels, which have 12% chromium content, now find use in such applications as coal rail cars and coal processing equipment. Accelerated laboratory tests and exposure panels indicate that A1010 outperforms weathering and galvanized steels in wet/dry salt-water environments and outperforms a variety of weathering steels in seaside locations.

A cellular box girder bridge located in a corrosion-prone environment of Colusa County, CA, uses 0.16-inch-thick A1010 steel. Research continues to develop production practices for more traditional bridge applications requiring thicker plate. A1010 steel can be considered when life cycle costs are the paramount criterion. These steels, however, are about twice the cost of grade 50W steels.

What's next

RECENT federal highway legislation known as the Safe Accountable Flexible Efficient Transportation Equity Act: A Legacy for Users (SafeTea-Lu) provides funding for research directed at high-performing steel bridges. The research has two goals: finding low-cost corrosion-resistant grades of steel and reducing maintenance costs through longer lasting coatings. The legislation provides $4.1 million per year for four years for this research, which will likely be carried out by universities under the supervision of the Federal Highway Administration and the National Steel Bridge Alliance.

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Captions

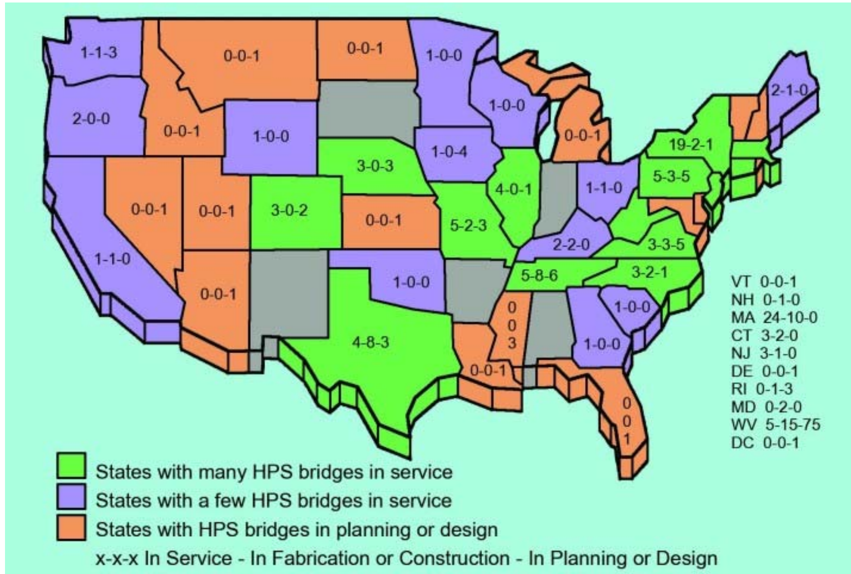

Figure 1. States with bridges using high performance steel as of December 2004.

Photo courtesy of University of Nebraska

Figure 2. Two-span bridge over Interstate 80 near Grand Island, NE. The webs and flanges of the box girders are of 100 ksi weathering High Performance Steel.

Photo courtesy of Lehigh University (Hassan H. Abbas and Richard Sause)

Figure 3. Demonstration bridge in Bradford County, PA, employs girders with corrugated webs in a trapezoidal configuration. The webs, flanges, and splice plates are of weathering High Performance Steel.

Photo courtesy of Mittal Steel

Figure 4. A cellular box girder bridge located in a corrosion-prone environment of Colusa County, CA, uses 0.16-inch-thick A1010 steel with 12% chromium content.