HIGH PERFORMANCE STEEL DESIGNERS' GUIDE

Second Edition, April 2002

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HIGH PERFORMANCE STEEL DESIGNERS' GUIDE

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T A B L E OF C O N T E N T S

Substantial effort has been made to assure that all data and information in this HPS Designers' Guide are accurate and useful to the designers in considering high performance steels in their bridge projects. This should not be considered as an official document for guidance on design and fabrication. The data and information may change with time. The designers must verify the accuracy and appropriateness of the data and information before finalizing the design and special provisions. Although this Guide is intended for use by designers competent in the design of highway bridges, the team leaders, supervisors, and managers of bridge engineering, and the general readers may also find the Guide helpful in gaining better understanding of the properties and benefits of high performance steels.

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1.0 INTRODUCTION

In 1994, a cooperative research program between the Federal Highway Administration (FHWA), the U.S. Navy and the American Iron and Steel Institute (AISI) was launched to develop high performance steels for bridges. A Steering Committee of experts from FHWA, Navy, AISI, and plate producing member companies, steel fabricators and American Welding Society (AWS) was formed to oversee and guide the research.

The initial research program was to develop HPS 70W and HPS 100W, weathering steel grades, with toughness Zone 3 requirements, and with significant improvement in weldability [1]. With the successful use of HPS 70W, bridge engineers are requesting an HPS version of 50W grade steel. They are interested in the higher toughness and improved weldability. HPS 50W and HPS 70W grades are now commercially available and the HPS 100W is in development. This HPS Designers' Guide only covers HPS 50W and HPS 70W.

HPS 70W has been most extensively researched, tested and used to date. As of this writing, a total of about 21 HPS 70W steel bridges are in service and 13 more bridges are in various stages of construction nationally. Many are ready for construction, being designed and in the planning stage. HPS 50W is only available and used recently.

The following four documents cover the design, fabrication and construction of steel bridges using high performance steels:

1. AASHTO LRFD Bridge Design Specifications with Interims (AASHTO LRFD).
2. AASHTO Standard Specifications for Highway Bridges, 16^{th}. Edition, 1996, 2000 Interim (AASHTO LFD)
3. AASHTO Guide Specifications for Highway Bridge Fabrication with HPS 70W Steel (AASHTO HPS Guide)
4. ANSI/AASHTO/AWS D1.5-95 Bridge Welding Code with Addendums (AWS Code).

These documents reflect the findings and experiences on the applications of HPS by researchers, fabricators, manufacturers, owners and engineers working with high performance steels, and are the best references, as they are modified over time. The designers must make sure that all or parts of these documents are made a part of the contract document and add any supplemental requirements in the project special provisions.

This HPS Designers' Guide discusses the key elements of the above four documents as applied to high performance steels, identifies factors that should be considered, and provides sources and references where designers can obtain additional information to assure successful use of HPS in highway bridge construction. This Guide will be updated periodically to keep pace with the latest developments in HPS, and as AASHTO and AWS modify their codes to reflect new research findings and construction experiences.

2.0 MATERIAL PROPERTIES

The AASHTO Subcommittee on Bridges and Structures, and the AASHTO T-14 Technical Committee for Structural Steel Design continues to review and adopt new specifications as the research and development of HPS progresses. They have modified the AASHTO LRFD Section 6.4.1 to include ASTM A709 Grade HPS 70W as a replacement of AASHTO M270 Grade 70W.

2.1 Chemical Requirements (ASTM A709-0)

The chemistry for HPS 70W (HPS 485W) and HPS 50W (HPS 345W) is shown in the following table:

Table 2.1.1 - Chemistry for Convention and High Performance Steels

		C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Al	N
Old 70W *	Min.	-	.80	-	-	.25	.20	-	.4	-	.02	-	
	Max.	.19	1.35	.035	.04	.65	.40	.50	.70	-	.10	-	
HPS 70W &	Min.	-	1.10	-	-	.30	.25	.25	.45	.02	.04	.010	
HPS 50W	Max.	.11	1.35	.020	.006	.50	.40	.40	.70	.08	.08	.040	.015

* The conventional ASTM and AASHTO 70W grade steel has been replaced by HPS 70W grade steel.

HPS 70W is produced by quenching and tempering (Q&T) or Thermal-Mechanical Controlled Processing (TMCP). Because the Q&T processing limits plate lengths to 50 ft. (15.2 m) in the U.S., TMCP practices have been developed to produce HPS 70W up to 2 inches (50 mm) thick and to 125 feet (38 m) long, depending on the weight.

The chemistry for HPS 50W grade steel is the same as HPS 70W shown in the table above. ASTM A709 Grade HPS 50W is contained in A709-01 and is produced using conventional hot-rolling or controlled rolling up to 4" thick in lengths similar to Grade 50W steel.

2.2 Mechanical Property Requirements (ASTM A709-01)

Table 2.2.1 - Mechanical Properties for High Performance Steel Plates

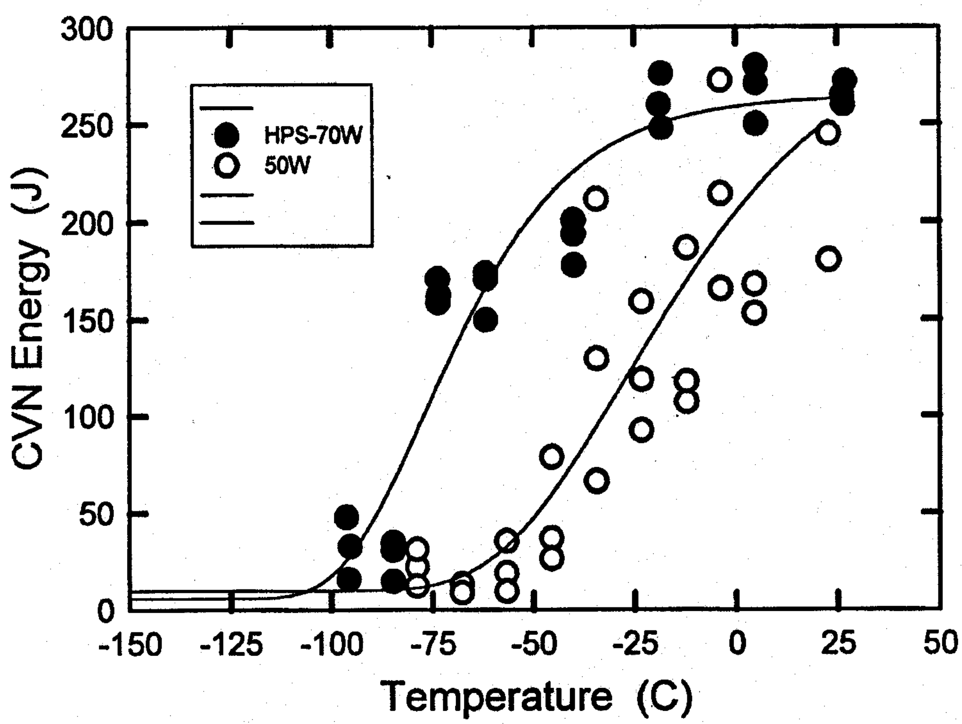
	HPS 50W Up to 4" As-Rolled	HPS 70W Up 4" (Q&T). 2" (TMCP)
Yield Strength, Fy, ksi (MPa) min.	50 (345)	70 (485)
Ultimate Tensile Strength, Fu ksi (MPa)	70 (485)	85-110 (585-760)
CVN, minimum* Longitudinal orientation	25 ft.-lbs. (41 J)@ 10^{O}F (-12^{O}C)	30 ft.-lbs. (48 J)@ -10^{O}F (-23^{O}C)

* One of the goals of the research program is to develop HPS with CVN toughness meeting the requirements of Zone 3. CVN tests show that HPS have CVN toughness far exceeding these minimum levels. Specification minimum requirements for fracture critical designs are 5 ft-lbs higher than the values shown in Table 2.2.1.

2.3 Fatigue and Fracture Properties

The fatigue resistance of high performance steels is controlled by the welded details of the connections and the stress range, as is the case for conventional steels. The fatigue resistance is not affected by the type and strength of steels. Tests on high performance steel conclude that the fatigue categories given in the AASHTO LRFD, Section 6.6.1 Fatigue also apply to high performance steel welded details.

The fracture toughness of high performance steels is much higher than the conventional bridge steels. This is evident from Figure 2.3.1, which shows the Charpy V-Notch (CVN) transition curves for HPS 70W(HPS 485W)and conventional AASHTO M270 Grade 50W steel. The brittle-ductile transition of HPS occurs at a much lower temperature than conventional Grade 50W steel. This means that HPS 70W(HPS 485W) remains fully ductile at lower temperatures where conventional Grade 50W steel begins to show brittle behavior.



T_F °F = 1.8 (T_C °C) + 32
1 ft.-lb. = 0.729 J

Fig. 2.3.1 CVN Transition Curve [2]

The current AASHTO CVN toughness requirements are specified to avoid brittle failure in steel bridges above the lowest anticipated service temperature. The service temperatures are divided into three zones as shown in Table 2.3.1 below.

Table 2.3.1 - Temperature Zones for CVN Requirements

Minimum Service Temperature	Temperature Zone
0°F and above	1
Below0° to –30°F	2
Below –30°F to –60°F	3

The AASHTO CVN requirements for these zones are shown in Table 6.6.2-2 Fracture Toughness Requirements in the AASHTO LRFD. The HPS 70W(485W) steels tested so far show ductile behavior at the extreme service temperature of -60°F for Zone 3. It is a major accomplishment of the HPS research and an important advantage of HPS in controlling brittle fracture.

With higher fracture toughness, high performance steels have much higher crack tolerance than conventional grade steels. Full-scale fatigue and fracture tests of I-girders fabricated of HPS 70W (485W) in the laboratory showed that the girders were able to resist the full design overload with fracture even when the crack was large enough to cause 50% of loss in net section of the tension flange [2]. Large crack tolerance increases the time for detecting and repairing fatigue cracks before the bridge becomes unsafe.

2.4 Weldability

A main thrust of the HPS Research Program is to develop bridge steels with significantly improved weldability [3]. Improving weldability reduces the high cost of fabrication associated high preheat temperatures, heat input control, post-weld treatment, and other stringent controls, and to eliminate hydrogen induced cracking in the weldment.

Hydrogen induced cracking, also known as delayed cracking or cold cracking, has been one of the most common and serious problems encountered in steel weldments in bridges. The common source of hydrogen is from moisture. Grease, oxides and other contaminants are also potential sources of hydrogen. Hydrogen from these sources can be introduced into the weld region through the welding electrode, shielding materials, base metal surface and the atmosphere.

Hydrogen-induced cracking can occur in the weld heat affected zone (HAZ) and in the fusion zone (FZ). While the reasons for cracking are the same, controlling the factors that cause cracking can be different for the HAZ and FZ. For the HAZ, control of cracking comes from the modern steel-making processes, which incorporate means to avoid susceptible microstructures and eliminate sources of hydrogen in the base metal (steel) and using proper welding techniques, including preheat and heat input. For the FZ, control of susceptibility to hydrogen-induced cracking is achieved by adding alloying elements in the consumables, and using proper welding techniques, including preheat and heat input.

The most common and effective method of eliminating hydrogen-induced cracking is specifying minimum preheat and interpass temperature for welding. In general, the higher the preheat the less chance for formation of brittle microstructures and more time for the hydrogen to diffuse from the weld. However, preheating is time consuming and costly. One of the goals in developing high performance steels is to reduce or eliminate preheat. This goal has been successfully accomplished as shown in Table 2.4-1 below:

Table 2.4-1 Minimum Preheat and Interpass Temperature

	Diffusible Hydrogen = H4*			
	To ¾”	Over ¾” to 1 ½”	Over 1 ½” to 2 ½”	Over 2 ½”
Grade 70W	50°F (10°C)	125°F (52°C)	175°F (79°C)	225°F (107°C)
HPS 70W	50°F (10°C)	70°F (21°C)	70°F (21°C)	125°F (52°C)

* Denotes the level of hydrogen measured in the laboratory in terms of milliliter per 100 grams of deposited weld metal, e.g. H4 means 4 ml/100g of diffusible hydrogen in the weld metal.

Minimum preheat for HPS 50W has not yet been established. It is the subject of ongoing research. The conservative approach is to specify the same preheat requirements as for M270 Grade 50W. On the other hand, the chemistry for HPS 50W is the same as for HPS 70W, it is reasonable to expect that the welding procedures for HPS 50W will be somewhat less stringent. In general, the AWS D1.5 Bridge Welding Code can be used for the fabrication of HPS 50W steel. However, until research results and fabrication experiences on the weldability of HPS 50W are available, the designers should specify weld procedures and qualification tests on a project-by-project basis.

2.4.1 AASHTO HPS Guide and AWS Code

The AASHTO HPS Guide and AWS Code contain supplementary welding provisions applicable to HPS. The designers should make sure that the applicable provisions of these two documents are made a part of the contract documents. Some key elements pertaining to welding of HPS are:

- The use of only low-hydrogen practices when reduced preheat is to be used.
- Only submerged arc (SAW) and shield metal arc (SMAW) welding processes are recommended for HPS. Research is ongoing for the use of gas metal arc (GMAW) welding process.
- The diffusible hydrogen level is limited to a maximum of 8 mL/100g (H8). SAW consumables should be handled such that the diffusible hydrogen is controlled to a level of H4 maximum if reduced preheat is to be used. SMAW consumables may meet level H4 or H8.
- Consumables with matching weld strength are recommended for SAW complete penetration groove welds connecting Grade HPS 70W plates. Consumables with undermatched weld strength are strongly recommended for all fillet welding. The designers should specify on the contract drawings or special provisions where undermatched fillet welding is permitted or required.
- For connecting HPS 70W to Grade 50W, consumables satisfactory for Grade 50W base metals are considered 'matching' strength. However, it is recommended that the diffusible hydrogen level be limited to H4 or H8.

2.4.2 Lessons Learned

- SAW consumable combination of Lincoln LA85 electrode and MIL800HPNi flux consistently produces acceptable quality weld metal. This applies to both Q&T and TMCP products.

- For first-time fabrication of HPS, it is beneficial to perform weld procedure qualification tests on mock-ups of HPS butt welds and HPS to Grade 50W butt and fillet welds using consumable combination proposed for the production welds prior to starting fabrication.
- Improved weldability still needs care and good workmanship to produce quality welds.
- The AISI Website (www.steel.org/infrastructure/bridges) contains a wealth of information on HPS and updates to the AASHTO HPS Guide.
- The cost effectiveness of HPS has been demonstrated by the design and construction of HPS bridges by many states.

2.5 Weathering Characteristic

It was part of the initial research objective to develop HPS with "weathering characteristic", meaning HPS should have the ability to perform without painting under normal atmospheric conditions. HPS steels have slightly better atmospheric corrosion resistance than the conventional grade 50W or 70W steels. For example, as measured in accordance with ASTM G101, the atmospheric corrosion resistance index (CI) for conventional Grade 70W is 6.0, while the index for HPS 70W is 6.5. Long-term atmospheric corrosion tests are underway to further support this projection.

The designers should follow the same guidelines and detailing practice for conventional weathering grade steels to assure successful applications of HPS steels in the unpainted conditions. Guidelines for proper application of unpainted weathering steels in highway bridges may be found in the FHWA Technical Advisory T 5140.22, Uncoated Weathering Steel in Structures, dated October 3, 1989.

3.0 DESIGN FEATURES

High performance steels give the designers another option to achieve durable and cost effective steel bridges [4]. HPS design follows the same design criteria and good practice as provided in Section 6 Steel Structures of the AASHTO LRFD Bridge Design Specifications.

Use of HPS 70W generally results in smaller members and lighter structures. The designers should pay attention to deformations, global buckling of members, and local buckling of components. The Service Limit State should be checked for deflection, handling, shipping and construction procedures and sequences.

The live load deflection criteria is considered optional as stated in Section 2, Article 2.5.2.6.2 of the AASHTO LRFD. The reason for this is that past experience with bridges designed under the previous editions of the AASHTO Standard Specifications has not shown any need to compute and control live load deflections based on the heavier live load required by AASHTO LRFD. However, if the designers choose to invoke the optional live load deflection criteria specified in Article 2.5.2.6.2, the live load deflection should be computed as provided in Section 3, Article 3.6.1.3.2 of the AASHTO LRFD. It may be expected that HPS 70W steel designs would exceed the deflection limit of L/800. The designers have the discretion to exceed this limit or to adjust the sections by optimizing the web depth and/or increasing the bottom flange thickness in the positive moment region to keep the deflection within limit.

The AASHTO HPS Guide encourages the use of hybrid girders, i.e. combining the use of HPS 70W and Grade 50W steels. A hybrid combination of HPS 70W in the negative moment regions and Grade 50W or HPS 50W in other areas results in the optimum use of HPS and attain the most economy.

3.1 HPS Design Experience

Many State Departments of Transportation and other agencies have designed and constructed HPS bridges. Several organizations have done comparative designs to optimize the use of HPS in combination with other grades of steels. Brief descriptions of the design experience and cost studies of some of the State DOTs and organizations are given in the following sub-sections.

3.1.1 First HPS 70W Bridge

Nebraska DOT was the first to use HPS 70W in the design and construction of the Snyder Bridge - a welded plate girder steel bridge (See Photo 3.1.1).

The bridge was opened to traffic in October 1997. It is a 150-foot simple span bridge with 5 lines of plate girders of 4' 6" deep. The original design utilized conventional grade 50W steel. When HPS first became available, Nebraska DOT replaced the grade 50W steel with HPS 70W steel of equal size. The intent was to use this first HPS 70W bridge to gain experience on the HPS fabrication process. The fabricators concluded that there were no significant changes needed in the HPS fabrication process.

Photo 3.1.1 Snyder Bridge

3.1.2 The Nebraska HPS Two-Box Girder System [5]

The Nebraska DOT in cooperation with the National Bridge and Research Organization commissioned J. Muller International to develop an innovative concept optimizing the use of HPS. The result of this initiative is a two-box girder bridge with full depth composite deck system. The cross section of the system is shown in Figure 3.1.2. This system has two spans of 120 feet each. It is designed for two lanes of traffic with wide shoulder, measuring 44' curb to curb. The system can be used for new bridges and to replace many existing grade separation structures.

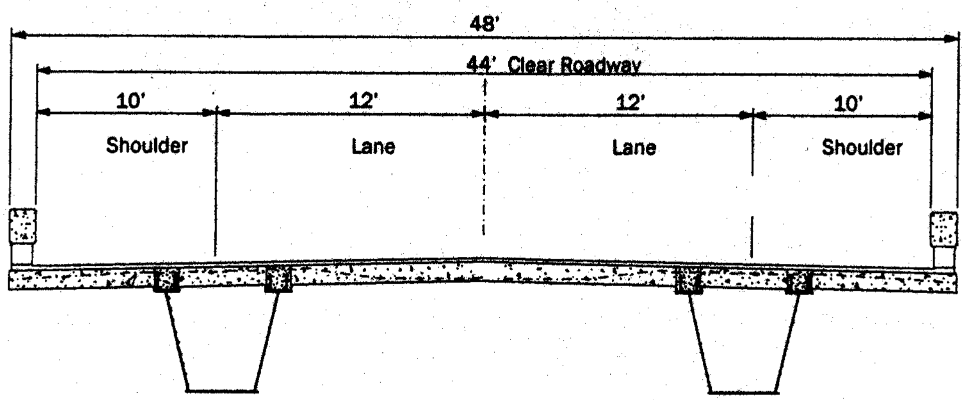


Fig. 3.1.2 Nebraska HPS Twin-Box

A two-box girder system was selected because of its simplicity, small size, and efficiency of load distribution, stability for handling and erection, and robustness against vehicle impact. The substructure might be semi-integral or fully integral abutment to eliminate joints and bearings. The superstructure might be semi-continuous or continuous for live load only, or fully continuous for dead load and live load.

3.1.3 HPS Cost Study [6]

HDR Engineering, Inc. in association with the University of Nebraska-Lincoln performed a study to compare the cost differences between bridge designs using HPS 70W, conventional grade 50W and a combination of the two grades of steels. A total of 42 different girder designs were made using the AASHTO LRFD Bridge Design Specifications - HL-93 Live Load. The girder designs had 2-span continuous layout, covering a span range of 150', 200' and 250', variable girder spacing of 9' and 12', and designs in grade 50W, HPS 70W and a variety of hybrid combinations.

The following unit cost data was obtained from the fabricators and used in the relative cost comparison of the various designs:

	Material Cost*	Fabricated Cost*
Grade 50W	$0.40/lb.	$0.61/lb.
HPS 70W Q&T	$0.54/lb.	$0.75/lb.
HPS 70W TMCP	$0.51/lb.	-

* These costs are subject to change. Contact NSBA for the most current information.

The study concludes that:

(1) HPS 70W results in weight and depth savings for all span lengths and girder spacing.

(2) Hybrid designs are more economical for all of the spans and girder spacing. The most economical hybrid combination is grade 50 for all webs and positive moment top flanges, with HPS 70W for negative moment top flanges and all bottom flanges.

(3) LRFD treats deflection as an optional criteria with different live load configurations. If a deflection limit of L/800 is imposed, deflection may control HPS 70W designs for

shallow web depth.

3.1.4 Tennessee Experience [7]

In 1996, Tennessee Department of Transportation (TNDOT) was completing the design of the SR53 Bridge over the Martin Creek using ASTM A709 Grade 50W steel (See Photo 3.1.4). It was TNDOT's first steel bridge design utilizing the new AASHTO LRFD Bridge Design Specifications. The bridge consisted of two 235.5-foot spans, carrying a 28-foot roadway on three continuous welded plate girders spaced at 10' 6" on centers.

Photo 3.1.4 Martin Creek Bridge

At about the same time, HPS 70W steel became available. With support from FHWA, TNDOT offered to test the application of HPS 70W in an actual bridge. In order to provide a true comparison, TNDOT optimized the redesign using HPS 70W for the girders and Grade 50W shapes for the cross-frames. The HPS redesign resulted in 24.2% reduction in steel weight and 10.6% savings in cost. The weight and cost savings of the HPS 70W bridge are shown below.

	Conventional Grade 50W	HPS 70W & Grade 50W
Steel Weight	675,319 lb.	511,908 lb.
In-Place Cost	$1.00/lb. *	$1.18/lb. **
Total Steel Cost	$675,319	$604,051

* Construction cost in Tennessee in 1996
** This unit cost includes change orders for $25,000 for additional shop splices and $10,000 for change in welding flux.

The bridge was opened to traffic in February 1998. Since then, TNDOT has completed two more HPS 70W bridges. The TNDOT is satisfied with the three HPS 70W bridges constructed to date. TNDOT is currently designing a fourth project utilizing HPS 70W TMCP for webs and flanges, and HPS 50W in other members. The use of HPS has become a routine practice in Tennessee.

Some of Tennessee's optimization techniques are:

- Use uncoated HPS steels.
- Use HPS 70W steel for flanges and webs over interior supports, where moments and shears are high.
- Use hybrid girder sections for composite sections in positive bending, where moments are high, but shears are low.
- Use undermatching fillet welds with HPS 70W to reduce cost of consumables.

- Use constant width plates to the greatest extent possible. Consider plate width changes at field splices wherever practical.
- Consider waiving live load deflection limits for lane loads.
- Use TMCP plates to greatest extent possible.
- Use the new AASHTO Guide For Highway Bridge Fabrication With HPS 70W Steel. Recommendations in the Guide should be followed, with no more stringent requirements added.

3.1.5 Pennsylvania Experience [8]

The Pennsylvania Department of Transportation (PennDOT) has used HPS 70W in the Ford City Bridge, which was opened to traffic in July 2000. PennDOT performed full-scale tension and fatigue testing, extensive material testing and weld testing on this project.

It is a three-span continuous welded steel plate girder bridge with spans of 320'-416'-320'. The first span is curved horizontally with a radius of 508'. The other two spans are on tangent. There are four lines of girders spaced at 13.5'. HPS 70W is used in the negative moment regions and grade 50W elsewhere. This hybrid combination of steels resulted in 20% reduction in steel weight, and enabled the girder sections to be constant depth instead of haunched. By eliminating the variable web depth, a costly longitudinal bolted web splice was avoided.

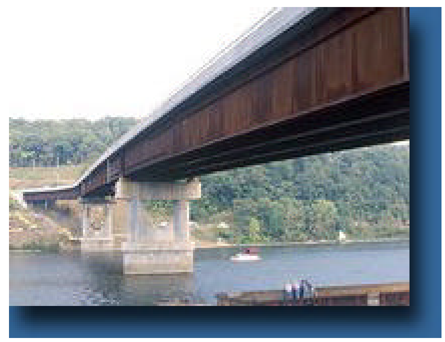


Photo 3.1.5 Ford City Bridge

PennDOT has several HPS bridges under construction and design. PennDOT is sponsoring research to realize additional benefits from HPS. It intends to construct an HPS demonstration bridge with innovative corrugated web I-girder. PennDOT is optimistic that HPS will reduce bridge construction costs.

3.1.6 New York State Thruway Authority Experience [9]

The New York State Thruway Authority (NYSTA) participated in a cooperative agreement with the Federal Highway Administration (FHWA) to evaluate and document the use of HPS 70W on bridges fabricated and constructed at various locations on the limited access highway system. Under this agreement, NTSTA constructed 7 structures.

The first project was the Berkshire Thruway over the Muitzes Kill Bridge using HPS 70W. It is a 200 ft. long simple-span, jointless bridge carrying two lanes of traffic and consisting of six 72 in. deep plate girders spaced at 8 ft. centers. This bridge was originally designed as a two-span structure using conventional Grade 50W steel. The plans were revised to take advantage of the strength of HPS 70W by eliminating an interior pier.

Photo 3.1.6-1 Berkshire over Muitzes Kill Bridge

The second project was the I-90 Exit 54 Interchange Overpass. It is a two-span, jointless bridge consisting of nine 29 in. deep plate girders spaced at 7.5 ft. centers. The span lengths are 105.5 ft. and 98.5 ft. The primary stress-carrying members, including stiffeners and connection plates, were fabricated of HPS 70W steel. The secondary members were fabricated of Grade 50W steel.

Photo 3.1.6-2 I-90 Exit 54 Interchange Overpass

Next, a series of five bridges that carry local traffic over I-90 were constructed of HPS 70W steel. The NYSTA engineers took advantage of the high strength of HPS 70W to design two-span jointless structures to replace the existing deficient four-span structures. A typical two-span structure is similar to that shown in Photo 3.1.6-2, and consists of 5 lines of 29 in. deep plate girders spaced at 7.5 ft. centers. The span lengths are 100 ft. each.

For all these bridges, weld procedure qualification tests and diffusible hydrogen tests were conducted prior to commencing fabrication. These tests used the submerged arc welding (SAW) process with matching consumables, i.e. Lincoln LA-100 electrodes in combination with Lincoln Mil800H flux. These bridges were welded in accordance with the Guide for Highway Bridge Fabrication with HPS 70W Steel.

NYSTA concludes that the 40% higher yield strength of HPS 70W over Grade 50W gives the engineers liberty to design longer, shallower spans when strength is the controlling limit state. NYSTA has found this to be beneficial when replacing simply- supported, multi-span structures with continuous-span structures. Should piers could be eliminated without increasing the depth of the girders and vertical clearance increased with little or no modification to the bridge approaches.

4.0 CONSTRUCTION SPECIFICATIONS

The provisions of the steel section of the State Standard Specifications for Roadway and Bridge Construction and the steel bridge Special Provisions are generally applicable to HPS, except for modifications as noted in the AASHTO HPS Guide and this HPS Designers' Guide, and supplemented with construction experience and research findings. A sample HPS construction specification is given in Appendix A - Sample HPS Special Provisions.

The AASHTO Guide Specifications for Highway Bridge Fabrication with HPS 70W Steel is now available exclusively through AASHTO, which can be ordered within the U.S. by calling the toll-free number (1-800-231-3475) or entering the bookstore online at www.transportation.org.

The book code for the fabrication guide is HBF-1. Updates to this document will be initially available on the AISI website.

Fabricators of HPS have reported varied experiences with drilling HPS 70W Q&T steel. The experiences range from "no difference than Grade 50W steel" to "drills and reamers dull quickly". The HPS Steering Committee recommends that drilled or reamed holes be flooded with lubricant during drilling or reaming. Fabricators also note that mill scale removal by descaler or grinding is very difficult for the HPS Q&T steel, and mill scale removal by abrasive blasting requires about the same work effort as Grade 50W steel.

Fabricators report that there is no difference in flame cutting procedures when compared with Grades 36, 50 or 50W steels. Flame cut edges of HPS steels do not get excessively hardened (RC30 or higher) as in the case of flame cut edges of grade 50W steel. It is prudent to verify this in the first couple of HPS projects.

Predicting pre-cut camber gain or loss requires experimentation, especially with Q&T steels.

Welding of HPS 70W steel is currently restricted to the submerged arc and shielded metal arc welding processes for both Q&T and TMCP products. Other arc welding processes are being studied. It is expected that other welding processes commonly used in bridge fabrication will be approved in due course.

5.0 AVAILABILITY AND COST

5.1 Availability

Currently, HPS 50W and HPS 70W steels are available in plates only in thicknesses shown in Table 2.2.1. Steel producers will welcome inquiry for custom orders of special sizes. The delivery time is approximately 6 to 10 weeks depending on market demand.

Based on industry information, the steel industry has responded to a market demand of over 400,000 tons of steel bridge fabrication in 1999 and 2000. The industry capacity for steel production is expected to be much greater in 2001 and beyond. Steel producers are well positioned to meet the growing demands for HPS in the years ahead.

5.2 Cost

The approximate unit prices for materials, fabricated members and in-place cost of steel structures are shown below:

	Material	Fabricated	In-Place
Grade 50W	\$0.35-0.42/lb.	\$0.55-0.62/lb.	\$1.00-1.25/lb.
HPS 50W	\$0.42-0.50/lb.	\$0.63-0.71/lb.	\$1.15-1.40/lb.
HPS 70W Q&T	\$0.48-0.60/lb.	\$0.75-0.83/lb.	\$1.18-1.50/lb.
HPS 70W TMCP	\$0.45-0.57/lb.	\$0.70-0.78/lb.	\$1.15-1.45/lb.

The actual unit cost for a project is expected to vary from region to region, from structure to structure depending on complexity, and to change based on market conditions. For the most current information, contact NSBA.

5.3 Producers

Presently, the following three manufacturers produce HPS steels:

- Bethlehem-Lukens Plate
  Modena Road
  Coatesville, PA 19320 and
  Box 248
  Chesterton, IN 46304
  Contact Person: Alex Wilson
  Phone: 610-383-3105
  E-Mail: alex.wilson@bethsteel.com
- Oregon Steel Mills
  14400 N Rivergate Boulevard
  Portland, OR 97203
  Contact Person: Joe Rosmus
  Phone: 503-978-6139
  E-Mail: rosmusj@osm.com
- U.S. Steel
  Plate Products, M.S. 42A
  One North Broadway
  Gary, IN 46402
  Contact Person: Mance Parks
  Phone: 219-888-1822
  E-Mail: mhparks@USS.com

The following industry organizations are very helpful in providing technical information regarding the design, specifications and fabrication of steel bridges using high performance steels:

- American Institute of Steel and Iron (AISI)
  Contact Persons: Camille Rubeiz, Director
  Phone: (202)452-7100
  E-Mail: Crubeiz@steel.org

  Roy Teal, Consultant
  Phone: 518-283-7278
  E-Mail: royteal@aol.com

- National Steel Bridge Alliance (NSBA)
  Contact Persons: Arun Shirole, Executive Director
  Phone: 612-591-9099
  E-Mail: shirole@aiscmail.com

Lynn Iaquinta, Regional Director (Western States)
Phone: 509-926-9507
E-Mail: iaquinta@aiscmail.com

These plate producers and industry organizations can best provide the latest project specific information on availability, delivery schedule and cost.

5.4 Suppliers and Fabricators

It is important that the designers establish open communication with the local suppliers and the fabricators of HPS steels. The communication should start from preliminary design to final design and PS&E. This open communication between parties with specific knowledge and experience will lead to cost effective design and successful construction. The latest information on availability and cost can best be obtained from local suppliers and fabricators when the PS&E is almost complete and the Engineer's Cost Estimate is being prepared.

The following industry representatives have extensive experience on the development and application of HPS. They will be happy to help designers with questions on HPS materials, fabrication and welding:

- Alexander Wilson, Customer Technical Service Manager, Bethlehem Steel Corporation, and Chairman of the High Performance Steel Steering Committee
  Phone: 610-383-3105 E-Mail: alex.wilson@bethsteel.com
- Duane Miller, Manager, Engineering Services, Lincoln Electric Company
  Phone: 216-383-2196 E-Mail: duane_miller@lincolnelectric.com
- Scott Kopp, Welding Technician, High Steel Structures, Inc.
  Phone: 717-390-4232 E-Mail: skopp@high.net

5.5 FHWA

The following individuals from FHWA can also provide information on research, design, fabrication and construction for cost effective use of HPS:

- James Cooper, Chief, Bridge Division
  Phone: 202-366-4589 E-Mail: james.cooper@fhwa.dot.gov
- Ben Tang, Senior Structural Engineer
  Phone: 202-366-4592 E-Mail: benjamin.tang@fhwa.dot.gov
- William Wright, Research Structural Engineer
  Phone: 202-493-3053 E-Mail: bill.wright@fhwa.dot.gov
- John Hooks, Team Leader, Bridge Technology Deployment
  Phone: 202-366-6712 E-Mail: john.hooks@fhwa.dot.gov
- Vasant Mistry, Steel Bridge Specialist
  Phone: 202-366-4599 E-Mail: vasant.mistry@fhwa.dot.gov
- Krishna Verma, Welding Engineer
  Phone: 202-366-3077 E-Mail: krishna.verma@fhwa.dot.gov
- Roland Nimis, Team Leader, Structural Engineer
  Phone: 415-744-2653 E-Mail: roland.nimis@fhwa.dot.gov
- Myint Lwin, Structural Design Engineer

Phone: 415-744-2660 E-Mail: myint.lwin@fhwa.dot.gov

5.6 State Departments of Transportation

The following State Departments of Transportation have completed HPS steel bridges and have performance experience to share with the designers:

- Lyman Freemon, Bridge Engineer, Nebraska Department of Roads/Bridge Division
  Phone: 402-479-4701 E-Mail: lfreemon@dor.state.ne.us
- Edward Wasserman, Civil Engineering Director, Division of Structures, Tennessee Department of Transportation
  Phone: 615-741-3351 E-Mail: epwasserman@mail.state.tn.us
- Scott Christie, Chief Bridge Engineer, Pennsylvania Department of Transportation
  Phone: 717-787-2881 E-Mail: rschristie@hotmail.com
- James O'Connell, Deputy Chief Engineer (Structures), New York State Department of Transportation
  Phone: 518-457-6827 E-Mail: joconnell@gw.dot.state.ny.us
- Peter Stapf, New York State Thruway Authority, Structural Design Bureau
  Phone: 518-436-2928 E-Mail: peter_stapf@thruway.state.ny.us
- Ralph Anderson, Engineer of Bridges and Structures, Illinois Department of Transportation
  Phone: 217-782-2124 E-Mail: andersonre@nt.dot.state.il.us

5.7 Academia

The following researchers/professors are actively involved in HPS applied research:

- Atorod Azizinamini, Director, National Bridge Research Organization (NaBRO)
  Phone: 402-472-5106 E-Mail: aazizi@unlserve.unl.edu
- John Fisher, Co-Director, ATLSS Center
  Phone: 610-758-3535 E-Mail: jwf2@lehigh.edu
- Dennis Mertz, Associate Professor, University of Delaware
  Phone: 302-831-2735 E-Mail: mertz@ce.udel.edu
- Yoni Adonyi, Professor, LeTourneau University
  Phone: 903-233-3241 E-Mail: adonyiy@letu.edu

5.8 Websites

The following websites contain a wealth of information on research, design, fabrication, construction, committee and advisory group activities, conferences and other technical aspects of HPS. They also link to other websites for additional information.

- The American Iron and Steel Institute (AISI) Website:
  http://www.steel.org/infrastructure/bridges
- FHWA, Office of Bridge Technology Website:
  http://www.fhwa.dot.gov/bridge
- National Bridge Research Organization (NaBRO), University of Nebraska-Lincoln, website:
  http://www.nabro.unl.edu

6.0 RESEARCH

The transition from research to practice has been very swift for high performance steels. In less than 3 years after the initiation of the joint research effort by AISI, FHWA and the Navy, HPS 70W steel plates became commercially available and used successfully by Nebraska, Tennessee, the New York State Thruway Authority and others for bridge design and construction. Many states are now using HPS steels. With continuing funding from the steel industry, state and federal governments, the HPS Research Program will continue to make improvements in material, design, fabrication and construction.

A key source of practical research ideas comes from the designers. As the designers work with HPS steels, issues relating to design, fabrication, construction, inspection will arise. Many of these issues will be solved by referring to this HPS Designers' Guide and/or contacting the sources listed in this Guide. There will be more difficult issues that cannot be solved readily. These difficult and more complex issues are potential topics for research.

The designers are encouraged to develop research problem statements on topics of state and national interest. Each year, State DOTs, FHWA, AASHTO, TRB and other research organizations are looking for research ideas for providing practical solutions and advancing the state-of-the-knowledge of bridge engineering.

The format for and a sample of research problem statement are shown in Appendix B. Research problem statements may be submitted to the Research Director, Office of Research, State DOT; Chairman, AASHTO Technical Committee for Research (T-11); Chairman, TRB Committee A2C02 Steel Bridges; and other research organizations.

The author is Chairman of the Subcommittee on Research Needs, TRB Committee A2C02 Steel Bridges. The author will be happy to help with preparing research problem statements and make recommendations for submitting them through the proper channel.

7.0 STATES WITH HPS BRIDGES

As of November 2001, 121 HPS bridges are at various stages of design and construction as noted below:

In-Service	21 bridges
Construction	13 bridges
Fabrication	11 bridges
Design	67 bridges
Planning	9 bridges

A listing of these bridges is given in Appendix C HPS Scoreboard. The list is maintained, updated and posted in the AISI website (www.steel.org/infrastructure/bridges). The designers can help keep the HPS Scoreboard current by furnishing to AISI basic information on HPS bridges from time of preliminary design through completion of construction.

Currently, California, Colorado, North Dakota, Oregon, Washington and Wyoming of the WRC states have HPS bridges under design, construction or in service.

8.0 CLOSING REMARKS

The development of high performance steels is a very successful story of putting research into practice in a very short span of time. It exemplifies the vision and leadership of a strong and collaborative partnership between governmental agencies, industry and academia. In recognition of the accomplishments of the joint effort, the Civil Engineering Research Foundation (CERF) awarded the Charles Pankow Award to AISI, FHWA and the Navy.

The cost effective application of HPS in bridge design and construction has already been demonstrated by the performance experience of in-service HPS bridges in many states as shown in Appendix C HPS Scoreboard. The major benefits of HPS are noted below.

- The high strength of HPS allows the designers to use fewer lines of girders to reduce weight and cost, use shallower girders to solve vertical clearance problem, and increase span lengths to reduce the number of piers on land or obstructions in the streams.
- Improved weldability of HPS eliminates hydrogen induced cracking, reduces the cost of fabrication by lower preheat requirement, and improves the quality of weldment by using low hydrogen practices.
- Significantly higher fracture toughness of HPS minimizes brittle and sudden failures of steel bridges in extreme low service temperatures. Higher fracture toughness also means higher cracking tolerance, allowing more time for detecting and repairing cracks before the bridge becomes unsafe.
- Good ‘weathering characteristics’ of HPS assures long-term performance of unpainted bridges under atmospheric conditions.
- Optimized HPS girders can be attained by using a hybrid combination of HPS 70W in the negative moment top and bottom flanges, and Grade 50W or HPS 50W in other regions.
- Optimized HPS girders have shown to result in lower first cost and are expected to have lower life-cycle cost.

High performance steels are justifiably claimed to be ‘The Bridge Construction Material for the New Century.’

9.0 REFERENCES

1. E.M. Foch and T.W. Montemarano, “Development of High Performance Steels for Bridge Construction, “ Proceedings of the International Symposium on High Performance Steels for Structural Applications, October 30-November 1, 1995, ASM International, Metals Park, OH, pp 141-154.

2. J.W. Fisher and W.J. Wright, “High Toughness of HPS: Can It Help You in Fatigue Design,” Conference Proceedings , Steel Bridge Design and Construction for the New Millennium with emphasis on High Performance Steel, November 30-December 1, 2000.
3. Y. Adonyi, “Weldability of High Performance Steels,” Conference Proceedings, Steel Bridge Design and Construction for the New Millennium with emphasis on High Performance Steel, November 30-December 1, 2000.
4. W.J. Wright, “High Performance Steels: Research to Practice,” Public Roads, Spring 1997, pp. 34-38.
5. K.D. Price, P.A. Cassity, and A. Azizinamini, “The Nebraska High Performance Steel Two-Box Girder System,” Conference Proceedings, Steel Bridge Design and Construction for the New Millennium with emphasis on High Performance Steel, November 30-December 1, 2000.
6. R. Horton, E. Power, K.V. Ooyen and A. Azizinamini, “High Performance Steel Cost Comparison Study,” Conference Proceedings, Steel Bridge Design and Construction for the New Millennium with emphasis on High Performance Steel, Nov. 30-Dec. 1, 2000.
7. E. Wasserman and H. Pate, “Tennessee’s Experience with High Performance Steel: An Owner’s Perspective,” Conference Proceedings, Steel Bridge Design and Construction for the New Millennium with emphasis on High Performance Steel, November 30-December 1, 2000.
8. T.P. Macioce, B.G. Thompson and B.J. Zielinski, “Pennsylvania’s Experience and Future Plans for High Performance Steel Bridges,” Conference Proceedings, Steel Bridge Design and Construction for the New Millennium with emphasis on High Performance Steel, November 30-December 1, 2000.
9. “Early Experiences of the New York State Thruway Authority,” FHWA-RD-00-106, June 2001.

10.0 ACKNOWLEDGEMENT

In writing the HPS Designers’ Guide, the author draws upon the fine works and experience of many professionals from academia, industry and government. He wishes to express his appreciation to these professionals who so generously share information through personal contact, research reports, conference proceedings, case studies, and presentations at technical committee meetings.

The author extends his thanks to the readers and designers who provided valuable comments on the First Edition, and, most especially, to the HPS Steering Committee, chaired by Mr. Alex Wilson, for the very fine suggestions for enhancing the content of this Guide. The comments and suggestions are reflected in the Second Edition.

The author likes to thank his Team Leader, Roland Nimis, for his constant encouragement in promoting innovative use of high performance materials, including HPS, for cost-effective and durable bridges that will last a century.

11.0 CONTINUOUS IMPROVEMENT

The author welcomes comments, design tips, efficient structural details, ideas and suggestions from the readers and designers for continuous improvement in the contents of this HPS Designers' Guide and the application of HPS in bridge design and construction.

12.0 APPENDICES

APPENDIX A – Sample HPS Special Provisions

A sample HPS Special Provisions is posted on the AISI website: www.steel.org/infrastructure/bridges**.** It serves as a very helpful guide in preparing project specific special provisions for HPS projects.

APPENDIX B – Research Problem Statement Format and Sample Statement

B.1 RESEARCH PROBLEM STATEMENT FORMAT

(For submission through AASHTO to NCHRP)

I. PROBLEM NUMBER

(Do not put anything under this category in the first stage. NCHRP will assign a number upon submittal.)

II. PROBLEM TITLE

(A suggested title, in as few words as possible.)

III. RESEARCH PROBLEM STATEMENT

(A statement of general problem or need – one or two paragraphs should suffice.)

IV. RESEARCH PROPOSED

(A statement of the specific research proposed and how it relates to the general problem statement in III above. Include a clear and specific statement of the objectives that are expected to be met by this particular research.)

V. ESTIMATE OF PROBLEM FUNDING AND RESEARCH PERIOD

(Recommended Funding: An estimate of the funds necessary to accomplish the objectives stated in IV above. As a general guideline, the present cost for research usually averages between $75,000 and $100,000 per person-year.)

(Research Period: An estimate of the number of months of research effort, including three months for preparation of a draft final report, necessary to the accomplishment of the objectives in IV above.)

(Note: These estimates may be changed by the AASHTO Standing Committee on Research in order that the problem will fit into the broad program.)

VI. URGENCY, PAYOFF POTENTIAL, IMPLEMENTATION AND SUPPORT FOR BUSINESS NEEDS

(Statements concerning the urgency of this particular research in relation to highway transportation needs in general and the potential for payoff from achievement of project objectives should be given.)

(A statement should be included that describes the anticipated product(s) from the research (e.g., recommended specification language, new instrumentation, or recommended test methods). The anticipated steps necessary for implementation of the research product should also be delineated (e.g., Will recommended specification language be considered for adoption by a committee within AASHTO? Will an industry group have to adopt a new test method or revise their current practices or equipment?). This information should be as specific as possible, noting particular documents that may be made obsolete. Any institutional or political barriers to implementation of the anticipated research products should also be identified.)

(A statement identifying the Thrust/Business Need that will be addressed by this research (refer to NCHRP 20-7, Task 121). What building blocks are addressed?)

VII. PERSON(S) DEVELOPING THE PROBLEM

(A statement of the specifics (name, title, address, telephone number, etc.) of the person(s) having developed the problem in all its detail. This information is needed to facilitate communications when coordination between submitters is required for development of a single second-stage submittal to reflect submittals that are duplicates or are very similar in nature.)

VIII. PROBLEM MONITOR

(This should be left blank at the first-stage submittal stage. It will be dealt with if a second-stage submittal is tendered.)

IX. DATE AND SUBMITTED BY

(Show date of submission and by whom problem is submitted.)

MAIL OR E-MAIL SUBMISSION TO:
Malcolm T. Kerley, P.E.
Chairman, AASHTO Technical Committee for Research (T-11)
Virginia DOT
1401 E. Broad Street
Richmond, VA 23219
FAX: 804/786-2988
E-MAIL: *kerley_mt@vdot.state.va.us*

PLEASE SEND COPY TO:
David B. Beal, Senior Program Manager
National Cooperative Highway Research Program (NCHRP)
2101 Constitution Avenue, N.W.
Washington, DC 20418
FAX: 202/334-2006
E-MAIL: dbeal@nas.edu

B2 SAMPLE RESEARCH PROBLEM STATEMENT

I. PROBLEM NUMBER

II. PROBLEM TITLE

Improving the Fatigue Performance of Steel Highway Bridges by the Use of Ultrasonic Impact Treatment (UIT).

III. RESEARCH PROBLEM STATEMENT

The service life of welded steel highway bridges is controlled by the fatigue performance of welded details. This is true for all grades of steel from M270 Grade 36 through Grade 100. Regardless of the grades of steel, the fatigue resistance of the components and welded details are subject to the same code provisions for fatigue design based on the detail categories. In other words, the fatigue resistance is the same for all strengths of steels when they are connected and welded in the same way. For example, the commonly used fillet-welded connections with welds normal or parallel to the direction of stress is classified as Detail Category E for fatigue consideration, no matter whether the steel is 36 ksi., 50 ksi. or 70 ksi. This is quite a penalty for the higher strength steels, including the new high performance steel. In terms of fatigue thresholds or allowables, Detail Category E has a threshold of 4.5 ksi., Detail Category D has a threshold of 7.0 ksi. and Detail Category C has a threshold of 10 ksi. If a Category E detail can be improved to a Category C detail, there is a significant gain in fatigue strength, resulting in more cost effective use of the higher strength steels.

The ultrasonic impact technique was first developed in Russia. In recent years, independent assessments of the method have indicated the effectiveness of UIT in post weld treatment to improve fatigue strengths of welded details. Preliminary fatigue tests conducted at the ATLSS Center of Lehigh University indicated that the ultrasonic impact technique improved the fatigue strength of the welded details tested. For example, a Category E' (2.6 ksi) coverplated detail was improved to Category C (10 ksi) detail. Unfortunately, the details of the UIT equipment used for the tests remained confidential or proprietary.

There is no secret in the concept and mechanism of the UIT technology. The UIT process is to utilize ultrasonic waves to improve weld profile, remove stress concentration, introduce compressive residual stresses and strengthen surface layer of a weld. The ultrasonic waves vibrate at about 27,000 HZ with maximum amplitudes up to 30 microns. AUIT equipment is expected to consist of a magnetoconstriction converter, an ultrasonic wave transmitter and a special tool with holder to isolate the operator from vibration. The tool tips are designed to fit the surface conditions of the welded details.

The ultrasonic impact technique is easy to learn, uses easy to handle tool, and produces much lower noise level than air hammer peening and achieves reproducible results. It has great potential for shop and field applications in improving the fatigue resistance of new and existing welded steel bridges.

IV. RESEARCH PROPOSED

The objectives of this research is to develop practical and cost effective techniques, procedures and light hand tools for the application of ultrasonic impact treatment to predictably and significantly improve welded connections from Detail Category E (4.5 ksi.) and Detail Category E' (2.6 ksi.) to Detail Category C (10.0 ksi.) or better. The quality of the treated welds should be verifiable by visual inspection and/or other nondestructive testing methods.
The proposed research will include, but not limited to, the following tasks:

Task 1 - Perform a literature search of the state-of-the-knowledge in ultrasonic impact and other treatments of welds for improving fatigue strength of welded structural steels.
Task 2 - Evaluate the findings from Task 1 and assess the potential for successfully meeting the objective of the proposed research. If the potential for success and payoff is high, proceed to Task 3. Otherwise, abort study.
Task 3 - Develop techniques, procedures and schematics for the design of light hand tools for performing the ultrasonic impact treatment. The schematics should provide the essential components and functions of a UIT equipment so manufacturers can further develop and build the equipment. The techniques should rely more on science than art, such that technicians can be trained to use the techniques and tools with repeatable results.
Task 4 - Perform laboratory and field tests together with acceptance criteria and inspection methods to verify and refine the techniques, procedures and tools.
Task 5 - Develop Technical and Training Manuals for the application of ultrasonic treatment of bridge welds in the shop and in the field together with acceptance criteria and inspection techniques. The manuals should include videotape and/or computer disks for demonstrating the techniques and procedures.
Task 6 - Prepare to conduct four training classes across the country.
Task 7 - Prepare a final report.

V. ESTIMATE OF PROBLEM FUNDING AND RESEARCH PERIOD

Estimate of Problem Funding: $350,000
Estimate of Research Period: 30 months

VI. URGENCY, PAYOFF POTENTIAL, IMPLEMENTATION AND SUPPORT FOR BUSINESS NEEDS

Many existing steel highway bridges have low fatigue category details, which are susceptible to fatigue cracking, if not already cracked. New steel bridges are designed under the constraint of Detail Category E and Detail Category E'. These details can be improved to Detail Category C by using ultrasonic impact treatment. There will be significant savings in expensive repair of existing bridges, and in effectively utilizing the higher strengths of modern steels in new bridges. The greatest benefit is in extending the service life of steel highway bridges with less disruption to the traveling public. The research results can be used immediately for fatigue retrofit of existing steel bridges and for new steel bridge design.

Thrust/Business Needs

- Efficient Maintenance, Rehabilitation, and Construction.
- Enhanced Specifications for Improved Structural Performance.

The associated building blocks include practical and cost effective techniques and procedures for improving the fatigue performance of welded details in existing and new steel bridges.

VII. PERSON(S) DEVELOPING THE PROBLEM

M. Myint Lwin
Structural Design Engineer
Federal Highway Administration
201 Mission Street, Suite 2100
San Francisco, CA 94105
(415) 744-2660
Myint.Lwin@fhwa.dot.gov

VIII. PROBLEM MONITOR

IX. DATE AND SUBMITTED BY

January 7, 2001
M. Myint Lwin
Structural Design Engineer
Federal Highway Administration
201 Mission Street, Suite 2100
San Francisco, CA 94105
(415) 744-2660
Myint.Lwin@fhwa.dot.gov

APPENDIX C – HPS SCOREBOARD

AISI maintains a list of HPS bridges that are being planned, under design, in fabrication, under construction and in-service. The list is posted in the AISI website: www.steel.org/infrastructure.bridges.