Steel Bridge Fabrication Technologies In Europe and Japan

U.S. Department of Transportation
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16. Abstract

The objective of this scanning tour was to conduct a broad overview of newly developed manufacturing techniques that are in use abroad for steel bridge fabrication and erection. The trip focused on the role of steel production, design, innovation, and fabrication in modern steel fabrication facilities in Japan, Italy, Germany, and the United Kingdom. The team also shared information on U.S. practice, initiatives, and research activities in these areas.

As a result of the review, the team identified six high-priority areas on which the U.S. industry should focus: computer aided drawing and computer aided manufacturing; automated recording of inspection, welding variables, and geometric measurements for quality control and virtual assembly; high-performance steels and coatings; cutting and joining steel components, members, and structures; certification and contracting of steel fabrication and erection; and design innovation.

Within each of these areas, the team made recommendations for further research, pilot studies, and modifications to existing procedures that will further modernize structural steel fabrication facilities in the United States.

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Computer aided drawing, computer aided manufacturing, high-performance steel, numerically controlled, weathering steel, robotic welding, computer integrated manufacturing.

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Steel Bridge Fabrication Technologies in Europe and Japan

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FHWA INTERNATIONAL TECHNOLOGY EXCHANGE PROGRAMS

The FHWA's international programs focus on meeting the growing demands of its partners at the Federal, State, and local levels for access to information on state-of-the-art technology and the best practices used worldwide. While the FHWA is considered a world leader in highway transportation, the domestic highway community is very interested in the advanced technologies being developed by other countries, as well as innovative organizational and financing techniques used by the FHWA's international counterparts.

INTERNATIONAL TECHNOLOGY SCANNING PROGRAM

The International Technology Scanning Program accesses and evaluates foreign technologies and innovations that could significantly benefit U.S. highway transportation systems. Access to foreign innovations is strengthened by U.S. participation in the technical committees of international highway organizations and through bilateral technical exchange agreements with selected nations. The program has undertaken cooperatives with the American Association of State Highway Transportation Officials and its Select Committee on International Activities, and the Transportation Research Board's National Highway Research Cooperative Program (Panel 20-36), the private sector, and academia.

Priority topic areas are jointly determined by the FHWA and its partners. Teams of specialists in the specific areas of expertise being investigated are formed and sent to countries where significant advances and innovations have been made in technology, management practices, organizational structure, program delivery, and financing. Teams usually include Federal and State highway officials, private sector and industry association representatives, as well as members of the academic community.

The FHWA has organized more than 40 of these reviews and disseminated results nationwide. Topics have encompassed pavements, bridge construction and maintenance, contracting, intermodal transport, organizational management, winter road maintenance, safety, intelligent transportation systems, planning, and policy. Findings are recommended for follow-up with further research and pilot or demonstration projects to verify adaptability to the United States. Information about the scan findings and results of pilot programs are then disseminated nationally to State and local highway transportation officials and the private sector for implementation.

This program has resulted in significant improvements and savings in road program technologies and practices throughout the United States, particularly in the areas of structures, pavements, safety, and winter road maintenance. Joint research and technology-sharing projects have also been launched with international counterparts, further conserving resources and advancing the state of the art.

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CONTENTS

OVERVIEW

PURPOSE

The purpose of the scanning tour was to conduct a broad overview of newly developed manufacturing techniques that are in use abroad for steel bridge fabrication and erection, as there is a need to further modernize structural steel fabrication facilities in the United States. The focus of the trip was on the role that steel production, design, innovation, and fabrication have in modern steel fabrication facilities in Japan, Italy, Germany, and the United Kingdom. In addition, the team shared information on U.S. practice, initiatives, and research activities to promote innovative steel bridge fabrication; erection techniques and high-performance steel production; and schemes to retrofit older steel structures.

The team's review concentrated on the following general topics:

- Computer aided drawing (CAD) and computer aided manufacturing (CAM).
- Automated recording of inspection, welding variables, and geometric measurements for quality control and virtual assembly.
- High-performance steels and coatings.
- Cutting and joining steel components, members, and structures.
- Certification and contracting of steel fabrication and erection.
- Design innovation.

> The focus of the trip was on the role that steel production, design, innovation, and fabrication have in modern steel fabrication facilities in Japan, Italy, Germany, and the United Kingdom.

These topics are discussed in detail in a separate section of this report. Recommendations are provided for the findings in each of these topic areas as candidates for implementation into U.S. practice, and for further study and development.

Before the trip, the team developed a list of amplifying questions and submitted it to the organizations that were visited in each country. The list of questions served to define the focus of the scanning tour, provided the basis for discussions, as well as elicited responses from many of the organizations that were visited. The list of questions is provided in appendix A.

In addition to the discussions held during the tour, the team participated in two workshops. One was held in Osaka and was organized by Prof. Chitoshi Miki, Tokyo Institute of Technology, and Mr. Kazuhiro Nishikawa, Japan Public Works Research Institute, Ministry of Construction. The program for this workshop is listed in appendix B.

A second workshop was held at The Welding Institute (TWI), in Cambridge, UK, and was organized by Drs. John Harrison and Stephen Maddox. The program also is listed in appendix B.

Appendix C contains a list of the documents provided before or during the tour that which were reviewed for the preparation of this report. Appendix D is the itinerary for the scanning tour.

SPONSORING ORGANIZATIONS

The scanning review was conducted under the auspices of the Federal Highway Administration's (FHWA) Office of International Programs. The National Steel Bridge Alliance (NSBA) and the American Iron and Steel Institute provided input during the initial planning stages.

TEAM MEMBERS

The team members and the agencies and organizations they represented are listed below.

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Arun Shirole	NSBA	National Steel Bridge Alliance, RI
Jerry Uttrachi	AWS	ESAB
Alexander D. Wilson	AISI	Bethlehem Steel Corp.
William J. Wright	FHWA	FHWA, McLean, VA

Appendix E provides biographical information on the team members, and Appendix F lists their contact information.

Appendix G contains a diagram of high speed rotating arc welding.

ORGANIZATIONS AND SITE VISITS

Background information on the organizations visited and a summary of their operations is provided below in this section. Details of the relevant information learned during the meetings and specific recommendations of the scanning team are provided in the section on findings.

JAPAN

In Japan, the team visited four bridge fabrication shops. In the greater Osaka area, the team visited Matsuo Bridge Company and the Yokogawa Bridge Corporation, met with corporate and plant personnel, and toured the fabrication facilities. The team then visited the NKK Bridge Works, in Tsu, and Kawada Industries, Inc., in Marugame, on the island of Shikoku.

The team traveled from Tsu to Nagoya to visit the second Tomei Highway project of Japan Highway Public Corporation, specifically, the Inabe River Bridge on-site field welding and nondestructive inspection.

Following the site tours, a one-day workshop was organized by Prof. Miki and Mr. Nishikawa. The workshop was convened at the U.S. Consulate in Osaka.

Matsuo Bridge Company, Ltd., is one of Japan's leading fabricators (in the top 10) and erectors of steel structures for bridges and steel-framed buildings. The company was established in 1925 and has plants in Sakai (Osaka), Chiba, and Shanghai, China. The Sakai plant was constructed in 1963 and occupies a land area of 86,000 m^2. Production capacity is 3000 metric tons per month. Its 225-m-long and 51-m-wide wharf allows it to erect blocks up to 7000 metric tons, which can be shipped directly from the wharf. The plant is qualified to construct major bridges in Japan and is ISO 9001 certified. Matsuo has fabricated components for several bridges for the Honshu-Shikoku Bridge Authority (HSBA), and for numerous projects in North and South America, Asia, and the Middle East.

In general, the fabrication practice at the Sakai plant was similar to that of many larger operations in the United States. Numerically controlled (NC) marking and cutting was carried out with gas and plasma arc cutting machines. Flux-core arc welding (FCAW) is the dominant process (65 to 70 percent), followed by solid wire gas metal arc welding (GMAW) (100 percent), CO_2 (20 percent), and submerged arc welding (SAW) (10 percent).

The following were observed during the visit:

- Implementation of CAD/CAM technology.
- NC plasma cutting and marking machines.
- Flange panel fabrication line — automatic tack and final CO_2 welding correcting angular distortion of ribs and flange (figure 1).
- Demonstration of automatic-scanning ultrasonic testing machine.
- Demonstration of 3-D measuring system for virtual assembly.
- Preassembly of steel piers for Ishimaru Bridge, with thick bent plates.
- Double-bevel groove welds with root grinding machine (figure 2).

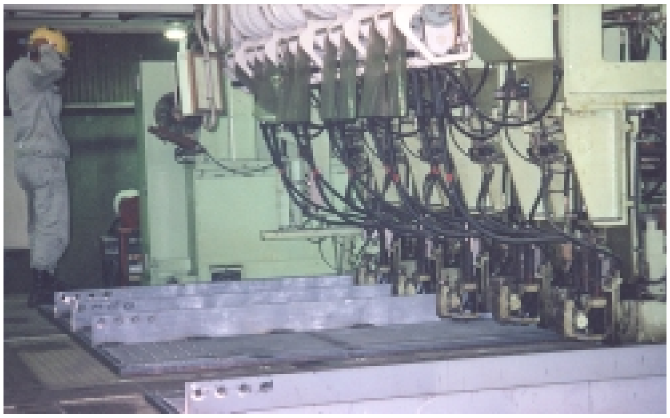

Figure 1. Flange panel fabrication line at Sakai plant of Matsuo Bridge Co., Ltd., in Japan.

Figure 2. Double-bevel groove welds with root grinding machine at Sakai plant.

Figure 3. Yokogawa Bridge Corp.'s Osaka plant wharf containing the 2000-ton, 115.1-m segment for North Kyushu Airport Connection Bridge in Japan.

- Fabricated components and preassembled sections.

The Yokogawa Bridge Corporation is one of Japan's top five fabricators and erectors of steel structures for bridges, steel-framed buildings, and communication towers. The company was established in 1907 and has plants in Sakai (Osaka) and Chiba. The Osaka plant was established in 1964 and occupies a land area of 113,830 m^2. Production capacity is 5000 metric tons per month. Its wharf is 130 m long and 30 m wide and contained the 2000-ton, 115.1-m segment for the North Kyushu Airport Connection Bridge (figure 3).

The plant is qualified to construct major bridges in Japan. It has the AISC Level III certification for major bridges in the United States and ISO 9001 certification. The plant has fabricated components for several bridges owned by HSBA and for bridges in North and Central America, Asia, and the Middle East.

In general, the fabrication practice at the Sakai plant was similar to many larger operations in the United States. NC marking and cutting was with 2.5-kW and 6-kW laser cutting machines, as well as gas and plasma arc cutting. FCAW is the dominant process (74 percent), followed by SAW (11 percent), solid wire GMAW (10 percent), and shielded arc metal welding (SMAW) (4.6 percent).

The following were observed during the visit:

- Implementation of CAD/CAM technology.
- NC laser and plasma cutting and marking machines.
- Cranes with lifting magnets to move multiple flange plates (figure 4).
- Automated flange and web panel fabrication with NC machines and robots.

- Assembled components of plate and box girder segments.
- Box unit being measured for virtual erection check (figure 5).
- Preassembly of 2000-ton segment of North Kyushu Airport connection bridge and field weld preparation (figures 3 and 6).

The NKK Corporation was founded in 1912 as Japan's first seamless pipe manufacturer and is Japan's second largest producer of steel. The Tsu Works was founded in 1969 as the Tsu Shipyard. In 1970, steel structure production was added, and in 1975 a large oil-production platform was fabricated. The first HSBA bridge order was obtained in 1977, and the Tsu Laboratories was established in 1976. The total Tsu Works plant occupies a land area of 1,820,000 m^2. The steel structures division is the most modern fabrication facility and is among Japan's top five fabricators of steel bridges. Production capacity is 4000 metric tons per month. Two large wharves are available for assembly and barge loading.

The plant, which is ISO 9002 certified, is qualified to construct major bridges in Japan and elsewhere in Asia, Europe, North and South America, and the Middle East.

In the late 1980s and early 1990s the facilities were renovated for automated bridge production lines with laser cutting and welding robots, using automated lines with CAD/CAM systems (see appendix C). Three parallel buildings house the operation. In the first, all plate stock is cleaned and cut using gas, laser, or plasma cutting. Six-kW lasers are used for plates up to 25 mm, and 3-kW lasers are used for plates up to 14 mm. These NC-controlled units provide precision cuts and long periods of operation.

The plate product then moves to the two assembly shops, which provide various assembly lines of nine computer-integrated facilities, including 29 articulated

Figure 4. Cranes with lifting magnets move multiple flange plates at Yokogawa plant.

Figure 5. Box unit is measured for virtual erection check at Yokogawa plant.

Figure 6. Preassembly of North Kyushu Airport Connection Bridge.

Figure 7. Robot demonstrating high-speed rotating arc welding at NKK Corp.'s Tsu Works plant in Japan.

welding robots equipped with the NKK high-speed, high-current rotating arc welding system (see appendix G) with arc sensor seam tracking control.

The following were observed during the visit:

- Structural laboratory with fatigue test of welded pipe joint for bridges.
- Demonstration of automated wave record type ultrasonic inspection system.
- Demonstration of surface stress measurements, using a magnetic anisotropy sensor.
- Demonstration of a robot with high-speed rotating arc welding (figure 7).
- Seaside (1 km) exposure test of a partial, full-scale, seaside weathering steel bridge with small-scale plate samples (figure 8).
- Parallel NC 3-kW CO_2 gas laser cutting lines: one for large members (flanges, webs, transverse ribs) and one for small members (gusset plates, splice plates, stiffeners) (figure 9).
- NC plasma cutting machine.
- Transverse (orthotropic deck) rib assembly line (figure 10).

Figure 8. Seaside exposure test by Tsu Works of a partial, full-scale seaside weathering steel bridge with small-scale plate samples.

Figure 9. Parallel NC 3-kW CO_2 gas laser cutting lines at Tsu Works: one for cutting large members, one for cutting small members.

- Fully automatic drilling line.
- Chamfering line for holes in splice plates, gusset plates, and stiffeners.
- I-section girder line (flanges, web, and stiffeners).
- Box girder web and flange panel assembly line (figure 11).
- 300-m × 60-m × 2-m experimental model of the mega-float structure.

Figure 10. Transverse (orthotropic deck) rib assembly line at Tsu Works.

The Japan Highway Public Corporation was founded in 1956 to administer nationwide toll roads. The New Meishin Expressway is one of the ring-roads around large cities, such as Nagoya. Japan Highway Public Corporation arranged for a visit to the Inabe River Bridge site, where construction of twin, box-steel continuous spans is under way through a joint venture of Ishikawajima-Harima Heavy Industries Company (IHI) and Hitachi Zosen Corporation. Segmental box segments were being field welded, on site, by the joint venture. The 100-mm flange groove welds were made by single-groove, automatic, 100-percent CO_2 GMAW. No preheating was used, as long as the base metal temperature exceeded 5° C. Both

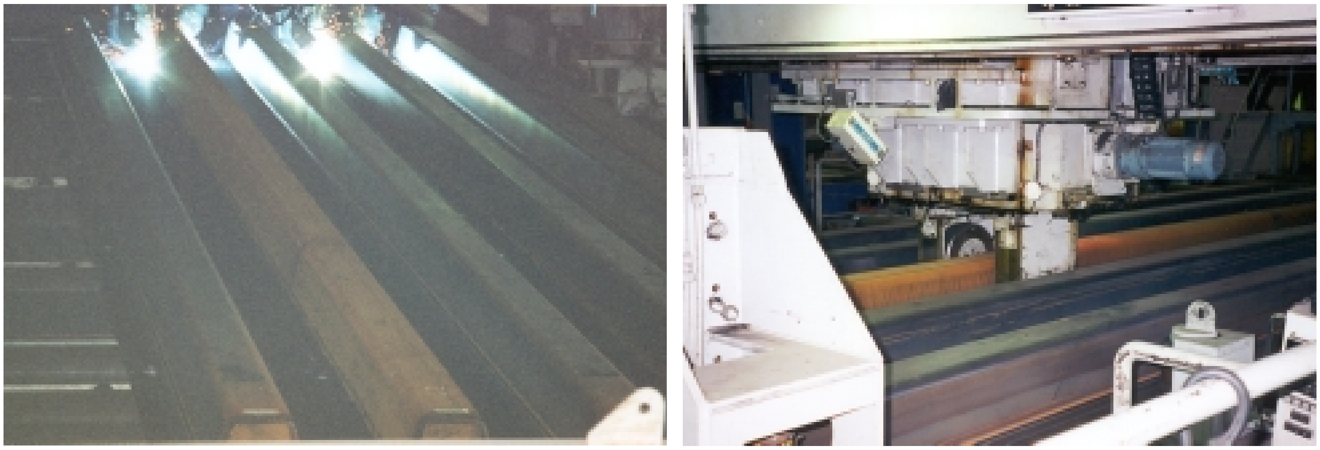

Figure 11. Box girder web and flange panel assembly line at Tsu Works.

manual and automatic ultrasonic testing were used to evaluate the finished product.

The following were observed during the site visit:

- Demonstration of the automated ultrasonic test equipment on a calibrated test sample.
- Demonstration of the automated equipment used to make the flange and web groove welds.
- Fabricated box sections stored on site (figure 12).

Figure 12. Fabricated box sections stored on site at Inabe River Bridge in Japan.

Kawada Industries, Inc., was founded in 1922 as Kawada Ironworks. The Shikoku plant was established in 1973, and it occupies a land area of 264,863 m^2. Kawada is among the top five fabricators of steel bridges. Production capacity is 7000 metric tons per month. Its wharf is 400 m long and is capable of supporting 3000 metric tons.

The plant is qualified to construct major bridges in Japan and has ISO 9001 certification (steel bridge design, development, fabrication, and temporary erection). The plant has fabricated components for several bridges owned by HSBA and for bridges in Asia and the Middle East.

In general, the fabrication practice at the Shikoku plant was similar to several larger operations in the United States. NC marking and cutting was observed with laser, plasma, and gas computer-numerically controlled (CNC) machines. Flux-core gas shielded and metal core gas shielded welding were used in 90 percent of the work. Submerged arc welding was used for the balance of the work. Welding was carried out with multiple-electrode welding machines for units for closed- and open-rib orthotropic deck panels. Plate and box girder web panels had stiffeners and gusset plates welded on with CNC welding robots, which also are used in other operations.

It was noted that about one-third of the Shikoku plant production involved bridge structures. The other two thirds included building applications.

The following were observed during the plant visit:

- Implementation of CAD/CAM technology.
- NC laser and gas cutting and marking machines.
- Automated web panel fabrication with NC welding robots (figure 13).
- 20-electrode GMAW welding machine for open and closed rib welding to orthotropic deck plates (figure 14).
- NC drilling machines.
- Preassembled units for field welding.
- Fabricated orthotropic deck sections (figure 15).

The scanning review of Japan concluded with a one-day workshop (see appendix B) on Steel Bridge Fabrication Technologies. The Japanese participants included representatives from all of the organizations that the team visited, as well as other attendees from universities and steel producers. The workshop, organized by Prof. C. Miki and Mr. K. Nishikawa, provided an opportunity to hear further responses to many of the amplifying questions.

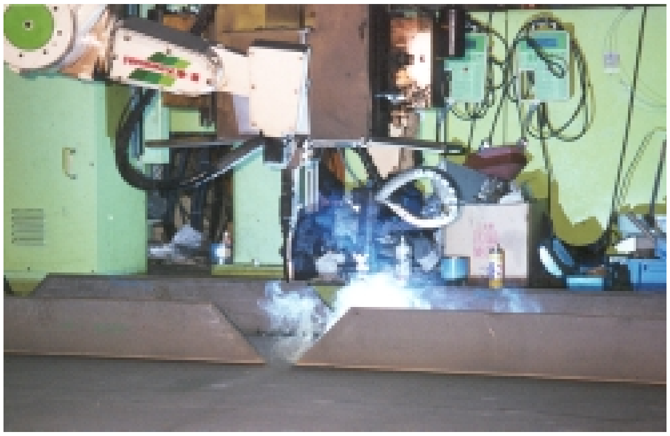

Figure 13. Automated web panel fabrication with NC welding robots at Shikoku plant of Kawada Industries, Inc., in Japan.

Figure 14. 20-electrode GMAW welding machine for open and closed rib welding to orthotropic deck plates at Shikoku plant.

Figure 15. Fabricated orthotropic deck sections at Shikoku plant.

ITALY

In Italy the scan team visited the fabrication facilities of the Cimolai companies in the area of Pordenone. The Cimolai Group originated from the company formed by Armando Cimolai in 1947. Four factories are in the region; the one in Pordenone occupies a land area of 55,000 m^2. A second factory, at Polcenigo (10 km from Pordenone), occupies a land area of 130,000 m^2. A third, at Piano (6 km from Pordenone), occupies an area of 140,000 m^2. A fourth, at San Quirino (7 km from Pordenone), occupies an area of 35,000 m^2. These plants' production capacity exceeds 3500 metric tons per month. The company is one of Italy's top fabricators and erectors of steel structures for bridges, buildings, shelters for aircraft and munitions, and towers for electricity and communication. The company has fabricated and erected major highway and railway bridges in Italy, France, the UK, and the Middle East.

In general, the fabrication practice at the Cimolai plants was similar to many operations in the United States. Like many Japanese companies, Cimolai plays a more active role in field erection than do many U.S. fabricators. NC flame and plasma cutting machines were in use. Current use of FCAW and metal core GMAW welding with tandem, twin arc, and automatic welding machines accounted for about 30 percent of weld applications. This use was projected to increase as SMAW decreased.

The following were observed during the plant tours:

- Implementation of CAD/CAM technology.
- NC gas and plasma cutting machines.
- NC robotic welding.
- Automated handling and assembly of welded beam members by machines designed and built by Cimolai (figure 16).
- NC drilling machines.
- Fabricated components (figure 17).

GERMANY

In Berlin the scan team visited the Federal Institute for Materials Research and Testing (BAM); a fabrication shop, Krupp Stahlbau Berlin; two bridge sites; and Potsdam Square, the new center of Berlin.

BAM originated in 1870 when the Prussian Ministry of Commerce, Trade, and Public Works formed a Mechanical and Technical Research Institute. In 1954, the Federal Republic of Germany took over responsibility from Berlin and established BAM to function as the national chemical and materials technology institute. The team visited Department VII – Safety of Structures. Briefings were provided by BAM, Krupp Stahlbau Berlin, and HRA.

The team viewed the following in experimental facilities:

- Tests on old, riveted truss-girder bridge members under cyclic loading (figure 18).
- High-speed testing of structural members.
- Welding of loaded structural members.

Krupp Stahlbau Berlin, GmbH, is one of Germany's medium-sized fabricators of steel structures for bridges and steel-framed buildings. The plant occupies an area of 43,000 m^2 and employs 220 people. Krupp Stahlbau Berlin produces about 10,000 metric tons per year, with annual revenues of about DM90 million (US$4.5 million).

The plant is qualified to fabricate and construct highway and railroad bridges in Germany. The company has fabricated and erected many bridges and buildings in the Berlin area, including the Havel River Railroad Bridge. NC flame and plasma cutting machines were in use. Current use of solid wire GMAW accounted for 85

Figure 16. Automated handling and assembly of welded beam members by machines designed and built by Cimolai in Italy.

Figure 17. Fabricated components at Cimolai factory.

Figure 18. Tests on old, riveted truss-girder bridge members under cyclic loading by BAM in Germany.

Figure 19. NC robotic welding at Krupp Stahlbau Berlin plant.

percent of the welding; the balance was SAW.

The following were observed during the plant tour:

- Implementation of CAD/CAM technology.
- NC gas and plasma cutting machines.
- NC robotic welding (figure 19).
- NC drilling machines.
- Fabricated components and assemblies (figure 20).

In addition, the team visited the Havel River Bridge, which was preassembled on site because transport capabilities limited the shipment size of components. The top flange was fabricated from three 50-mm plates in a layer, as shown in figure 21.

Figure 20. Fabricated components and assemblies at Krupp Stahlbau Berlin plant.

The team also made a site visit to the Humboldthafen Rail Bridge, which crosses the River Spree and connects to the Lehrter Station, in Berlin. Figure 22 shows the large-cast steel bearing connections and the tubular support structure, with cast steel nodes.

UNITED KINGDOM

In the UK, the team visited the fabrication facilities of Fairfield-Mabey at Chepstow, Wales. The company dates from its founding in 1849, when it built the Wye Railway Bridge in Chepstow. The plant occupies a land area of 170,000 m^2 and its production capacity is 2500 metric tons per month. Fairfield-Mabey leads the

Figure 21. Havel River Bridge in Germany, fabricated from three 50-mm plates in a layer, was preassembled on site.

Figure 22. Large-cast steel bearing connections and tubular support structure, with cast steel nodes, of the Humboldthafen Rail Bridge in Germany.

UK, with about 80 percent of the current bridge market. The company fabricates and erects steel structures for highway and railway bridges, offshore modules, bridge-maintenance gantries, and steel-framed buildings. It has fabricated and erected major highway and railway bridges in England, the Middle East, and Central and South America.

The fabrication practice at the Chepstow Plant is focused on steel plate fabricated products, and steel bridges remain its core market. As was observed elsewhere on the tour, the company plays a more active role in field erection than do many U.S. fabricators. CAD/CAM modeling and CNC cutting and welding machinery were in extensive use. Current use of GMAW and FCAW accounted for about 50 percent of the shop work, and SAW for the balance of shop work. It was noted that design/

build was growing in the UK and that Fairfield-Mabey workers were often on more than one team.

The following were observed during the plant tour:

- Implementation of CAD/CAM technology.
- NC gas and plasma cutting machines (figure 23).
- NC robotic welding.
- Automated handling and assembly of welded beam members.
- NC drilling machines.
- Fabricated components (figure 24).
- Video of Chepstow plant operations.

Figure 23. NC gas and plasma cutting machines at Fairfield-Mabey's fabrication plant in Chepstow, Wales.

Figure 24. Fabricated components at Chepstow plant.

The Welding Institute (TWI), at Abington, was founded in 1946 and is one of the world's largest independent research and technology organizations, with branches and associates worldwide. It is involved with all aspects of materials joining and related technologies. TWI has played a major role in the development of design- and material-selection specifications in the UK Bridge Rules (BS5400), for avoiding fatigue and fracture in steel bridges. A UK-U.S. Workshop on Innovation in Steel Bridge Construction was organized by J. Harrison, M. Ogle, and S. Maddox (see appendix B). The workshop provided an opportunity to review the amplifying questions from the perspectives of designers, fabricators, and owners, as well as hear of the TWI work on laser welding and cutting and other high-energy welding systems.

SUMMARY OF SCAN FINDINGS

On the basis of the scan review of steel bridge fabrication in Japan, Italy, Germany, and the UK, the team identified the following top priority implementation topics in six areas of focus.

HIGH-PRIORITY TOPICS

CAD/CAM

- Establish a task group of owners and fabricators, possibly through the AASHTO/NSBA Steel Bridge Collaboration, to develop a documentation standard.
- Promote development of a computer integrated manufacturing (CIM) software package.
- Conduct a pilot project on digital fabrication shop documents in lieu of shop drawings.
- Develop a storage protocol for achieving as-built documents.

Automated Recording

- Evaluate existing measurement technologies.
- Explore feasibility of digital geometric measurements on fabricated components for virtual assembly in lieu of preassembly.
- Carry out a pilot project, working closely with owners to ensure their confidence in the virtual approach.

High-Performance Steel (HPS) and Coatings

- Study applicability of “seaside” weathering steels for U.S. marine environments.
- Promote the use of a 50-ksi, low-carbon HPS for improved weldability and toughness.

Cutting and Joining

- Develop a workshop on gas-shielded welding and new methods of welding for shop and field fabrication for fabricators and owners.
- Work with FHWA and State departments of transportation (DOTs), with American Welding Society (AWS) Bridge Code support, to gain acceptance for gas-shielded welding as a preapproved welding process.
- Explore using the high-speed rotating arc technique with enhanced tracking for fillet welding.
- Promote the use of ultrasonic inspection, with record producing capability, in lieu of radiography.
- Modify welding-procedure qualification requirements to allow unlimited life, provided an alternative, demonstrated quality program is in place.

Certification and Contracting

- Set up a task group, possibly through AASHTO/NSBA Steel Bridge Collaboration, to develop a Qualification Program for fabricators, which allows them to be responsible for quality.
- Explore incorporating appropriate parts of ISO 9001 in the AISC Certification Program.
- Explore incentives to enable a fabricator to accept responsibility for both fabrication and erection, to achieve optimum cost and delivery.

Design Innovation

- Reexamine the design practice, FHWA directives, and AASHTO specifications related to two lines of support and fracture-critical members in view of modern materials, joining, and quality control developments.
- Support national programs, such as the AASHTO/NSBA Steel Bridge Collaboration, to develop standard design details.

LOWER PRIORITY TOPICS

- Evaluate the European paint practice of applying the final coat of paint in the field after erection.
- Evaluate the cost-effectiveness of tapered plate for use in girder flanges.
- Conduct a pilot project, working closely with owners to ensure their confidence in the virtual approach.

CAD/CAM

All of the fabricators that the team visited had CAD and CAM software. These systems also included three-dimensional (3-D) bridge modeling that can be used to verify assembly/field erection location and elevation checks. The software was purchased from a variety of vendors or developed in house. None of the software was completely integrated, so the results of one package were manually input into the next. In most of the shops, the data are generated by hand from design drawings. The generation of a digital representation of the structure is crucial to a modern fabrication shop. The information is used to verify the geometry input and simultaneously produces manufacturing NC data. The CNC code can be sent directly to the applicable machine using a local area network. No detail drawings are required in this modern fabrication shop. Large size drawings were rarely made. Sketches are produced on a small format, 8.5 by 11 in, and are generally produced for the shop along with a cutting schedule. This is often in the form of a traveler following the work through the shop.

The U.S. practice is evolving along similar lines. Fully integrated systems are planned, and cooperative development among fabricators was discussed.

Fairfield-Mabey uses a 3-D solid model as the source information for all CNC programs for cutting, drilling, and marking operations. All the data are electronically transferred among packages. The only manual intervention is to apply allowances for predicted longitudinal welding shrinkage to webs and flanges, which is done by the application of a factor, rather than by redrafting.

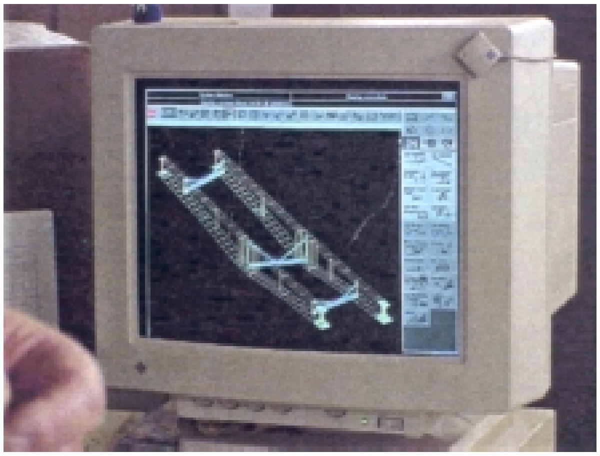

Figure 25. CAD of girder bridge and cross frames used by Fairfield-Mabey.

As shown in figure 25, the software used by most of the fabricators had the ability to perform a virtual assembly of pieces. This virtual assembly was used to check for dimension errors and interference of pieces in the assembled structure. The programs were often running on personal computer platforms, and modified versions of AutoCAD were used in two shops. Procedures to document changes that occurred during the production of the fabrication documents have to be carefully considered. Tracking of these changes is important. In Fairfield-Mabey only one set of design drawings is allowed on the premises. All changes are documented on the drawings and placed in a single binder with a copy to the designer or owner. Any necessary approval is recorded in the same binder. The transfer of information from the fabricator to the owner or engineer is via fax or Internet.

Shop detail drawings are not needed in the modern automated shop. Shop drawings no longer need to be available nor need to be reviewed by the owner. In many of the shops that the team visited, the submittal and approval of shop drawings had been eliminated. This process of submittal and approval can take from 4 to 6 weeks up to 6 months in the United States. The elimination of shop drawing submittal and approval by the owner speeds up the job and reduces costs. The cost to produce the drawings and review them is eliminated. Shop drawings offer little benefit to the shop, even though they are required by owners. In U.S. shops that have a strong record, owners may be willing to eliminate this requirement, if other forms of quality assurance are in place. The job must still be represented numerically in order to program the NC equipment. Elimination of the generation and the approval of shop drawings could provide a significant savings reduction in fabrication of the steel and also speed up the fabrication process. This step requires the owner’s trust and confidence in the fabricator’s ability to perform the job. In Japan this process entails a prebid selection of qualified shops, something that also should be undertaken on a trial basis in the United States.

One of the highest priority goals of U.S., European, and Japanese fabricators is development of a CIM software package. The software would provide assembly data, based on 3-D modeling and section dimensions, taking into account shrinkage and distortion from welding and cutting.

AUTOMATED RECORDING

Fabricated Elements – Virtual Assembly

Automated recording of fabrication was employed to a limited extent by some of the fabricators visited. Various geometric-measurement systems were used by the

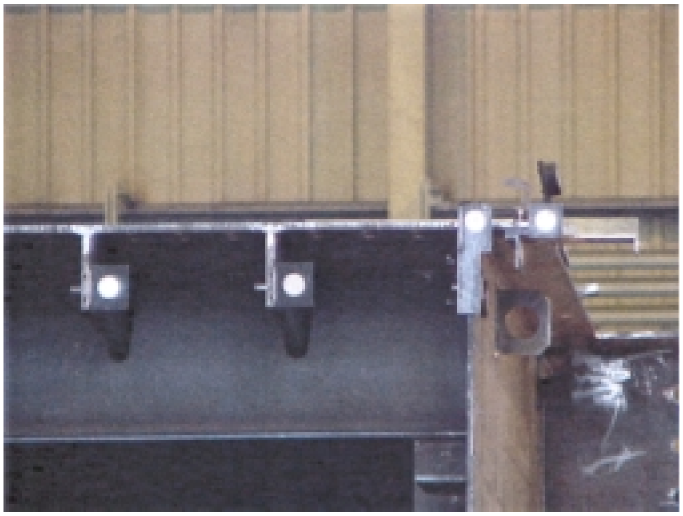

Figure 26. Targets for CATS geometry checking system at Yokogawa Bridge Corp. in Japan.

fabricators to determine the conformance of the geometry, as illustrated in figure 5. A range from simple digital surveying equipment to the more sophisticated CATS system was employed to measure the structure and compare it with the geometry generated in the computer drawing and manufacturing system. As shown in figure 26, this system allowed the position of various critical locations on the subassembly to be located. These systems allow a virtual assembly of the components. The virtual assembly provides a complete geometric record of the completed structure and readily identifies tolerance questions.

The shop assembly of the fabricated pieces can be eliminated by using these sophisticated measuring systems, which results in a considerable savings in cost and time. Some shops used standard digital surveying equipment to perform the measurements. The measured dimensions were checked against the CAD files. Laser equipment available in the United States can easily perform these measurements, and implementation of existing U.S. technology to perform the geometric checks of large fabricated elements should be pursued.

Nondestructive Inspection

Automated and digitally recorded ultrasonic inspection was used in the shop and field inspection of welds. All of the Japanese fabricators had automated ultrasonic inspection in their shops. The units consisted of three shear wave transducers controlled by the scanner. The data were recorded and provided a permanent record of the inspection results. A typical setup is shown in figure 27. A laptop computer is used to control the scanning and record the data.

Figure 27. Automated ultrasonic inspection equipment used in Japan.

This technology is used in other industries in the United States, but has not yet found its way into bridge fabrication. The equipment in Japan was often U.S. equipment. The use of this modern method of ultrasonic inspection needs to be evaluated for use in bridge fabrication. It was interesting to note that, in the UK, only ultrasonic inspection was used, while in Germany only radiographic inspection was accepted. Only a portion of the weld was inspected by ultrasonic equipment, with

100 percent inspection by radiography. It should be pointed out, however, that in the UK, the proportion of ultrasonic testing varied with the criticality of the feature. For example, transverse butt welds in tension flanges of primary structural members are always 100-percent tested, while testing of longitudinal butts may be as low as 10 percent.

One fabricator employed continuous monitoring and recording of welding variables. The improved accuracy and detailed record of the welding process serves as an effective means of quality assurance, in lieu of an owner's representative witnessing tests.

HIGH-PERFORMANCE STEELS AND COATINGS

Introduction

The steels used for bridges around the world are governed either by individual country specifications or by the new Eurocode. The yield strength levels are very similar to those used in the United States, and 50 ksi (345 MPa) is the most common strength grade. All of the countries have a steel grade in the 65 to 70 ksi (450 to 480 MPa) yield strength range, and report growing interest in their use. Thermo-mechanical controlled processing (TMCP) is used by all countries for higher strength levels and is aggressively used in Japan for improving weldability. The improved weldability is the result of the low carbon and carbon equivalence of these steels. Quench and temper (Q/T) processing is used for steels from 70 to 100 ksi (480 to 680 MPa) yield strength, although steels greater than 70 ksi (480 MPa) are rarely used. Weathering steel is used in all countries visited, and there are initiatives to increase its use. Japan has developed two new, higher-alloy "seaside" weathering steels for areas close to the coast. Zinc-rich primers are commonly used in all the countries for painted bridges. Aluminum metallizing is often used instead of primer in the UK. The major findings are described in the following sections.

Steel Quality and Properties

The quality of bridge steel is excellent in all the countries that the team visited. Thin plates were used extensively in Japan, with about 80 percent of the plate for bridges having a thickness less than 14 mm. The primary structure form in Japan is a rectangular steel box comprised of thin plate elements with multiple stiffeners. The thin plates can be laser cut. Laser cutting requires plates that are very flat, and it reduces residual stresses. There were no claims of special "laser-cutting" steel, although steel makers are evaluating this idea. In most of Europe, thicker plates are more common, and no laser cutting was seen in any of the shops. In Germany, the maximum plate thickness is limited to 60 mm; thicker plates are permitted, but only by special agreement with the road or railway agency involved. Figures 21 and 28 show a flange built of three thin plates for a railroad bridge girder in Germany. Thicker plates, 75 to 100 mm, are not used as much as they are in the United States.

In Japan, most of the plates are delivered from the mill in a blasted and primed condition when they are specified for use in painted structures. The primers are different, depending on the topcoat system specified for the final structure.

Figure 28. Multiple plate top flange for railroad bridge girder in Germany.

Weathering steel plates are delivered in the blasted condition with mill scale removed. The surface quality of all plates was observed to be excellent. In Europe, steels are delivered without blasting.

All countries specify toughness for bridge steels. For most service conditions, 20 ft-lb@10F to 20 ft-lb@-40F are typical requirements. This is similar to the toughness requirements used in the United States.

Japan and the UK aggressively control carbon equivalent of steels to facilitate zero preheat welding. Whenever possible, Japan uses TMCP for this purpose. Welding processes and consumables also are selected to make this possible. The elimination of preheat is crucial if automatic and robotic welding are used.

Steel Processing

Most of the bridge steel provided in all countries is hot rolled; some is normalized for yield strength between 35 and 50 ksi (240 and 345 MPa). Japan leads the use of TMCP for production of 50 to 70 ksi (345 to 480 MPa) steel, when no preheat welding is required. TMCP is also being used in some cases in Europe. The direct Q/T process is sometimes used for this purpose in Japan. The Q/T process is used in all countries for steels with strength greater than 70 ksi (480 MPa). The U.S.-grade HPS-70W has superior toughness properties and tighter chemistry controls than the European steels and is equivalent to the Japanese versions. In most of the countries, steel is referred to by its minimum tensile strength, whereas in the United States, steel is identified by its yield strength.

Weathering Steel

All countries recognize the economic benefit of using weathering steel. Owners' policies vary about when and under what conditions this steel can be used. In Italy, up to 90 percent of the bridges are weathering steel, and Japan uses it for about 14 percent of bridges. In the UK, typical usage is about 10 percent, but existing restrictions are expected to be relaxed, which may increase proportions in the future. Germany had a moratorium on weathering steel use that has recently been rescinded.

Japan is currently implementing higher alloyed “seaside” weathering steels for use in marine environments. Three grades are in use: a 3-percent nickel version; a 1.5-percent nickel, 0.3-percent Molybdenum version; and a 1-percent copper, 1-percent nickel version. These new steels provide enhanced corrosion performance for seaside locations, and test samples are shown in figure 29. The extensive coastal regions of Japan provide a large market for improved-performance steels.

Japan also has developed "weathering primers" that are applied to prevent initial staining problems and, possibly, enhance the formation of a stable rust patina. It is unclear what advantage these primers offer; they have not been used extensively and are under evaluation. No other country is currently using or evaluating similar primers.

Figure 29. Weathering steel and primer corrosion test samples in Japan.

Coating Systems

Painting is still in use in all countries, but the systems vary significantly. In Japan, six-coat systems are used over seawater locations. In Europe, three-coat systems are more common. Most practices start with a zinc-rich primer. In the UK, metallizing is used, in many cases, in place of the primer coat. Metallizing eliminates the volatile organic compound (VOC) from paints and may provide a more robust primer. Epoxy and urethane paints are applied over the metallized coating.

In Japan, the plate is received from the mill in a blasted and primed condition (see figure 30). All other coats are applied in the shop. In Europe, the practice is to blast, prime, and epoxy coat in the shop and apply a urethane topcoat in the field. The field-applied topcoat eliminates the need to touch up damage that occurs during shipping and handling.

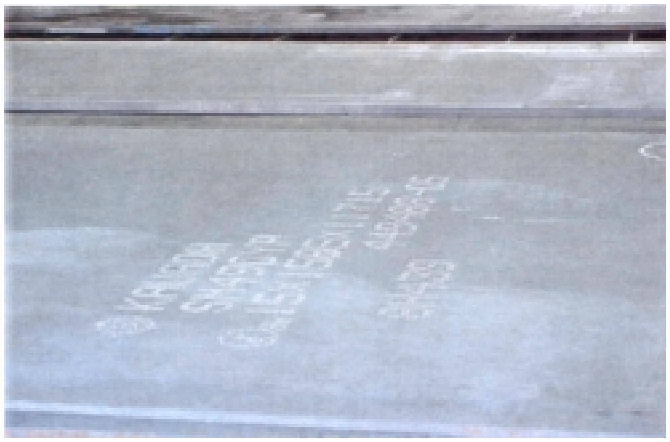

Figure 30. Mill-coated steel plate used in Japan.

Longitudinally Profiled (LP) (Tapered) Plates

Plates have been rolled with variable thickness along their length for use in girder flanges. In Japan, 16 bridges have been built with tapered flanges in the negative moment area over the piers (total of 2500 tons). LP plates also have been used in limited quantities in Europe. The use of these plates is not increasing because of questionable economics. The economics of tapered plates is dependent on the cost of production versus the reduction in weight and the number of splices in a girder. The variation in thickness is normally 10 to 20 percent of the thickest part.

CUTTING AND JOINING

Introduction

The type of cross section of the bridge dictated the processes used in the shops visited. In Japan, the majority of the bridges appear to be closed steel boxes with orthotropic steel decks. Relatively thin plates, less than 15 mm thick, were used for most of the construction. Much of the plate was less than 25 mm thick, with multiple longitudinal and transverse stiffeners. Thin plate structures also were used in Germany and Italy. The maximum plate thickness for bridges in Germany is 40 mm.

Thick flanges were made by fillet welding together multiple thinner plates. Laser cutters were used by two of the fabricators to cut plates up to 16 mm thick. The laser cutters were typically used to cut detail pieces such as stiffeners. Often, the more complex cuts were made on the laser cutter with a multiple-torch machine, used to strip out the stiffeners. Similar techniques are used in the United States, using plasma and oxygen-fuel cutting. Large cutting tables, which could accommodate a number of plates, were used. The single-head laser or conventional cutting torch were computer controlled. Underwater plasma cutting was used in England to reduce distortion. Most of the plants had a marking head on the cutting equipment, which allowed the same machine to do the marking and cutting. The short shipping lengths in Japan restricted the shop length to 15 m or less. Consequently, many repetitive pieces and operations were required, which benefitted from automation.

Automation

The degree of automation varied among the shops. All shops used NC equipment and some form of robotic welding. Automated, robotic welding was used for stiffeners in Japan, and a typical operation is shown in figure 31. FCAW-G (gas shielding) or GMAW welding were used almost exclusively to produce these automated welds. These welding processes do not require separate handling of the flux, which reduces the complexity of the equipment, and provide a visible arc source that enhances tracking. A new, rapidly rotating arc was used by NKK to provide an electrical feedback to correct the robotic tracking. The robots did all the welding, including the wrapping of the weld of the end of the stiffener.

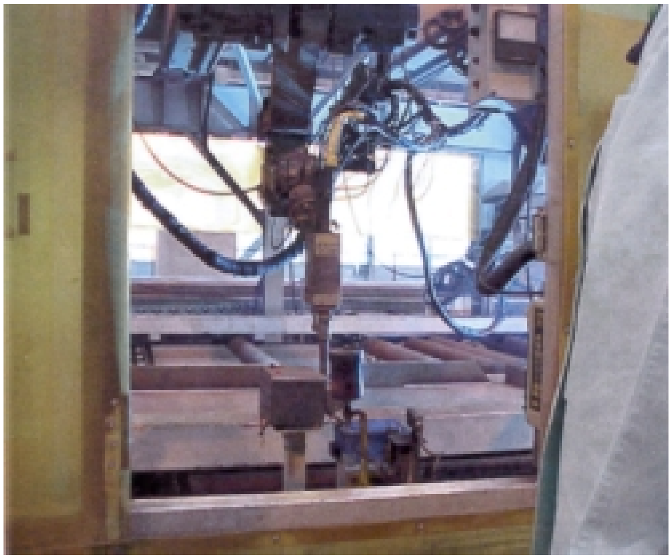

Figure 31. Robotic welding of girder web stiffener in Japan.

Automated straightening lines were used to straighten girder webs after welding the stiffeners. This straightening was done by cold bending, which is normally not used in the United States, as fabrication practice differs and automated equipment is not often available. Heat straightening also was employed, but to a much lesser degree than in the United States. A web straightening setup is shown in figure 32. The hydraulic rams apply force to the plates through a set of heads that bear on each side of the stiffener.

The widespread use of orthotropic steel decks in Japan and, to some extent, in Europe allowed the fabricators to develop and maintain automated (machine and robot) deck lines. The automated welding of the longitudinal stiffeners to the deck plate, using multi-head welders, is shown in figure 33. The Japanese employed trapezoid-shaped stiffeners, while the Italians used triangular stiffeners. The cold bending of the stiffeners was performed by subcontractors.

Figure 32. Web straightening press at NKK in Japan.

Weld Processes

The welding processes used in the shops were very different from current U.S. practice. In the United States, SAW is used exclusively by many bridge fabricators. In many of the shops that the team visited, SAW was the least used process. Table 1 breaks down the reported use of various welding processes both in the shop and field. Most of the automated welding was done using solid or metal cored GMAW

Location	Welding Process	Matsuo	Yokogawa	NKK	Kawada	Japan Highway	Cimolai	Krupp	Fairfield Mabey
Shop	GMAW	20% solid 1.2-mm wire	10.2% 1.2-mm solid wire	80% all solid wire ~ 1/2-high speed rotary arc with robots-80% Ar, 20% CO_2	50% solid core 20% metal cored	NA	30% all 1.2-mm solid wire	80% all solid wire, 1.2-mm, one two arc robot using up to 385 amps on 1.2-mm wire. Semi-automatic welders using high deposition GMAW at 500 ipm wfs with 1.2-mm wire use both argon helium, and CO_2 shielding gas	50% solid wire, 1.2-mm flux-cored; metal cored on robot
	FCAW	65% flux cored, 1.5-mm wire	74.3% 1.4-mm flux cored wire	60% flux-cored, 1.2-mm wire	30% flux cored	NA	NA	NA	NA
	SAW	10% fused flux, exclusively	10.9% fused flux, exclusively	10% SM570-fused flux, lower-strength bonded flux	NA	NA	70%	15%	50%
	SMAW	5%	4.6%	7%	NA	NA	NA	NA	NA
	Electro-slag/gas	NA	NA	NA	EGW used for web welds, ESW used for buildings	NA	NA	NA	NA
Field	GMAW	automatic used for webs	automatic used for flanges	automatic used for webs	automatic used for webs	automatic used for webs	NA	semi-automatic, for heavy, tubular weldments	used for webs
	SAW	deck plates w/ceramic backing	deck plates w/ceramic backing	deck plates w/ceramic backing	deck plates w/ceramic backing	deck plates w/ceramic backing	NA	deck plates w/ceramic backing	deck and upper flanges
	ESW/EGW	EGW used for web splices	EGW used for web splices	NA	EGW used for web splices	NA	NA	NA	NA

EGW=Electrogas welding.
ESW=Electroslag welding.

Table 1.

or FCAW-G welding. This type of welding does not require separate flux-handling equipment and minimizes slag cleaning. In Japan, 80 to 90 percent of the shop welds are made using these processes, with similar percentages in Germany. The percentage of use in Italy and the UK was less, but still in marked contrast to U.S. fabrication practice.

High deposition rates were used with 1.2- and 1.4-mm wire, both flux and metal cored wires. Manual welding at fast wire feeds was used in Germany. Most of the fillet welding observed was single-pass welds done automatically. Butt welds were generally made with either track welders or large welding gantries.

In the field, GMAW was used for vertical welds. In Japan, fully automated GMAW vertical web splice welds, as shown in figure 34, were used in the field. In addition, electrogas welding was also used in the field for full-penetration vertical web welds. Electroslag welding was not used for bridge construction.

Field welding was much more prevalent than in the United States. The Japanese welded the complete box sections together in the field (figure 35). This was on a bridge that was being erected by launching, which allows the welding to be done on land without the need for temporary shoring of the structure. Field welding also was very prevalent in Germany. All of the floor beams of a twin-girder railroad bridge (figure 36) were field welded to the girders. The floor beams were stubbed out from the girders and then joined to the center section by field welding both the web and flanges.

Preheating of plates was not evident in most of the fabricating shops. In the UK and Japan, the plates are ordered to a low carbon equivalence. Such steels, welded with semiautomatic or automatic processes (e.g., GMAW, SAW) eliminate the need for preheat. The elimination of preheat

Figure 33. Automated multiple robots at NKK in Japan.

Figure 34. Automated GMAW vertical web welding setup in Japan.

Figure 35. Welding of complete box sections together in the field in Japan.

Figure 36. Floor beam field welds in German railroad bridge.

Figure 37. Automated beam welder in Italy.

facilitated automatic welding and decreased fabrication costs. The U.S. Bridge Welding Code, AWS D1.5, contains an appendix that details how to determine the preheat temperature or the need to preheat that accounts for the level of hydrogen of the consumables, carbon equivalence of the steel, the thickness of the plate, and the restraint. These provisions are seldom used in the United States. The TMCP steel plate used in Japan eliminates preheat.

Ceramic backing strips were used both in the field and in the shop in Japan. The ceramic backing strips allow the welding of one-sided butt splices. This type of joint eliminates the need to turn the plate and back gouge the root of weld followed by welding of the root. This is a particular advantage for field welds. All of the Japanese fabricators used ceramic backing to field weld the deck plates of box girders in the field. These were used with both SMAW and GMAW welding processes.

Automated beam lines were used in Japan, the UK, and Italy to fabricate beam sections. Very few, if any, rolled sections were evident in any of the shops visited. Most of the fabrication was plate-type work, with smaller beam sections produced by the fabricator on a beam line. An automated beam welder is shown in figure 37. SMAW is used to make the web to flange welds. Figure 38 shows a small beam section in production at a beam welder. These size sections would typically be rolled shapes in the United States.

Figure 38. Small beam section produced in beam line in Italy.

Weld Details and Grinding

The scan tour encountered various means of handling the intersection of welds. In Japan, many of the bridges were fabricated without cope holes. The welds were allowed to intersect. Use of this detail is based on research by Professor Miki (see appendix C). The photo in figure 39 shows a typical weld intersection on a deck section. Cope holes would be used in the United States to prevent the intersection of the welds and eliminate the lack of penetration that results from the intersection.

Figure 39. Typical weld intersection on deck section in Japan.

In some locations cope holes were used, as shown in figure 40. The welds were wrapped around the end of the stiffener welds to seal the connection, which is not the practice in the United States. The U.S. practice is to stop the weld short of the cope to prevent the undercut of the cope when the weld is wrapped.

Figure 40. Wrapping of welds at cope at Kawada Industries in Japan.

The grinding of edges was done in all the Japanese fabrication plants. Specialized equipment was used to grind the edges, as illustrated in figures 41 and 42. In one shop, robots were used for grinding. Mr. Shoji Tamai, of Yokogawa Bridge Corp., explained that the purpose of exterior grinding is to enhance the corrosion performance of paints. Radius edge grinding is often requested by clients and, for this, specialized equipment is used. For interior grinding, Yokogawa Bridge applies a 1-mm cut, using a manual tool.

Figure 41. Edge grinding equipment in Japan.

Figure 42. Ground edge, as used in Japan.

CERTIFICATION AND CONTRACTING

All of the fabricators visited were certified in accordance with ISO 9001. The clients accept this accreditation and do not have the expense of their own inspectors in the shops. No owners or third-party inspectors were evident in any of the shops. Numerous inspections were being performed, and evidence of prior inspections was noted on some pieces. A similar type of certification by U.S. fabricators could lead to an increase in quality and a reduction in cost.

In most of the countries, the contract with the fabricator includes both fabrication and erection of the structure. This type of contract eliminates the conflict between the fabricator and erector, concerning fit-up and paint damage. This allows the fabricator to choose whether shop assembly is required and determine the most efficient method of erection. Often, the erector is a subcontractor to the fabricator. This method of contracting should be tried in the United States.

Design-build-finance-operate and transfer projects are favored in the UK. Partial payment for material and progress typically are included in contracts for large projects in both Japan and Germany.

BRIDGE DESIGN

Introduction

Although design was not a focal point of the scan, the trends and innovations in steel bridge design were noted and compiled. Differences between design in the United States and around the world exist not so much from technology or innovation, but from differences in the local bridge-construction culture and practice.

Perhaps the most significant design-related observation of the scan team was the rest of the industrialized world's more liberal view of the importance of redundancy. Two-girder bridges, as well as other structure types considered nonredundant and fracture critical in the United States, are not discouraged and, in fact, are used extensively as safe and cost-effective bridge designs. Kawada Industries cited redundancy studies it performed to demonstrate adequate redundancy of its two-girder systems with widely spaced, mid-depth cross beams. No special design, fabrication, or inspection requirements for such bridges were apparent. The U.S. design philosophy for nonredundant bridges should be reconsidered, based upon these observations and improvements in steel toughness.

Twin-girder railroad bridges are common in Germany. The single-cell box girder, commonly used for elevated roadways in urban areas of Japan, would be classified as fracture critical in the United States, but has provided excellent performance.

Some other design innovations were observed. Corrugated steel webs were noted on a composite girder bridge with concrete flanges and corrugated steel web, but not on steel bridges. Tubular steel members were seen on one monumental bridge under construction in Berlin, where the steel tubes formed the compression members of an arch. This bridge, at the railroad station in Berlin, included unique cast joints to enhance connection of the tubular elements (figures 23 and 43). The

Figure 43. Unique cast joints at a railroad station in Berlin.

material usage on this bridge was in sharp contrast to U.S. design practice. Concrete-filled steel tubes also were proposed for a bullet-train bridge.

The culture of steel-bridge design around the world is very different from that in the United States, which results in many differences in bridge design. In Japan and Europe, innovation appears to be the primary motivation, with cost-effectiveness secondary. The absence of innovation in the United States should be noted and contemplated. Foreign innovation does not necessarily suggest that U.S. practitioners should move in the same direction, but it demonstrates what is possible, if cost-effectiveness can also be achieved, for the U.S. bridge market. Consider the following design observations in the countries visited by the scan tour:

Japan

As discussed previously, steel bridges in Japan are substantially more costly than steel building fabrication. The ratio approaches 3 in Japan, whereas the ratio in the United States is between 1.2 and 1.5, depending on the type of structure. Thus, many practices in Japan are technically interesting, but warrant much more investigation, especially with regard to cost-effectiveness, before proposing their implementation in the United States. The observed design practices that differ from U.S. practice and the cultural reasons for these practices include:

- Short field sections because of highly restrictive over-the-road shipping dimension restrictions.
- Cross sections of relatively thin plates with welded multiple stiffeners (both transverse and longitudinal) made possible by a high degree of automation.
- Use of closed box sections alone (no tub girders), because of lateral-torsional buckling experience encountered three decades ago.
- Field welding for field splices to avoid the multiple, unsightly bolted splices necessitated by short field sections.
- Use of noncomposite concrete decks (now being replaced in new design with composite decks), because of concrete durability problems in the past.

In Japan, the team observed an interesting design alternative to the intermediate cross-frame diaphragms in wide use in U.S. girder bridges. Shallow (approximately 1/4 depth), widely spaced cross beams connected to full-depth transverse connection plates with a moment connection perform as our cross frames, because of frame action, as illustrated in figure 44. Perhaps this detail could replace U.S. cross frames, which steel fabricators indicate are many times more costly.

Figure 44. Shallow cross-beam diaphragms observed in Japan.

As of 1999, the Japanese bridge design specification does not include a fatigue limit state, although implementation of fatigue specification provisions is anticipated. It is unclear how fatigue is prevented with the multiple stiffened webs, orthotropic steel decks, and other complex welded sections used for bridges. Evidently, the design stress levels are maintained low enough to minimize the formation of fatigue cracking. Lack of fatigue design provisions result in the use of many low fatigue resistant details, which increases the risk of fatigue cracking in the future. Special fatigue provisions are used by some of the tollway authorities.

Italy

In Italy, one interesting practice that could find cost-effective application in the United States is a simplified approach to camber. Where possible, the camber is put into the girder at the bolted field splices (i.e., slightly kinked field splices), with the girder field sections essentially straight between the splices.

Also, in the fabrication shops of Cimolai, the team gained insight into bolted-splice design practice. Apparently, the Europeans (the team saw bridge components destined for different European countries) design for the net section alone, replacing boltholes with thicker plates. Closed web stiffeners were used on some Italian girders, as illustrated in figure 45. These closed stiffeners provide torsional, as well as displacement, restraint, thereby increasing the buckling capacity of the plate or reducing the size of the stiffener. Corrosion may be a problem when this type of stiffener is used on an external surface such as a girder web.

Figure 45. Closed web stiffener used in Italy.

Germany

The limited time in Germany revealed one unique design practice of using multiple, edge welded plates (up to 40 mm thick) instead of thicker plates (see figures 21 and 28). This is apparently a holdover from earlier concerns about uniform properties in thicker, single plates.

The use of heavy tubular members resulted in developing large steel castings that were capable of connecting the multiple members that framed into the joints. This application drew upon technology being applied in large, offshore structures.

United Kingdom

The steel industry in the UK rolls relatively short plates, which results in more welded shop splices than is typical in the United States, where longer as-rolled plates are available. This requires more butt welds and has resulted in more automation of the process in the UK than is in use in the United States. Steel-producer rolling practice has impacted fabrication practice in the UK.

Interestingly, elastomeric pads, which are gaining more widespread use for steel bridges in the United States, are not in use on steel bridges in the UK. The U.S. experience with steel bridges that have elastomeric pads could be of interest to UK designers and owners, with regard to more cost-effective bearings for steel bridges.

ACKNOWLEDGMENTS

The team wishes to thank the hosting organizations and their staffs in Japan, Italy, Germany, and the United Kingdom for their hospitality and for sharing their time and experience with the team members.

In Japan, Professor Chitoshi Miki of the Tokyo Institute of Technology and Mr. Kazuhiro Nishikawa of the Public Works Research Institute provided input on the visit, joined the team on the tour, and were responsible for organizing the workshop in Osaka.

In addition, the scanning team acknowledges the cooperation and assistance provided by Mr. Tetsuzo Mohri, Mr. Isamu Miyaki, Mr. Koji Yamaguchi, Mr. Ryohei Iwata, Mr. Shinji Takaba, Mr. Kazuo Ohata, and Mr. Eric Beyer of the Matsuo Bridge Company, Ltd.; Mr. Tsunehiro Sasaki, Mr. Hiroshi Suzuki, Mr. Kousou Zenihiro, Mr. Shoji Tamai, Mr. Hirohito Kaji, Mr. Yoshihiko Mine, Mr. Suguru Kenjo, and Mr. Shigeo Murata of the Yokogawa Bridge Corporation; Mr. Takao Miyamura, Mr. Shigeru Ogaya, Mr. Tadashi Fujioka, Dr. Osamu Yamamoto, Mr. Masaharu Honda, Mr. Toru Watabiki, Mr. Atsunori Kawabata, Dr. Hisashi Ito, Mr. Naohiro Tamaoki, Mr. Koji Yamada, and Mr. Kiyoharu Takahata of the NKK Corporation; Mr. Kazuyuki Mizuguchi and Mr. Makoto Nakasu of the Japan Highway Public Corporation; Dr. Akio Kasuga of Sumitomo Construction Company, Ltd.; Mr. Minoru Sawada of the IBI, East JV; and Mr. Tadaki Kawada, Dr. Kunikatsu Nomura, Dr. Shigeru Echigo, Mr. S. Morikawa, Mr. Kazumori Takada, Mr. Toshio Omura, Mr. Hidenori Kondou, Mr. Shogo Kataoka, Mr. Syunhei Uchida, Mr. Toshihiro Masui, Mr. Fumitaka Machida, Mr. Tsutomu Shimura, Mr. Wataru Fugimoto, Mr. Masaharu Yoshimura, Mr. Makoto Yuda, Mr. Takashi Onaaru, Mr. Sean Johnstone, and Mr. Martin Densmore of Kawada Industries, Inc.

In Italy, the team acknowledges Dr. Luigi Cimolai and the entire Cimolai Family, Mr. Stefano Piovan, Mr. Antonio Polita, and Mr. Roberto Bassi of Construzioni Cimolai Armando S.P.A.

In Germany, Dr. Klaus Brandes of the Federal Institute for Materials Research and Testing (BAM) assisted with the visit to Berlin. Thanks are due Mr. Juergen Hertor, Ms. Rosemarie Helmerich, and Dr. Wolfgang Florian of BAM; Prof. Dr. Joachim Lindner, Technical University, Berlin; Dr. Thomas Klaehne, HRA Engineers; Mr. Gerd Wilhelm, DB Project, Knoten, Berlin; and Mr. Thomas Gregull and Mr. Frank Moeller, Krupp Stahlbau, Berlin.

In the UK, the team acknowledges the assistance of Dr. Peter Lloyd, Mr. Geoffrey Booth, and Mr. David Bicknell, Fairfield-Mabey Ltd.; Dr. John Harrison, Dr. Stephen Maddox, Dr. Richard Dolby, Dr. Martin Ogle, and Dr. Owen Gorton of The Welding Institute (TWI); Mr. Alan Hayward, Cass Hayward, and Partners; Mr. Bill Ramsey, British Steel; Mr. Harold Dewsnap, Kvaerner Cleveland Bridge Ltd.; and Mr. Sibdas Chakrabarti, Highways Agency, London.

APPENDIX A: AMPLIFYING QUESTIONS

I. Application of Innovative Structural Shapes and Bridge Configurations

1. What new, cross-sectional shapes and overall geometry have you used in bridges?
2. Is there a preference for open or closed shapes? Why?
3. Please respond to the following questions in terms of
    - (1) cost-effectiveness,
    - (2) good or bad performance,
    - (3) any special design criteria required:
        - (a) Have you constructed any bridges using corrugated steel webs?
        - (b) Have tubular members been used in truss or girder elements?
        - (c) Are single box bridges used?
        - (d) Have any modular steel bridges been developed?
        - (e) Are steel piers used as much now as in the past?
        - (f) Are steel bridges used with integral pier caps?
        - (g) Are there innovative bridge decks?
        - (h) Where are orthotropic steel decks used?
        - (i) Have any steel bridge configurations been developed to enhance fatigue resistance to minimize the need for designs controlled by fatigue factors?
        - (j) Have innovative, seismic-resistant steel bridges been developed?
4. Do standardized steel bridges exist?
    - (a) What type and span?
    - (b) Are typical bridge design details standardized in your region? By whom?
5. What innovations have you made in the construction of short-span (<40 m) to medium-span (<80 m) steel bridges? What is your experience with costs and trends?
6. Has prestressing been used in the construction of steel bridges?
    - (a) Has it been cost-effective and does it provide good performance?
    - (b) Are there special design criteria?
7. How do rolled “I” shapes compare with welded plate girders?
8. What is the trend in the use of bracing and diaphragms?
    - (a) What standards exist?

(b) Are removable diaphragms used?

9. Are steel castings used for connections?

   (a) What materials are used?

   (b) What specifications have been developed?

II. Applications of New Materials

1. How are higher-strength steels (485 MPa to 800 MPa yield strength) being used?

   (a) What are the future trends for these steels?

   (b) Are all of the higher-strength steels produced as TMCP or is Q/T material also used?

   (c) What toughness, sampling frequency, and locations are used?

2. Are tapered (thickness) plates used very often?

   (a) Are there thickness-tolerance specifications?

   (b) What is the availability of such plates?

   (c) What is their relative cost?

3. How much weathering steel is being used versus painted steel?

   (a) Are there any special fabrication requirements?

   (b) Are there any improvements being made to basic weathering?

   (c) What do you see as the future use of weathering steels?

   (d) Are special joints and details used?

   (e) Is staining a problem? How do you manage it?

4. What is the maximum thickness of plate used in steel bridges?

   (a) Are there differences for pedestrian, vehicular, and railroad bridges?

   (b) Are there standard codes?

   (c) What is the basis for the criteria that are used?

   (d) Is toughness considered when determining thickness limits?

5. What are the actual levels of P and S used in bridges? Is calcium treatment used or specified on all bridge steels? To what extent is vacuum degassing used?

6. What organization(s) is responsible for writing the specifications for bridge steel?

   (a) Are steels certified to more than one specification? Is this required by the owner? Does this practice cause fabrication problems?

   (b) What substitutions are allowed for steels specified in contract documents?

7. Who is responsible for encouraging new steel development?
8. Have advanced composite materials been used in conjunction with structural steel to construct bridges?
9. Is undermatched weld metal used for design and fabrication?
   (a) How is it being used?
   (b) What is the range of applications?
10. What use is made of stainless and clad steels in bridge structures?
11. What new steels are used for pins, bolts, and bearings?

III. Techniques for Cutting and Joining Steel Members (shop/field and field erection techniques)

1. What recent innovations have been developed in the areas of welding consumables, equipment, and processes?
   (a) Are high-energy welding processes (i.e., electron beam, laser, or other) in common use?
   (b) Are high deposition rates used?
   (c) Is electroslag or electrogas welding used? What are the requirements? What thicknesses?
   (d) Are multiwire, sub-arc systems being used? How many wires? What type of power?
   (e) Is solid wire Mig/Mag weld permitted?
      1. Is short circuiting welding permitted? Under what conditions?
      2. Is pulsed-arc Mig welding permitted? Under what conditions?
   (f) What other processes are used?
   (g) Is flux-core self shielded, flux-core gas shielded, or metal core welding used?
   (h) What percentage of welds are made by these different processes?
   (i) What is your planned future use?
2. What cutting systems are in common use?
   (a) What is used in the field?
   (b) Do you weld directly on the cut surface?
   (c) Are thermal cut holes used with or without further treatment?

3. Is automated handling of materials for assembling member elements being used in the shop? In the field?
4. Are there in-process distortion controls?
    - (a) How does material variability influence this process?
    - (b) How is welding distortion predicted?
    - (c) What dimensional checks are used?
    - (d) How is drilling accounted for?
5. What cambering and heat-straightening techniques are used?
    - (a) Is the process automated?
    - (b) Where are the control points?
6. Are in-process NDT testing and monitoring techniques being used to assess weld quality?
    - (a) How often?
    - (b) What statistical principles are applied?
7. What are the fit-up requirements for preassembly and construction?
    - (a) Are shop fit-up requirements imposed by owners?
    - (b) Is this a partial or full fit-up?
    - (c) What does the fabricator do in the shop to ensure compliance?
    - (d) Are computerized preassembly methods permitted?
    - (e) What procedures are used to ensure success?
    - (f) What has been your experience with this method?
    - (g) Are special criteria applied to horizontally curved girders?
8. Is field welding used to any extent?
    - (a) To what extent is the process automated?
    - (b) How are consumables stored on site?
    - (c) What processes are used?
9. How are weld procedures and personnel qualified?
    - (a) Are statistical methods employed?
    - (b) Are welders who are qualified for other applications (i.e., pressure vessels, ships) accepted for bridge work without additional qualification?
10. How are weld acceptance procedures applied?
    - (a) Are fitness for service criteria allowed?

   (b) Who is responsible for Quality Control (QC)/Quality Assurance (QA) of the fabrication and erection?

   (c) Who develops the standard?

11. What role does automation play in the assembly and welding of orthotropic steel decks?
12. What are the size and length limitations or restrictions in fabrication? Is this controlled by transportation or construction limitations?
13. Are structural adhesives being used to join steel components?
14. Have electrodes maintained compatibility with base metal weldability?
15. What procedures are used for plate and shape bending?

   (a) What thickness and radius criteria are applied for cold bending?

   (b) Do fracture toughness requirements impact these procedures?

   (c) What role does the type of steel play?

16. What kind of pre- and post-welding treatments are used? What role do ceramics, metal spacers, back-gouging, peening, or other “improvements” have in these treatments?
17. What percentage of field splices are bolted? What percentage are welded?

   (a) If bolted splices are used, are special treatments or sealants required for corrosion protection?

   (b) Are these treatments specified or used at the discretion of the fabricator?

18. Are there special installation requirements for anchor bolts?

IV. Automated Recording Procedures for Shop and Field Inspection

1. Is automated, ultrasonic scanning of groove welds performed in the shop? Would it be possible to see this demonstrated during our site visit?
2. How is the integrity of the inspection records maintained?
3. Who is responsible for the database input?
4. Are automated inspection procedures used in the field? How often?
5. How are fillet welds inspected?

V. Integrated CAD/CAM Procedures and Robotic Fabrication

1. How are design drawings translated into shop drawings?
2. Are electronic design documents used in the bidding process? Are they used for fabrication?
3. How are shop drawings approved?

   (a) Are they electronically submitted? If so, how is the approval given?

    (b) How are shop-generated machine codes checked?

4. How are robots monitored? How often?
5. What are the requirements for qualification of operators of robotic and automated machinery?
6. What types of automated field erection are used?
7. What has been your experience regarding the measurements used to monitor the transition from old methods to automated, computer-integrated manufacturing in terms of:
    - (a) direct and indirect labor ratios.
    - (b) man-hours per ton.
    - (c) efficiency improvements.
    - (d) cost differentials.
    - (e) capital differentials.
8. What direct labor cost increases or decreases occur as a result of automation?

VI. Additional Topics of Interest

1. Are there committees established to identify, review, and promote technological advances at different government or authority levels (i.e., regional or national)?
2. Is heat straightening used to assist repair of damaged bridge members?
3. What bearings are being used?
    - (a) Are comparable bearings used for steel and concrete bridges?
    - (b) Are they fabricated in the shop or by specialty manufacturers?
    - (c) What controls the type selection?
    - (d) What do you see as trends for the future?
4. How closely do design engineers work with fabricators/erectors/inspectors prior to fabrication and erection?
5. What part of the design/fabrication/construction process has the potential for most improvement?
6. What measures are being taken to make steel bridges more competitive?
7. What percentage of your budget is invested in research and development? What government incentives are provided?

APPENDIX B: Workshop Agendas

JAPAN-U.S. WORKSHOP
“STEEL BRIDGE FABRICATION TECHNOLOGIES”

10:00-12:00 Moderator: Prof. C. Miki

Design of steel bridges in Japan	Mr. Nishikawa, PWRI
New structural forms of bridges, using concrete-filled girders	Prof. Nakamura, Tokai University
Innovations in bridge fabrication procedure	Mr. Takahata, NKK
Computerized assembly and testing systems	Mr. Hosoya, Mr. Tamai, and Dr. Kozakura, Yokogawa Bridge
Recent welding materials for bridge structures	Mr. Kasai, Kobe Steels Dr. Honnma, Nittetu Welding Mr. Tukamoto, Sumikin Welding
New technology in weathering steel	Mr. Watanabe and Dr. Honnma

12:00-13:00 Lunch

13:00-15:00 Moderator: Mr. Krishna Verma

Recommendations from the Williamsburg Bridge tests	Prof. John Fisher
Cross-frames for steel bridges	Mr. R. Kase
High-performance steel research in the United States	Mr. A. Wilson
Narrow-gap improved electroslag welding	Mr. K. Verma
Evaluation of welding qualification requirements	Prof. K. Frank

15:30-17:30 Moderator: Mr. K. Nishikawa

Design and fabrication of orthotropic steel bridge decks	Dr. Ohashi and Prof. Miki
High-efficiency welding procedures and fatigue strength improvement detail of simplified orthotropic steel decks	Mr. Machida and Dr. Etigo
New welding technology for field joints of bridge sections	Mr. H. Hirano
Quality control of field welded joints of heavy section girder flange	Mr. Mizukuti, Mr. Murawama, Prof. Miki
Weld detail of field joints in two-girder bridge of weathering steel	Mr. Yabe and Prof. Miki

Japanese Participants

Coordinators
Chitoshi Miki, Tokyo Institute of Technology
Kazuhiro Nishikawa, Public Works Research Institute, Ministry of Construction

Advisor
Yushi Fukumoto, Fukuyama University

From Universities
Atusi Ishikawa, Professor, Tokyo Institute of Technology
Kengo Anami, Research Associate, Tokyo Institute of Technology
Eiichi Sasaki, Research Associate, Tokyo Institute of Technology
Shunichi Nakamura, Tokai University
Eiki Yamaguchi, Kyushu Institute of Technology
Tetsuya Yamasawa, Tokyo Metropolitan University

From Public Corporations
Kazuyiki Mizuguchi, Japan Highway Public Corporation
Akira Murayama, Japan Highway Public Corporation
Harukazu Ohashi, Honshu-Shikoku Bridge Authority

From Fabricators
Tomohide Hosoya, Yokogawa Bridge
Shoji Tamai, Yokogawa Bridge
Yoshitaka Kozahura, Yokogawa Bridge
Hiroyuki Hirano, Ishikawajima-Harima Heavy Industries
Fumitaka Machida, Kawada Industries
Kiyoharo Takahata, NKK
Shinji Takaba, Matsuo Bridge
Kazuo Ohata, Matsuo Bridge

From Steel Makers
Takashi Kusunoki, Nippon Steel
Motohiro Okushima, Nippon Steel
Koji Honma, Nippon Steel
Shigeo Ohayama, Nippon Steel
Kazuyuki Matsui, NKK
Shozo Nakamura, Kawasaki Steel
Yuichi Watanabe, Sumitomo Metal Industries
Kengo Abe, Kobe Steel
Noboru Kasai, Kobe Steel

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American Participants

Panel Chairman
Krishna Verma, Federal Highway Administration

From Federal Highway Administration Offices
Milo Cress, Nebraska
Kathleen Linehan, Washington, DC
Bill Wright, Turner-Fairbank Highway Research Center

From Universities
John Fisher, Lehigh University
Karl Frank, University of Texas at Austin
Dennis Mertz, University of Delaware

From Professional Associations
Hardy Campbell, American Welding Society
Bill McEleney, National Steel Bridge Alliance
Arun Shirole, National Steel Bridge Alliance

From State Departments of Transportation
Ralph Anderson, Illinois
Ronnie Medlock, Texas

From the Steel Industry
Jim Hamilton, Utah Pacific Bridge
Bob Kase, High Steel Structures
Pat Loftus, High Steel Structures
Randy Sathre, PDM Bridge
Jerry Uttrachi, ESAB
Alex Wilson, Bethlehem Lukens Plate

Coordinators
John Almborg, American Trade Initiatives
John O'Neill, American Trade Initatives
George Yamamoto, CalTrans

WORKSHOP ON INNOVATION IN STEEL BRIDGE CONSTRUCTION
TWI, GRANTA PARK, ABINGTON, CAMBRIDGE
FRIDAY, 4TH JUNE 1999

FINAL PROGRAMME

09:00-09:30	***COFFEE***
09:30-09:35	**WELCOME**
09:35-10:20	**DESIGN**

Small to Medium Bridges – Presentation from Cass Hayward – 15 minutes

Long Span Bridges – Presentation from Mott Macdonald – 15 minutes

Discussion

10:20-11:10	**MATERIALS**

Steels – Presentation from British Steel – 15 minutes

New Toughness Requirements – Presentation from TWI – 10 minutes

Discussion

11:10-11:30	***COFFEE***
11:30-13:00	**FABRICATION**

Bridge Construction – Presentation from Kvaerner Cleveland Bridge – 15 minutes

CAD/CAM Robotics – Presentation from Fairfield-Mabey – 10 minutes

Discussion

New Joining Methods – Presentation from TWI – 15 minutes

Discussion

13:00-14:00	***LUNCH***
14:00-15:00	**LABORATORY VISIT**
15:00-15:30	**PRESENTATIONS BY U.S. GROUP**

High Performance Steels – Alex Wilson

Orthotropic Deck Test – John Fisher

ESW Narrow Gap – Krishna Verma

15:30-16:00	***TEA***
16:00-16:30	**INSPECTION OF FABRICATION**

New Quality Standards – Presentation from TWI – 15 minutes

Discussion

16:00-17:00 **FINAL DISCUSSION**

17:00 **RETURN TO CAMBRIDGE**

19:30 or 20:00 ***DINNER AT PETERHOUSE COLLEGE***

ATTENDANCE LIST

John O'Neill	ATI
Krishna Verma	FHWA
Ralph Anderson	Illinois DOT
Hardy Campbell	AWS
Milo Cress	FHWA
John Fisher	Lehigh University
Karl Frank	University of Texas
Jim Hamilton	Utah Pacific Bridge
Bob Kase	High Steel Structures
Kathleen Linehan	FHWA
Pat Loftus	High Steel Structures
Ronnie Medlock	Texas DOT
Dennis Mertz	University of Delaware
Bill McEleney	NSBA
Randy Sathre	PDM Bridge
Arun Shirole	NSBA
Jerry Uttrachi	ESAB
Alex Wilson	Bethlehem Lukens Plate
William Wright	FHWA
Chris Davis	Mott Macdonald
Howard Dewsnap	Kvaerner Cleveland Bridge
Sibdas Chakrabati	Department of Transport
Geoff Booth	Fairfield Mabey
Alan Hayward	Cass, Hayward, & Partners
Bill Ramsey	British Steel
Martin Ogle	TWI
Stephen Maddox	TWI
Owen Gorton	TWI
John Harrison	TWI

APPENDIX C: List of Documents

JAPAN

Matsuo Bridge Co., Ltd., Sakai Plant

- Brochure on 70th Anniversary, 1996
- Information on Sakai and Chiba Works
- Yumeshima-Maishima Movable Floating Bridge
- Response to Amplifying Questions

Yokogawa Bridge Corporation Osaka Plant

- Brochure on Yokogawa Bridge, 1997
- Brochure on Osaka Factory
- Brochure on Prefabricated Steel Plate Power Slab
- Computed Assembling Test System (CATS)
- North Kyushu Airport Connection Bridge Section
- Response to Amplifying Questions

NKK Bridge Engineering, Tsu Works

- Brochure on NKK Bridge Engineering
- Tsu Laboratories
- Tsu Works Layout and Details of Facilities
  - Laser Cutting Line
  - Plasma Cutting Equipment
  - Transverse Rib Assembly Line
  - Automatic Drilling Line
  - Chamfering Line
  - I-Section Girder Line
  - Box Girder Panel Assembly Line
- Tsu Works Laser Cutting Line and Robot Assembly Line
- New-BristLan (New Bridge and Steel Structure Lofting Language)
- Takaku, Tatsumasa, Fujimura, Ken and Ogaya, Shigeru, Bridge Factory Innovations Structural Engineering International, IABSE 1/94
- Fujimura, K., Ogaya, S., Takahata, K., Kuwamura, T., Sugitani, Y., and Kanjo, Y., Bridge Factory Innovations at Tsu Works, Laser Cutting and Robotic Assembly Lines, NKK Tech. Review No. 67, 1993.
- High Speed Rotating Arc Welding
- Minimal Maintenance Steel Bridge Exposure Site
- Wave Record Type Ultrasonic Inspection System

- Mega-Float
- Response to Amplifying Questions

Japan Highway Public Corporation

- General Information Brochure 1998
- Development of Technology for Expressway Bridges 9/98
- Inabe River Bridge Construction of Superstructure and Field Welding Process for Main Girder
- Kiso & Ibi River Bridges New Meishin Expressway
- Ultrasonic Testing Procedure and Defect Judgment Process

Kawada Industries, Inc.

- Kawada Brochure 1997
- Building a Better Tomorrow
- Kawada Brochure on Shikoku Plant
- Response to Amplifying Questions

Japan-USA Steel Bridge Workshop

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- Takaku, T., Hashimoto, M., Iwaoka, N., Shikata, A., Mori, N., and Takawashi, M., Integrated CAD/CAM System for Steel Bridges II, New BRISTLAN SYSTEM, NKK Technical Review No. 71 (1994), 8 pgs.
- Hosoya, T., Tamai, S., and Kozakura, Y., Inspection System for Assembly Configuration of Steel Arch Bridge Members, Yokogawa Bridge Co., 18 pgs.
- Technical Committee, Welding Consumables Div., The Japan Welding Engineering Society, Kasai, N., Homma, H., and Tsukamoto, M., Recent Trends of Welding Consumables for Bridge Construction in Japan, 16 pgs.
- The Kozai Club, Watanabe, Y. and Homma, K., New Technology in Weathering Steel, 10 pgs.
- Miki, C., and Ohashi, H., Improved Fatigue Details of Orthotropic Steel Deck and the Recent Study, 20 pgs.
- Machida, F. and Echigo, S., High Efficiency Welding Procedure and Fatigue Strength Improvement Detail of Simplified Orthotropic Steel Deck, Kawada Industries, 9 pgs.
- Hirano, H, Summary of Welding Process for Simple Structure Bridges, Ishikawajima-Harima Heavy Industries, Ltd., 15 pgs.

- Hirano, H., Murata, S., and Yamanchi, K., Technical Development of Field Welding for Simple Structure Bridge, Ishikawajima-Harima Heavy Industries Co. Ltd., 8 pgs.
- Mizuguchi, K., Murayama, A. (JPHC), and Miki, C. (TIT), Quality Control of Field Welded Joints of Heavy Section Girder Flange, 14 pgs.
- Miki, C., Chidorinosawa River Bridge, Tokyo Institute of Technology, 7 pgs.
- Miki, C., Nishikawa, K., and Konishi, T., Cooperative Research on Nondestructive Testing Methods for Welding Joints of Steel Bridges, 10 pgs.
- PWRI, The Kozai Club and Japan Association of Steel Bridge Construction, Cooperative Research on Application of Weathering Steel to Bridge Structures March 1993 (in Japanese).

ITALY

Costruzioni Cimolai Armando S.P.A.

- Cimolai Brochure on Facilities and Products
- Offshore Structures
- Viaduc de Cheval Blanc, TGV Mediterranean
- Viaduct over Grand Canal Maritime at LeHavre
- Civil Buildings
- Welded Beams and Corrugated Panels
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- Responses to Amplifying Questions

GERMANY

Federal Institute for Materials Research and Testing (BAM)

- Profile of BAM
- Brochure on Organization
- Brochure on Buildings and Structures Division VII.2
- Brochure on Special Test Facility for Component Weld Simulation (GAPSI)
- Brochure on Nondestructive Testing
- Brochure on Design for Durability
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Krupp Stahlbau Berlin

- Drawings on Havel River Bridge at Spandau HRA Beratende Ing. Im Bauwesen, Berlin
- Drawings on Rail Bridge over Humboldthafen, Lehrter Station in Berlin

UNITED KINGDOM

Fairfield-Mabey Ltd.

- Brochure on Steel Structures (1997)
- Brochure on Plate Girder Automated Line
- Brochure on the Mabey Group
- British Steel Brochure on Nene Bridge, Peterborough
- British Steel Brochure on M5 Widening Overbridges, Rashwood to Catshill
- British Steel Brochure on River Wye Crossing Chepstow
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The Welding Institute (TWI)

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APPENDIX D: Itinerary

JAPAN

May 24, 1999	Meeting and shop visit with Matsuo Bridge Co., Sakai Plant
May 24, 1999	Meeting and shop visit with Yokogawa Bridge Corp., Osaka Plant
May 25, 1999	Meeting and shop visit with NKK Bridge Co., Tsu Works
May 26, 1999	Meeting with Japan Public Highway Corp. in Nagoya; site visit to Second Tomei Highway Project, Inabe River Bridge
May 26-27, 1999	Meeting and shop visit with Kawada Industries Corp., Shikoku Plant at Marugame
May 28, 1999	Japan-U.S. Workshop on Steel Bridge Fabrication Technologies at U.S. Consulate, Osaka

ITALY

May 30-31, 1999	Team Review Meeting and meetings and shop visits with Construzioni Cimolai Armando in Pordenone area

GERMANY (BERLIN)

May 30-31, 1999	Meeting at Federal Institute for Materials Research and Testing and laboratory visits. Meeting and shop visit to Krupp Stahlbau Berlin.
June 2, 1999	Site visits to construction site of the Humboldthafen Bridge, the Potsdamer Platz, and the Havel River Rail Bridge at Spandau.

UNITED KINGDOM

June 3, 1999	Meetings and shop visit to Fairfield-Mabey Plant at Chepstow
June 4, 1999	UK-U.S. Workshop on Innovation in Steel Bridge Construction at The Welding Institute, Abington; laboratory tour of TWI
June 5, 1999	Team Review Meeting

APPENDIX E: Biographic Sketches

The team consisted of representatives of U.S. Federal and State Governments as well as academia, the steel fabrication industry, a steel producer, a welding and cutting product producer, and trade associations. Information about team members at the time of the scan was provided in the following biographic sketches.

Krishna K. Verma, the Panel Chairman, is a Structural and Welding Engineer with the Bridge Division of the Federal Highway Administration in Washington, DC. In this position, he is responsible for policy formulation, with regard to bridge welding, fabrication, fatigue, fracture, and bridge painting. He is currently serving as a member of the American Association of State Highway and Transportation Officials (AASHTO) T-14 Committee on Structural Steel Design, AASHTO-AWS D-1.5 Bridge Welding Code Committee, the TRB Committee on Fabrication and Inspection of Metal Structures (A2F07), AASHTO NSBA Steel Bridge Collaboration, and the International Institute of Welding Commission V on Quality Control and Quality Assurance of Welded Products and Commission XIII on Fatigue Behavior of Welded Components and Structures. Mr. Verma is a Registered Professional Engineer in Pennsylvania. He has a Bachelor of Science Degree in Civil Engineering from Benaras, India; a Master's Degree in Structures from the University of Calgary, Canada; and a Master's Degree in Materials Engineering from the Rensselaer Polytechnic Institute of Troy, New York.

Ralph E. Anderson is the Bureau Chief of Bridges and Structures for the Illinois Department of Transportation in Springfield, Illinois. He is responsible for developing, reviewing, and approving all structure plans for the State highway system. He is also responsible for establishing procedures for the field inspection of existing bridges. He currently serves on several technical committees of the Highway Subcommittee on Bridges and Structures of AASHTO. Mr. Anderson is Chairman of the Technical Committee for Bearings and Expansion Joints and of the Pontis Bridge Management System. He serves as Vice Chairman of the Technical Committee for Structural Steel Design. He is a member of the Technical Committee for Seismic Design of Bridges and the Technical Committee for Bridge Replacement Surveys and Inspection Standards. Mr. Anderson is a Licensed Professional Engineer and Structural Engineer in the State of Illinois. He has served more than 21 years with the Illinois Department of Transportation. He has a Bachelor of Science Degree in Civil Engineering from the University of Illinois in Urbana, Champaign.

Hardy Campbell III is a Senior Staff Engineer with the American Welding Society. In this capacity he also serves as Secretary to the D1 Structural Welding Committee responsible for several structural welding documents, for example the D1.1 Structural Steel Code and the AASHTO/AWS D1.5 Bridge Welding Code. He has extensive experience in the design, construction, and inspection of heavy steel structures, and frequently acts as a resource for answering questions about the D1.5 code. He received a Bachelor of Science Degree in Civil Engineering from the University of Houston in 1976. He is a voting member on the IIW and ASTM steel committees, and a member of AWS, ASNT, ASM, ASCE, and NACE. In addition, he is the Chairman of the IIW Subcommission XV-G on Seismic Design and Construction.

Milo Cress is the Bridge Engineer for the USDOT Federal Highway Administration's Nebraska Division Office. He is responsible for review and approval of Nebraska Department of Roads' structures, hydraulics, hydrology, design, construction, maintenance, policies, and procedures applied to highway projects using Federal aid funds and the Bridge Safety Inspection and Maintenance Program in Nebraska for both State and local bridges. Mr. Cress has coordinated with Federal, State, contractor, and steel-fabricator interests to effectively implement advanced materials, such as high-performance steel (HPS), high-performance concrete (HPC), and fiber-reinforced polymers (FRP) in Nebraska and the surrounding States. As part of his duties, he has carried out steel fabrication (and other materials) plant reviews and construction inspections and actively participated in full-scale laboratory testing of steel bridge components. He currently serves on the Advisory Panel for the National Bridge Research Organization (NABRO) Division of the Mid-America Transportation Center (MATC), University of Nebraska, Lincoln. Mr. Cress holds a B.S. Degree in Civil Engineering and a Master's of Science Degree in River Mechanics from Colorado State University. He is a member of the ASCE and Lincoln Engineer's Club. He has worked for private materials testing companies, the Colorado Department of Transportation, and the Federal Highway Administration.

John W. Fisher has been Professor of Civil Engineering at Lehigh University since 1969. He was named to the Joseph T. Stuart Chair in Civil Engineering at Lehigh in July 1988. He has been Director of the Engineering Research Center on Advanced Technology for Large Structural Systems (ATLSS) since its establishment by NSF in May 1986. A structural engineer, Dr. Fisher is a specialist in structural connections; the fatigue and fracture resistance of riveted, bolted, and welded structures; the behavior and design of composite steel-concrete members; and the performance of steel bridges. Dr. Fisher is a graduate of Washington University, St. Louis, Missouri. He received his Master of Science and Doctor of Philosophy Degrees from Lehigh University. He received an honorary doctorate degree from the Swiss Federal Institute in Lausanne, Switzerland. He is a member of the American Institute of Steel Construction Specification Committee and the American Railway Engineering and Maintenance-of-Way Association Committee 15 on Steel Structures. He also serves on the Executive Committee of the Transportation Research Board.

Karl H. Frank is a Professor of Civil Engineering at the University of Texas at Austin. His current research interests are the design and behavior of girder and box composite steel and concrete bridges, static and fatigue performance of weldments and bolted connections, and load rating of existing bridges. He authored much of the AASHTO LRFD Specifications for steel girder bridges. He has been a professor at The University of Texas at Austin for more than 20 years. Before coming to the University, he worked at the Turner-Fairbank Highway Research Center of the Federal Highway Administration. He graduated with a Bachelor of Science Degree from the University of California at Davis and received a Master of Science and Ph.D. from Lehigh University. He is a registered Engineer in the State of Texas. Dr. Frank serves on the AASHTO/AISI Steel Bridge Task Force, the TRB Steel Bridge Committee, and the Committee on Fabrication and Inspection of Steel Structures. He is also a technical team leader and a researcher in the Materials and Fracture effort in SAC research project dealing with the design and behavior of steel moment frames in earthquakes.

Jim Hamilton is the General Superintendent for Utah Pacific Bridge & Steel. He is responsible for the entire fabrication process of bridge girders and systems. In addition, he is responsible for the implementation of new technology and fabrication methods. He is skilled in all functions of a bridge shop including project planning, scheduling, fit-up, welding, girder assembly, painting, and safety. His fabrication career spans 35 years, and he has supervised the fabrication of more than 450 steel bridge structures.

Bob Kase is Vice President for Engineering, Field Operations, and Technology at High Steel Structures, Lancaster, Pennsylvania. Mr. Kase's responsibilities include direction of Quality Control and Quality Assurance functions in fabrication facilities and field sites, CAD/CAM in engineering and fabrication, field operations, and technology implementation. He directs engineering R&D functions associated with new product and material development along with interfacing with U.S. academia to prepare test samples used to further research in the bridge industry. He has 31 years of experience in engineering, fabrication, transportation, and erection of bridges, including suspension, truss, arch, bascule, and cable-stayed bridges. Mr. Kase is a graduate of Villanova University holding a Bachelor's and Master's Degree in Civil Engineering. He is a Licensed Professional Engineer and Land Surveyor in Pennsylvania, and a Licensed Professional Engineer in Massachusetts and Maryland. Mr. Kase currently serves on various AWS, AISI, AISC, NSBA, FHWA, U.S. Navy, SSPC, and AASHTO Bridge and Technical Committees and Task Groups.

Kathleen Linehan is a Division Bridge Engineer in the Washington, DC, Division of the Federal Highway Administration. Ms. Linehan is currently responsible for oversight of the Federal Aid Bridge program in the city of Washington, DC. Her work includes providing technical assistance and guidance in bridge design, construction, and Federal Aid program issues to the DC Department of Public Works. She has served with the FHWA for 8 years, including time in California, Colorado, and Texas. Ms. Linehan is a graduate of Marquette University in Milwaukee, Wisconsin. She is a Licensed Professional Engineer in California and serves on a technical committee of the AASHTO/National Steel Bridge Alliance Steel Bridge Collaboration.

Pat Loftus is President of High Steel Structures, Inc., Lancaster, Pennsylvania. He is responsible for the overall operations, strategic direction, and profitability of the United States' largest bridge plate girder fabricator. He is also Chairman of the Executive Committee of the National Steel Bridge Alliance. As Chair of the NSBA, he is charged with helping to improve steel bridge market share in the United States. Mr. Loftus has more than 30 years of experience in steel fabrication including shipbuilding, pressure vessels, and tunnel systems. His early background was in Quality Assurance and Welding Engineering. Mr. Loftus holds a Bachelor of Science Degree from Boston College with a concentration in Industrial Management. He is an active member of the American Welding Society, and holds Board of Directors seats with the AISC, American Road and Transportation Builders Association, and Associated Pennsylvania Constructors.

Ronnie Medlock is the Steel Bridge Fabrication Director at the Texas Department of Transportation (TxDOT), in Austin, Texas. He is responsible for Quality Assurance, including inspection, for all steel bridge members fabricated for TxDOT, where he has 10 years of experience. Mr. Medlock also serves on various committees related to steel bridge work, including the following: member, AASHTO/AWS D1.5 Bridge Welding Code Committee; member, AWS Structural Welding Code Committee and Chair of the Fabrication Subcommittee; member, Committee on Fabrication and Inspection of Metal Structures of TRB; Chair, Texas Steel Quality Council; and co-founder and Chair of Steering Committee, AASHTO/ NBA Steel Bridge Collaboration. Mr. Medlock is a Licensed Engineer in the State of Texas. He received a Bachelor's Degree and a Master's Degree in Structural Engineering from the University of Texas, Austin.

Dennis Mertz is an Associate Professor of Civil Engineering at the University of Delaware in Newark, Delaware. His current research emphasis includes innovative bridge design and construction practices, steel bridge design methodologies and, most recently, the interaction of technology and culture in the construction of bridges. Before joining the faculty at the University of Delaware, Dr. Mertz was an Associate of the bridge design firm of Modjeski and Masters, Inc., of Harrisburg, Pennsylvania. He is a graduate of Lehigh University in Bethlehem, Pennsylvania, and holds a Master's Degree and Doctorate from Lehigh. He is a Licensed Professional Engineer in Pennsylvania. Professor Mertz is also the founding editor of the ASCE's *Journal of Bridge Engineering*.

Bill McEleney is a Regional Director of Construction Services for the National Steel Bridge Alliance in Cranston, Rhode Island. He currently represents the steel bridge fabricating industry on matters of steel bridge fabrication and construction. His duties include fabricator education and training. Prior to joining NSBA, he spent 10 years as a Regional Engineer for the American Institute of Steel Construction performing similar duties. He is graduate of the University of Rhode Island and holds a Bachelor of Science Degree in Civil Engineering. He has served on ASCE technical committees and various code and standards-writing organizations.

Randy Sathre is a Maintenance/Facilities Engineer for PDM-Bridge, a division of Pittsburgh-Des Moines, Inc. His responsibilities include facility planning, equipment procurement, material flow, and design of special equipment for fabrication facilities. He also is responsible for research and implementation of innovative technologies into bridge fabrication facilities. He is a graduate of North Dakota State University with a Bachelor's of Science Degree in Mechanical Engineering.

Arun M. Shirole is the Executive Director of the National Steel Bridge Alliance, a unified organization for all steel bridge related activities in the United States. Before assuming this position, he was the Director of Structures Design and Construction Division and Deputy Chief Engineer for the New York State Department of Transportation. He received a Bachelor's Degree in Civil Engineering from the Indian Institute of Technology, Bombay, a Master's Degree in Civil Engineering from the South Dakota School of Mines and Technology, and a

Master's of Business Administration from the University of Minnesota. Mr. Shirole was also a Transportation Fellow at Harvard University. He has authored 34 papers and publications in national and international publications. He has been a member of the AASHTO Subcommittee on Bridges and Structures and Chairman of AASHTO Committee T-11 on Research. He was Chairman of the Transportation Research Board Committee on Construction Management and Bridge Management and currently chairs its subcommittee on Bridge Management. He is a Licensed Professional Engineer in Minnesota and New York.

Jerry Uttrachi is Vice President of Equipment Marketing at ESAB Welding & Cutting Products. He has been Manager of the Welding Market Development Department and Laboratory Manager of the Welding Materials Technology Department. During his 35-year career, he has been responsible for the development of automatic welding processes, welding equipment, and welding materials. Some of his work was reported in papers entitled "Three-Wire Submerged Arc Welding of Line Pipe," "A New DC Power System for Submerged Arc Welding," "Electroslag Welding Speeds the Making of Ships," and "Multiple Electrode Systems for Submerged Arc Welding," all published in *The Welding Journal*. Mr. Uttrachi also published an article in *Welding Design & Fabrication* entitled "What Do Robots Need in Welding Equipment." He holds a number of U.S. and foreign patents in the welding process and materials areas. Mr. Uttrachi has Bachelor's and Master's Degrees in Mechanical Engineering and a Master of Science Degree in Engineering Management from New Jersey Institute of Technology. He is a member of ASME and AWS. In addition, he serves as Chairman of the AWS Marketing Committee and is a member of a number of other AWS committees.

Alex Wilson is the Customer Technical Service Manager for Bethlehem Lukens Plate, a division of the Bethlehem Steel Corporation located in Coatesville, Pennsylvania. He currently manages the technical support activities to plate steel customers and end users. He is currently involved with the development of high-strength steels with improved weldability for bridge applications. Mr. Wilson has been with the Lukens Steel Company for 24 years, since it merged with Bethlehem Steel. His previous research involved clean steels, fracture mechanics evaluations, and steel development. Mr. Wilson is a graduate of the Massachusetts Institute of Technology and holds Bachelor's and Master's of Science Degrees in Metallurgy. He is Chairman of the Transportation and Infrastructure Committee of the American Iron and Steel Institute and Chairman of the Steel Bridge Forum.

William Wright is a research structural engineer for the U.S. Federal Highway Administration at the Turner-Fairbank Highway Research Center in McLean, Virginia. He is the manager of the structures testing laboratory and directs FHWA's research program in the area of steel structures. Current laboratory research includes testing of a full-scale curved girder bridge and the fatigue and fracture testing of HPS girders. The recent emphasis of the steel research program has been to develop new high-performance steels to enable more efficient fabrication and design of bridges. Mr. Wright holds Bachelor of Science and Master of Science Degrees in Structural Engineering from the University of Maryland, in College Park. He is a Licensed Professional Engineer in Maryland and serves on several technical committees of the ASCE and the Transportation Research Board.

APPENDIX F: Technology Panel

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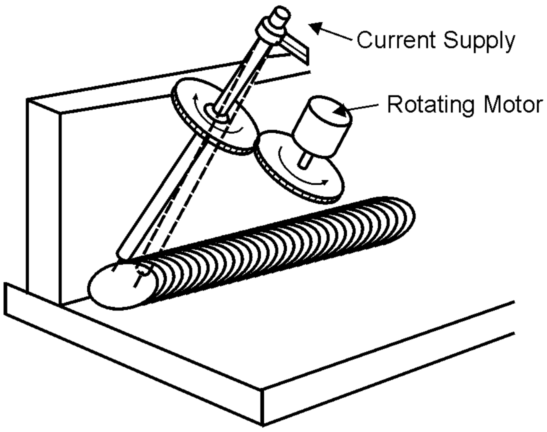
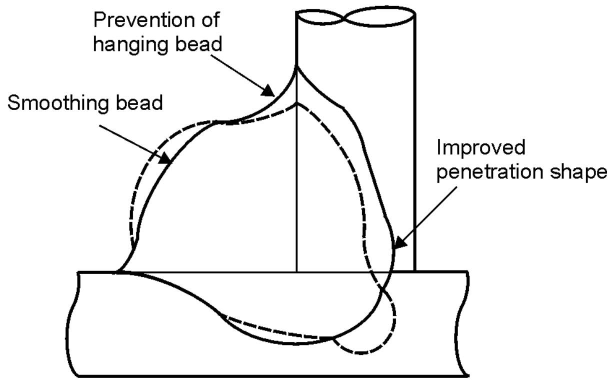
APPENDIX G: NKK High Speed Rotating Arc Welding

PATENTS (Japan, U.S.A., Germany, U.K., France and Sweden)

Rotating mechanism

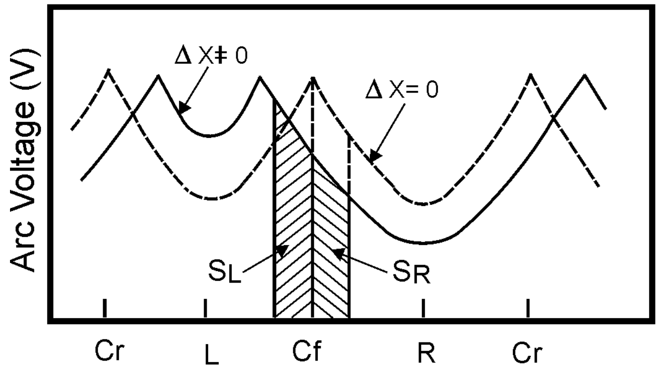


Improvement bead shape



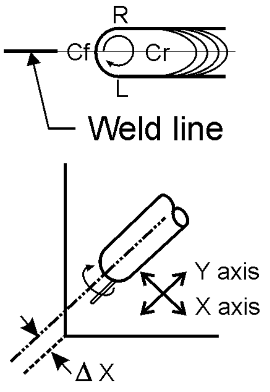
—— Arc rotating method
-------- Conventional method (without rotation)
Welding speed: 100 cm/min.
Welding current: 400A

Principle of arc sensor seam tracking control



Rotating position of arc

Rotating position of arc



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