Research Report
KTC-03-16/SPR 269-03-1F

KENTUCKY TRANSPORTATION CENTER

College of Engineering

SURVEY OF WELDING PROCESSES

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Survey of Welding Processes

By

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in cooperation with

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16. Abstract

The current KYTC "SPECIAL PROVISION NO. 4 WELDING STEEL BRIDGES" prohibits the use of welding processes other than shielded metal arc welding (SMAW) and submerged arc welding (SAW). Nationally, bridge welding is codified under ANSI/AASHTO/AWS D1.5M/D1.5:2002 Bridge Welding Code. That document allows the use of other welding processes including flux core arc welding, gas metal arc welding, electroslag welding and electrogas welding after passing qualification tests.

Both the KYTC Special Provision and the Bridge Welding Code were reviewed. Representatives from 14 state highway agencies, fabrication shops, universities and welding equipment firms were questioned regarding the wider use of the welding processes allowed by the Bridge Welding Code but prohibited by the KYTC Special Provision. Based upon those responses, recommendations are provided to KYTC for updating the Special Provision and more fully adopting the Bridge Welding Code.

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EXECUTIVE SUMMARY

Background

Welding processes impact steel bridge fabrication costs. KYTC officials were concerned that the current KYTC Special Provision for Welding was too restrictive and might result in unnecessary fabrication costs for welded steel bridges. This study was initiated to review that KYTC Special Provision for Welding, compare it with the ANSI/AASHTO/AWS D1.5M/ D1.5:2002 Bridge Welding Code, and determine whether other welding processes could be incorporated into the KYTC Special Provision for Welding. KTC researchers performed four tasks under this study: Those were to:

1. Review current welding processes prohibited or restricted under AWS/AASHTO codes and KYTC special provisions.
2. Contact Representatives of government agencies, technical societies, universities, and firms involved with bridge welding about suitable welding processes.
3. Determine "best practices" and future welding trends incorporating those welding processes and identify which ones KYTC may employ in limited or unrestricted applications.
4. Seek sources of training to educate KYTC designers and construction officials in the Bridge Welding Code and use of approved welding processes. Determine if opportunities exist to cooperate with the FHWA, other SHAs, technical societies, and fabrication shops to introduce more economical welding procedures.

Task 1.

Currently, the KYTC Special Provision for Welding, "SPECIAL PROVISION NO. 4 WELDING STEEL BRIDGES," limits fabrication shops to the use of shielded metal arc welding (SMAW) and the submerged arc welding (SAW) processes. The Bridge Welding Code permits additional welding processes including electroslag welding (ESW), electrogas welding (EGW), gas metal arc welding (GMAW) and flux core arc welding (FCAW). Under the Code, only SMAW is prequalified and testing must be done with all other methods to prove they can produce acceptable welds. Use of ESW and EGW are restricted to structural members not subjected to tensile stresses and stress reversals.

Task 2.

KTC researchers contacted representatives from the FHWA, fabrication shops, universities, welding equipment manufacturers, and state highway agencies, to obtain information from other parties concerning the use of welding processes other than SMAW and SAW for steel bridge fabrication. The general consensus of those contacted was that FCAW, GMAW, ESW, and EGW were acceptable when applied under the conditions (qualification testing) and restrictions set forth in the Bridge Welding Code.

Task 3.

Currently, most U.S. fabrication shops employ SAW for the bulk of their welding operations. If KYTC adopts the Bridge Welding Code, it probably will not result in significant changes in welding processes used for most KYTC steel bridges. However, that accommodation will give fabricators greater flexibility to select cost-effective welding processes.

A recent scanning tour was conducted by U.S. officials to investigate bridge welding in fabrication shops in Europe and Japan. Participants observed that in Japan, FCAW and GMAW processes are predominant in most bridge fabrication shops and only about 10 percent of bridge welding is done with SAW. European fabrication shops have greater use of SAW than in Japan, but there is a growing trend towards other processes, especially GMAW. In the U.S., about 90 percent of bridge welding is done using SAW.

The current U.S. welding trends relate to research and approval of weld procedures for HPS 70W and HPS 100W steels. The focus of that research is to incorporate those materials using existing welding processes. Currently, there does not appear to be any major effort to investigate welding methods outside those accepted by the Bridge Welding Code. The codification process in the U.S. is very deliberate. While the previously noted scanning tour participants observed, foreign practices worth exploring, it will likely take significant time before those are considered or adopted by AASHTO.

Task 4.

AWS and other sources including various welding technical institutes and universities offer survey and certification courses related to various aspects of welding and welding processes, but none of those address the Bridge Welding Code. None of the major sources of training or technology (i.e. FHWA, the National Highway Institute, and AASHTO) offer training related to use of the Bridge Welding Code.

In discussions with the fabrication shop representatives, it became clear that the best approach to obtaining more economical welds would be to adhere to the Bridge Welding Code. A major problem for fabricators is that nearly half of the state highway agencies have exceptions to the Code. Additional training about the Bridge Welding Code could be directed toward minimizing exceptions and promoting reciprocity on PQR testing. However, that effort should be sponsored by AASHTO or the FHWA.

Recommendations

The following actions are recommended for KYTC in relation to the objectives of this study:

1. Eliminate KYTC “SPECIAL PROVISION NO. 4 WELDING STEEL BRIDGES”.
2. Incorporate in the current KYTC Specifications for Steel Bridges that fabrication will be per AWS D1.5 (current edition), except welding processes (ESW) and EGW) must be approved by the Department and Engineer, also process (FCAW) may be used on secondary members but must be approved by the Department and Engineer for main members.
3. Actively participate in AASHTO to seek incorporation of important exceptions into the Bridge Welding Code and to promote a better, more universally accepted document that will, to the greatest degree possible, provide for uniform state highway agency requirements to fabrication shops. KTC researchers can assist in this effort.

INTRODUCTION

Background

Steel bridge fabrication employs a significant amount of welding. To obtain economic structures, it is desirable for low-cost, high productivity welding processes to be employed. Such processes are characterized by high weld metal deposition rates and a minimal amount of cleaning between weld passes to facilitate overall deposition times.

Gas-metal arc welding (GMAW) provides lower welding costs by avoiding the use of slag-forming components. That minimizes the need for cleaning between weld passes. Electro-slag welding (ESW) and electrogas welding (EGW) are continuous welding processes that eliminate the need for multiple weld passes and possess high deposition rates for welding thick sections of steel plate. Flux-cored arc welding (FCAW) using either gas-shielding or self-shielding employs continuous wire feed to provide high deposition rates while employing slags.

The most common welding process used to fabricate steel bridges in the U.S. is submerged arc welding (SAW). It has a relatively high deposition rate, but requires slag removal between passes. Conventional shielded metal arc welding (SMAW) uses stick electrodes of limited length and diameter. SMAW requires numerous starts and stops in the welding process for slag removal and electrode replacement and is probably the slowest welding process used based upon deposition rates. It is frequently used for tack welding, stiffener to flange welds, attachments, and repairs.

FCAW and GMAW are commonly employed in fabrication shops for minor welding operations such as tack welds, ancillary products (bearings, expansion dams, etc.), and attachments. EGW has not been widely used in U.S. bridge construction. ESW had been prohibited for bridge use from 1977 to 2000 until FHWA-sponsored research resulted in process improvements (narrow gap electroslag welding) that made it acceptable for bridge applications (1-3). In part, restrictions on those welding processes stem from low toughness values obtained from them in the past. Also, ESW provided steel microstructures that were difficult to inspect using some nondestructive evaluation methods. In recent years, most of those problems have been resolved, though some state highway agencies have not adopted those welding processes.

The properties of the base metals (structural steels) used in bridges have significant impacts on the welding processes that can be employed with them. Typical structural steels used in the U.S. and overseas have yield strengths in the range of 36 to 50 ksi, with some control-rolled and quenched & tempered steels with yield strengths of 70 to 100 ksi. In the U.S., there is a growing trend towards using weathering steels with yield strengths in the range of 50 to 100 ksi which may have some impacts on welding processes.

Current Kentucky Transportation Cabinet specifications are satisfactory for producing quality welds. However, with the pressure to contain bridge costs, more economical welding procedures must be investigated, and if practical, adopted. The latest practices permitted by other state highway agencies and approved or under review by the American Association of State and Highway Transportation Officials – AASHTO and other organizations (e.g. the American Welding Society – AWS) need to be considered. In authorizing this study, KYTC officials were aware of the desirability of considering other welding processes and sought to review this situation to determine whether the current KYTC welding specifications could be expanded to cover a wider range of welding processes.

Study Objectives/Tasks

To address issues related to KYTC-permitted welding processes, an SPR study, KYSPR 03-268 “Survey of Welding Practices” was initiated. Study objectives were approved by the Study Advisory Chairperson, James R. Lile, of the KYTC Division of Construction. Those were:

1. Review current KYTC-specified welding processes and those that are being prohibited or restricted.
2. Identify current prohibitions and restrictions on those processes being imposed by other SHAs and variances of those with the KYTC Special Provision.
3. Determine “best practices” and pending welding trends incorporating currently prohibited/restricted welding processes and identify which ones KYTC may employ in less limited or unrestricted applications.
4. Seek sources of training to educate KYTC designers and construction personnel in the specification and use of those welding processes and identify opportunities for cooperation with other SHAs and fabrication shops to introduce improved welding processes/practices.

To address those goals, KTC researchers were assigned four tasks. Those were to:

1. Review current welding processes prohibited or restricted under AWS/AASHTO codes and KYTC special provisions.
2. Contact Representatives of government agencies, technical societies, universities, and firms involved with bridge welding about suitable welding processes.
3. Determine “best practices” and future welding trends incorporating those welding processes and identify which ones KYTC may employ in limited or unrestricted applications.
4. Seek sources of training to educate KYTC designers and construction officials in the Bridge Welding Code and use of approved welding processes. Determine if opportunities exist to cooperate with the FHWA, other SHAs, technical societies, and fabrication shops to introduce more economical welding procedures.

WORK ADDRESSING STUDY TASKS

Task 1. Review of KYTC and AWS/AASHTO Welding Requirements

Current KYTC Special Provisions for Welding Steel Bridges – The KYTC specification covering welding processes is “SPECIAL PROVISION NO. 4 WELDING STEEL BRIDGES” (hereafter referred to as the KYTC Special Provision for Welding). This document applies when indicated on the plans or in the proposal. Section references are to the Department’s 2000 Standard Specifications for Road and Bridge Construction. For all welding items, this document conforms to the requirements of the Bridge Welding Code, ANSI (American National Standards Institute)/AASHTO/AWS D1.5-95 (i.e., the 1995 Edition). Numbering of Sections, articles, parts, paragraphs, etc. that are included in KYTC Special Provision for Welding are based upon the numbering of that document.

The KYTC Special Provision for Welding modifies the scope of welding processes. In its *"SECTION 1 GENERAL PROVISIONS"* under subsection *"1.3 Welding Processes"*, it adds a paragraph as follows:

"Gas Metal Arc (GMAW), Flux Cored Arc (FCAW), Electroslag (ESW) and Electrogas (EGW) weld processes shall not be used at any location."

This mandates a complete prohibition of the use of those welding processes even for ancillary products. That provision is the focus of this study and report.

ANSI/AASHTO/AWS Welding Code – The current national code impact welding of bridge steel is the joint ANSI/AASHTO/AWS D1.5M/D1.5:2002 Bridge Welding Code (hereafter referred to as *the Bridge Welding Code*). This document (in earlier versions) was the result of a joint subcommittee formed in 1982 between AASHTO and AWS to "seek accommodation between the separate and distinct requirements of bridge Owners and existing provisions of AWS D1.1. The Bridge Welding Code is the result of an agreement between AASHTO and AWS to produce a joint AASHTO/AWS Structural Welding Code for steel highway bridges that addresses essential AASHTO needs and makes AASHTO revisions mandatory." The first version of this welding code was AASTHO/AWS D1.5:88 with succeeding revisions in 1995, 1996 and 2002 (the current edition). The Bridge Welding Code addresses new construction and does not cover strengthening and repairing of existing structures (i.e. field welding).

The AWS D1.1 Structural Welding Code addresses statically loaded structures and tubular structures. The other primary differences between it and the Bridge Welding Code relate to the desire of bridge owners to take steps in the selection of materials and in the qualification and control of weld procedure specifications (WPSs) through rigorous qualification testing if necessary [See the Bridge Welding Code Section 5 Part A *Weld Procedure Specification (WPS) Qualification*]. Material selection can include base metal, weld metal, flux, and shielding gas. Weld procedure control includes control of welding heat inputs and attendant cooling rates. Weld qualification testing requires significant testing and documentation of all process variables including base metal, welding materials (wire, flux and/or gas), weld equipment, equipment settings, weld method setup, and ambient conditions. Test variables are recorded along with subsequent post weld mechanical/chemical tests of the completed weld material to assure that it meets essential performance parameters (e.g., strength, ductility, toughness and hydrogen content). The qualification test data is recorded in a Procedure Qualification Record (PQR) and the WPS is based upon the PQR. Welder qualification is also contained in Chapter 5 of the Bridge Welding Code under Part B *Qualification Testing of Welding Personnel*.

A major difference between the Bridge Welding Code and AWS D1.1/D1.1M:2002 Structural Welding Code-Steel is that the latter allows WPSs to be prequalified (exempt from PQR qualification testing) when in conformance to specific requirements. The Bridge Welding Code requires PQR testing on nearly all welding processes except SMAW when electrodes are used that provide weld metal with yield strengths matching the base metal.

The Bridge Welding Code differs from the KYTC Special Provision for Welding in that it allows the use of SMAW, SAW, GMAW, FCAW, ESW, and EGW processes. Other welding processes not delineated in the Bridge Welding Code may be used if permitted by the Engineer. As previously noted, PQR testing of WPSs is required for nearly all of those processes. If a state highway agency is doing continuing work in a specific fabrication shop that requirement may not be too significant. When qualified, a WPS may remain in effect for 60 months and be extended to other projects if the agency is using similar weld variables. In the Bridge Welding Code, the use of ESW and EGW are restricted to groove welds in butt joints of compression members. GMAW-S (short circuit arc) is not recommended for bridge members. For nonredundant structural members, a fracture control plan is provided. Under that plan, SMAW, SAW, FCAW, and GMAW (with metal cored electrodes) are approved (but not prequalified). ESW and EGW are prohibited from use on nonredundant members and GMAW (solid wire) may only be used with the approval of the Engineer. Ancillary products such as drainage components, expansion dams, sheet piling, etc. may be welded using SMAW, SAW, FCAW and GMAW and the WPSs considered prequalified and exempt from PQR tests if they are not subject to live loads in service nor welded to main members in tension areas (Section 1.3.6).

While the Bridge Welding Code is less restrictive than the KYTC Special Provision for Welding, it does not provide blanket approval for any welding process. It requires that WPSs be based upon PQR testing and if welding variables are changed re-testing using the new parameters (Section 5). The following mechanical tests of completed weldments have been accepted by most state highway agencies as being sufficient to ensure the proper service performance of bridge welds: 1) side-bend, 2) reduced section tension, 3) charpy V-notch, 4) macro-etch and 5) all-weld-metal-tension (Section 5.7).

Task 2. Contact Representatives of Government Agencies, Technical Societies, Universities, and Firms Involved with Bridge Welding about Suitable Welding Processes

Following the review of the KYTC Special Provision for Welding and the Bridge Welding Code, KTC researchers contacted welding experts throughout the U.S. representing the major participants in the bridge welding industry. The purposes of those interviews were to: review current U.S. bridge welding practices, assess the codification of bridge welding throughout the country, and, lastly, determine whether the current KYTC Special Provision for Welding warranted revision.

Initial contact was made with Mr. Krishna Verma, a welding engineer with the FHWA Headquarters in Washington, DC. Mr. Verma favored state highway agency adherence to AWS D1.5. He stated that highway agencies should consider welding processes other than SMAW and SAW. He noted the FHWA had done significant development and educational work on the narrow gap electroslag welding process. However, he stated that no fabrication shops or highway agencies had adopted the process. Mr. Verma provided further guidance in identifying contacts that might provide insight relative to bridge welding.

In the KYTC Special Provision for Welding, reference is made to the use of ASTM A 441 and ASTM A 242 steels. A review of the current ASTM specifications for structural steels for bridges, ASTM A 709/A 709M-01a, *Standard Specification for Carbon and High-Strength Low-Alloy Structural Steel Shapes, Plates, and Bars and Quenched-and-Tempered Alloy Structural Steel Plates for Bridges*, does not list those steels in Section 1.1.1 (5). ASTM A 441 is no longer listed in ASTM A 6/A 6M-01 for standard structural steels (6). While steel specifications were not to be specifically addressed in this study, they factor into the welding process. A marketing representative of U.S. Steel was contacted about the appropriate steel specifications to be used for bridge construction. The representative stated that he had not encountered the use of ASTM A 441 in the past 5 years. He recommended only using steels referenced under ASTM A 709 (i.e. ASTM A 36/A 36M, A572/A572M, A 992/A 992M, A 588/A 588M and A 514/A 514M). It should be noted that the same steels are covered under a separate specification by AASHTO – M270M (M270). The Bridge Welding Code Section 1.2.2 *Approved Base Metals* generally refers to the use of ASTM/AASHTO specified steels, but allows the use of nonstandard steels in Section C5.4.3 *Unlisted Base Metals*.

Thereafter, KTC researchers contacted representatives of three steel bridge fabricators that have conducted work for KYTC. Those fabricators included Stupp Brothers Inc. of St. Louis, MO, Carolina Steel Corporation of Greensboro, NC, and High Steel Structures Inc. of Lancaster, PA. All of the representatives, Dennis Nash of Stupp Bros., Bill Smith of Carolina Steel, and Bob Kase of High Steel Structures, noted that the bulk of their welding is performed using SAW. Their work varied from plate girder structures (Stupp Bros.) to a variety of structures including cable-stayed and curved beam bridges (High Steel Structures and Carolina Steel). SAW is commonly used for flange and web splices and for flange-to-web welds. Typically, most primary welds on structural members are performed in either the flat or horizontal positions. SAW is commonly used for primary welds and also for secondary welds such as stiffeners using two-sided welding (e.g. DART Welder) on deep girders. More states have allowed the use of shielded FCAW for tack welding and welding of secondary members and attachments. Mr. Smith noted that for curved bridges, shielded FCAW was not allowed on cross frames as those were considered primary structural members. GMAW was also being used for tack welding with follow-on weld completion using SAW. In some cases, shop layouts and available equipment favored the use of SMAW for stiffener-to-flange welds and other attachments. Mr. Smith noted that ESW and EGW had limited utility in bridge welding (typically for thick flange splices) and that most shops avoided using those methods. Mr. Nash noted that the weld toughness of shielded FCAW had improved over the past 30 years and now was comparable to that obtained with SAW. Mr. Kase noted his firm had performed some experimental work with GMAW though it had not been used extensively. While all three representatives' firms used a considerable amount of SAW, they all thought that it would be desirable for bridge owners to work within the Bridge Welding Code and give the fabrication shops the latitude to use the processes they considered best within the framework of the WPS qualification process. The representatives were aware of the FHWA initiative for ESW and a demonstration of that method had been performed at High Steel Structures. However, those representatives stated that there was not sufficient impetus to proceed with use of ESW at this time.

Several representatives of manufacturers of welding equipment, Dean Phillips of Miller Electric Mfg. of Appleton, WI and Lon Yost of Lincoln Electric Co. of Milwaukee, WI were contacted concerning welding processes for bridge fabrication. Both representatives believed that FCAW and GMAW could be used more widely if a state highway agency elected to allow their use. They both commented that welding technology related to those methods had improved significantly over the past 10-20 years. Mr. Phillips noted that when GMAW was specified for fracture-critical members, metal core wire should be used rather than solid wire. They both noted that FCAW and GMAW were used for tack welding and attachment of secondary members. Mr. Phillips stated that GMAW was also used in welding of thin sections and in root pass welds. Mr. Yost noted that significant improvements in welding controls had occurred in recent years which enabled improved welding by a variety of processes and provided more data which could be used to indicate weld quality He had been involved in recent welding research for the HPS70 steel and noted that initial fabrication shop tests were beginning with HPS100W steel. He stated that a large heavy equipment manufacturer had used GMAW successfully for years. He commented that the Bridge Welding Code addressed the mode spray transfer by prohibiting the use of GMAW (short circuit). Both representatives noted that the ESW and EGW methods were approved for bridge welding under certain circumstances, but were unaware of their current use nationwide for such applications. . Both parties felt that the Bridge Welding Code was very conservative with a significant margin of safety to ensure proper welds.

KTC researchers also contacted several researchers involved with welding including Yoni Adonyi of Le Tourneau University, Longview, TX and Christopher Hahin of the Illinois DOT Bureau of Materials and Physical Research, Springfield, MO. Dr. Adonyi had recently completed research on welding of HPS 70W steel that could be welded in sections up to 2 inches thick without preheat. His work had been provided to the American Institute of Steel Institute and voted and approved by AASHTO in June 2003 (7). Dr. Adonyi noted that welding research was on-going for HPS 70W and HPS 100W steels. Dr. Adonyi stated that FCAW and GMAW could be used successfully to weld bridge steels. He noted that recent samples of FCAW welding wire showed significant reductions in hydrogen content. Dr. Adonyi stated that some research still needed to be performed to address issues pertaining to welding some of the lower strength steels. Mr. Hahin noted previous work he had conducted using GMAW, SAW, and SMAW had revealed comparable weld toughness values. FCAW welds provided lower toughness values for those tests and he recommended avoiding the use of self-shielded FCAW.

KTC researchers contacted state highway officials from 14 states including California, Kansas, Illinois, Indiana, Iowa, Michigan, Missouri, Minnesota, Nebraska, New York, Ohio, Tennessee, Virginia, and Wisconsin. The highway officials were asked what welding processes their states permitted and what restrictions were placed upon them. California, Kansas, Illinois, Indiana, Michigan, Minnesota, Missouri, Nebraska Ohio and Tennessee adhere to the Bridge Welding Code in qualifying welding processes. Virginia adheres closely to the Bridge Welding Code, except ESW and EGW are prohibited. Iowa allows SMAW, SAW and FCAW on main members with PQR testing. Primary welds (flange and web butt splices and flange-to-web splices) must be SAW. Flange-to-web splices must be deposited by automatic welding. GMAW is restricted to tack welds. New York currently does not follow the Bridge Welding Code. It restricts bridge girder welding to SMAW and SAW. FCAW and MIG have been allowed on sign and pedestrian bridges. ESW and EGW are not permitted. Automatic welding is required for some welds. Self-shielding FCAW is not permitted. Wisconsin allows only SAW on primary welds. FCAW and GMAW have been allowed on secondary welds.

A final contact was James Sothen of the West Virginia DOT. Mr. Sothen was the recent chairman for AASHTO Committee T-17 for Welding. Mr. Sothen provided a copy of a recent survey on state highway agency use of the Bridge Welding Code performed in June 2003. He had contacted all state highway agencies and the District of Columbia. Of the 43 agencies that responded, 37 used the D 1.5-02 edition of the Bridge Welding Code. Five highway agencies used D 1.5-95 or D 1.5-96 and one highway agency (New York State DOT) had its own specification. Mr. Sothen noted that of the 37 highway agencies using D1.5-02, 24 had exceptions to the Code. He stated that a future objective of the AASHTO Committee should be to reduce the number of highway agency exceptions. He believed that would have a beneficial impact on steel fabrication costs.

Task 3. Determine "best practices" and future welding trends incorporating those welding processes and identify which ones KYTC may employ in limited or unrestricted applications.

SAW is the most common welding method used in the U.S. for primary bridge welds (and probably a bulk of the stiffener-to-web welds). It is available primarily in automatic processes that many state highway agencies now require. Increased computerization is allowing for recoding of welding variables such as current, wire feed rate, and welder travel speed which provide additional indicators of weld quality. It has a long history of successful welding. Automated equipment is available for other welding processes such as FCAW and GMAW. But they are not widely used by U.S. bridge fabrication shops. In part, the wide use of SAW relates to the fact that some state highway agencies mandate that process and other state highway agencies that are amenable to a variety of welding processes will accept it. Therefore, U.S. bridge fabrication shops commonly use SAW. If KYTC adopts the Bridge Welding Code provisions for allowable welding processes, it will not result in significant changes in the welding processes used to fabricate KYTC structures as most bridge fabrication shops will still be using SAW for the bulk of the welding. By adopting the Bridge Welding Code, KYTC will indicate flexibility for dealing with fabricators that may result in some cost savings over time. Dennis Nash of Stupp Bros. commented that KYTC has recently allowed the use of GMAW for tack welds and FCAW for stiffener to flange welds. Those accommodations are not reflected in the current KYTC Special Provision for Welding.

To a great degree, the Bridge Welding Code subordinates weld process to final weld quality. The only major restrictions preclude GMAW (short-circuit), GMAW (solid wire) for fracture-critical members and ESW and EGW for welds in tension areas. Currently, prohibitions against the use of ESW and EGW by some highway agencies are relatively meaningless as most fabricators are not using them. The PQR testing process is intended to filter out unacceptable welding processes/welding operators based upon results. The current "best practice" is to fully employ the Bridge Welding Code and provide fabricators with the opportunity to employ cost-effective welding processes of their choosing.

A recent scanning tour was organized by the FHWA to investigate bridge welding in fabrication shops in Europe and Japan (8). In Japan, FCAW and GMAW processes are predominant in most bridge fabrication shops and only about 10 percent of bridge welding is done with SAW. In the U.S., about 90 percent of bridge welding is done by SAW. In some Japanese fabrication shops, the welding process variables are continuously monitored to insure proper welding procedures are being used. In Europe, there is higher use of SAW than in Japan, but there is a growing trend towards other processes, especially GMAW. Many attendant factors impact welding processes. The Japanese use thermo-mechanically controlled processing (TMCP) or controlled rolling along with chemical composition (low carbon and carbon-equivalent values) to provide steels that have high toughness and avoid the need for pre-heating. Japanese fabricators typically rely heavily on automatic welding processes in both the shops and the field. Japanese and European bridge designs allow the use of field welding. Typically, Japanese and Europeans use thinner steel sections than employed in the U.S. Weld designs and detailing differ from the U.S. as do some major bridge design features. According to some sources interviewed for this report, Japanese fabrication shops have greater control in selecting their welding operations than U.S. shops. The Japanese are using one welding procedure rotating arc welding for fillet welds that show promise for adoption in the U.S. Many of the advancements noted in weld process were Japanese and the scanning group was preparing a list of topics based on tour findings for investigation and possible application in the U.S.

In a recent trip to Perm Russia, KTC researchers noted the use of welded field splices on bridges instead of bolting and observed sophisticated weld designs with excellent workmanship (Figures 1-3). The weld beads indicated that they had been deposited using automatic or semi-automatic processes. Some of the welds appeared to have been made by SAW.

The current U.S. welding trends relate to research and approval of weld procedures for HPS 70W and HPS 100W steels. The focus of that research is to incorporate those materials using existing welding processes. Currently, there does not appear to be any major effort to investigate welding methods outside those accepted in the Bridge Welding Code. The codification process in the U.S. is very deliberate. While the previously noted scanning tour participants observed foreign practices worth exploring, it will likely take significant time before those are considered or adopted by AASHTO.

Task 4. Seek sources of training to educate KYTC designers and construction officials in the Bridge Welding Code and use of approved welding processes. Determine if opportunities exist to cooperate with the FHWA, other SHAs, technical societies, and fabrication shops to introduce more economical welding procedures.

AWS and other sources including various welding technical institutes and universities offer survey and certification courses related to various aspects of welding and welding processes, but none of those address the Bridge Welding Code. Mr. Verma noted that the FHWA had conducted regional seminars on narrow-gap ESW, but no other FHWA courses exist addressing the Bridge Welding Code. The National Highway Institute and AASHTO were also contacted, but neither offered technical courses related to the Bridge Welding Code. The Lincoln Electric technical representative stated that if there was sufficient interest in such a course, his company could provide such training.

In discussions with the fabrication shop representatives, it became clear that the best approach to obtaining more economical welds would be to adhere to the Bridge Welding Code. A major problem for fabricators is that nearly half of the state highway agencies have exceptions to the Code. Those variances effectively increase the costs of welding fabrication for all highway agencies. Also, many states do not accept qualification of welding procedures/welding operators by other states that may be using similar or identical procedures and welding operators. This requires unnecessary duplication of PQR testing and results in extra costs to state highway agencies. Added cooperation between state highway agencies is needed to eliminate that duplication. Additional training about the Bridge Welding Code could be directed toward minimizing exceptions and promoting reciprocity on PQR testing. However, that effort should be directed by AASHTO or the FHWA.

If KYTC is to work within the framework of AASHTO/AWS regarding welding processes, it will need to adhere to the Bridge Welding Code. KYTC involvement in advancing the Bridge Welding Code will be discussed below. The general range of comments received during the KTC interview process indicated that the Code was a conservative document and that incorporation of advancements was a deliberate process that did not accommodate rapid-paced innovation.

CONCLUSIONS

This study was undertaken with the intent of determining the suitability of the current KYTC Special Provision for Welding. That document refers to a non-current edition (1995) of ANSI/AASHTO/AWS D1.5M/D1.5 which is now in the 2002 edition. Iowa, Ohio, and Pennsylvania still use that 1995 edition of the Bridge Welding Code exclusively. Vermont uses both the 1995 and 1996 edition of the Code. Other states with existing projects begun under previous versions of the Code still have them in effect until those projects are finished. However, for new projects they are using the 2002 edition. At least 13 state highway agencies currently agree with the provisions in the 2002 Bridge Welding Code sufficiently to have adopted it without exceptions. It seems reasonable that the KYTC special provision on welding steel bridges should be updated to conform to the current edition of the Bridge Welding Code.

Most parties paneled under this study believed that the Code was sufficiently conservative to provide suitable welds using any acceptable process (SMAW, SAW, FCAW, GMAW, ESW and EGW) when used for the appropriate weldments. As previously noted, most fabrication shops used by KYTC probably employ SMAW and SAW for the bulk of their welds. Very few, if any, shops are capable of using ESW or EGW so exceptions prohibiting those processes may be relatively meaningless at this time. Several state highway officials recommended that self-shielded FCAW be excluded. However, that can be proven by PQR testing. The goal of this study was to seek lower cost welding methods. Revising the KYTC Special Provision for Welding to accept all methods approved under the Bridge Welding Code will provide fabricators the opportunity to seek the most economical weld methods. This should result in cost savings to KYTC. KYTC has already accommodated some variances in the current special provision by allowing Stupp Bros. to use GMAW for tack welding and FCAW for stiffener-to-flange welds. Full adoption of the Bridge Welding Code would eliminate the need for fabrication shops to have to seek special exemptions and allow the PQR testing process to determine the suitability of proposed welding procedures/methods.

Some of the persons interviewed under this study stated that the current Bridge Welding Code is not perfect. This is reflected in the fact that 24 of the 37 states in the AASHTO survey stated that they have exceptions to the Code, some of which are not related to welding processes. However, those exceptions increase fabrication costs for all state highway agencies even if they have completely adopted the current Bridge Welding Code. In part, some of those exceptions may be dated and state highway agencies need to review their special provisions to modernize them. In other cases, the exceptions may merit incorporation in future editions of the Code.

The issue of exceptions and its resolution were best summarized by Todd Niemann of the Minnesota DOT in responding to the KTC questionnaire on state steel bridge welding practices. He stated, ”Minnesota by and large has been a very conservative and restrictive state in terms of fabrication and welding practices over the years, as well (*as Kentucky*). We were specifying similar process restrictions (*to Kentucky's*) up into the mid 1990's. I have been working to bring our state to a less restrictive place and follow the AASHTO/AWS 1.5 code with fewer exceptions. In terms of welding processes, there really are no reasons to deviate (*from the Bridge Welding Code*). AASHTO is heavily involved with the writing and revising of this code now and as current chairman of the D1.5 specification, I highly encourage your (*state's*) full adoption of it. If your state has specific concerns, I encourage you to address them to the (*AASHTO Welding*) Committee so that exceptions and deviations are not needed.” Mr. James Sothen of the West Virginia DOT and past Chairman of the AASHTO T-17 Committee on Welding agreed that it was important for state highway agencies to work together to seek more inclusive acceptance of the Bridge Welding Code and try to eliminate exceptions.

The current Bridge Welding Code is not perfect and it will need revision to be improved and to accommodate greater acceptance of all of its provisions. The most cost-effective method for highway agencies to address concerns with the current Code is to work within AASHTO to revise its unacceptable provisions and make it a better more practical document. That is going to require additional effort on the part of KYTC, but it will be beneficial and cost-effective over time. As noted in the Foreword to the Bridge Welding Code *Commentary on Bridge Welding Code,* “When States have the same basic requirements for essentially the same tasks, better understanding and utilization of the specifications by both Owner and Contractor representatives will improve quality while costs are reduced or contained. Duplication of effort in testing of welders and WPSs is discouraged by the Bridge Welding Committee, AASHTO, and FHWA. Procedures have been developed for the qualification of WPSs with a minimum of complexity and effort, yet with sufficient detail to ensure reliability.”

RECOMMENDATIONS

The following actions are recommended for KYTC in relation to the objectives of this study:

1. Eliminate KYTC “SPECIAL PROVISION NO. 4 WELDING STEEL BRIDGES”.
2. Incorporate in the current KYTC Specifications for Steel Bridges that fabrication will be per AWS D1.5 (current edition), except welding processes (ESW) and EGW) must be approved by the Department and Engineer, also process (FCAW) may be used on secondary members but must be approved by the Department and Engineer for main members.
3. Actively participate in AASHTO to seek incorporation of important exceptions into the Bridge Welding Code and to promote a better, more universally accepted document that will, to the greatest degree possible, provide for uniform state highway agency requirements to fabrication shops. KTC researchers can assist in this effort.

REFERENCES

1) FHWA, "Technical Information Guide for Narrow-Gap Electroslag Welding," Report No. FHWA-SA-96-053, 1996.

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3) FHWA, "Bridge Welding Code Proposed Revisions to Include Narrow-Gap Improved Electroslag Welding," Report No. FHWA-SA-96-050, 1996.

4) Document provided by Trevor Booker, Division of Construction, July 3, 2003.

5) ASTM, "A709/A709M-01a "Standard Specification for Carbon and High-Strength Low Alloy Structural Steel Shapes, Plates, Bars and Quenched-and-Tempered Alloy Structural Steel Plates for Bridges," **ASTM Book of Standards,** Vol. 01.04, 2003, pp. 344-351.

6) ASTM A 6/A 6M-01 "Standard Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling," **ASTM Book of Standards,** Vol. 01.04, 2003, pp. 13-75.

7) AISI, "Guide Specification for Highway Bridge Fabrication with HPS 70W (HPS 485W) Steel, 2nd Edition, June 2003.

8) "Steel Bridge Fabrication Technologies in Europe and Japan," Federal Highway Administration, Report No. FHWA-PL-01-018, March 2001.

9) ANSI/AASHTO/AWS D1.5M/D1.5:2002 Bridge Welding Code, pp.255.

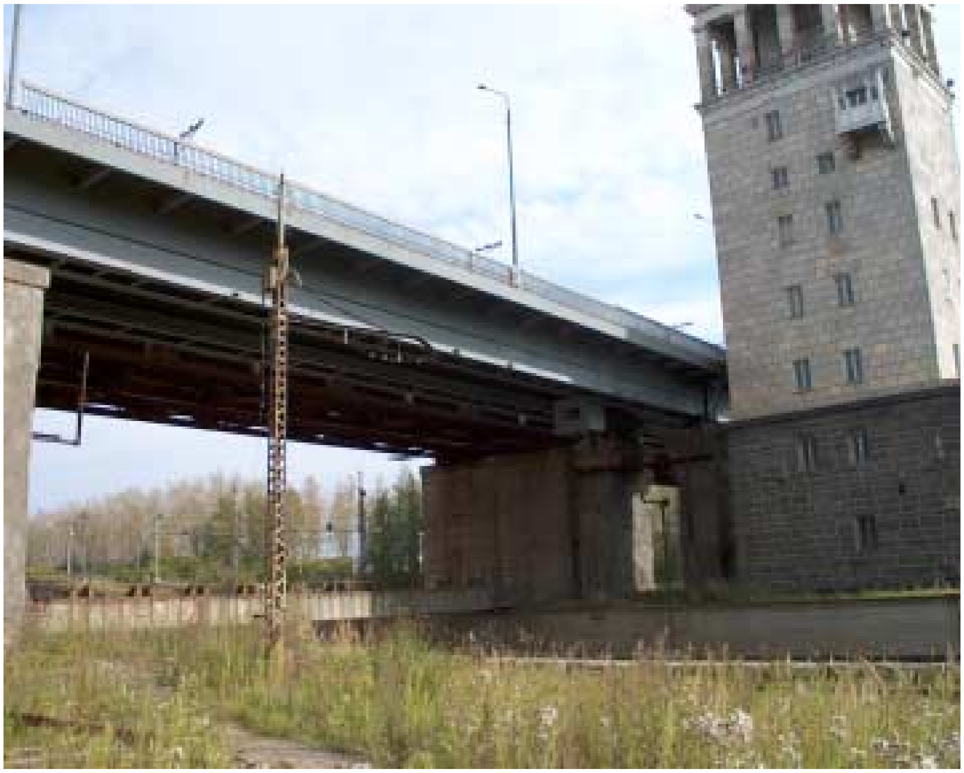

Figure 1. Kamskaya Dam Bridge in Perm Russia Having Field Welded Splices (September 2002).

Figure 2. Welded Tub Girder Sections for the Kama River Bridge at Perm Russia (September 2002).

Figure 3. High Quality Welds on Tub Girder Section for Kama River Bridge at Perm Russia (September 2002).