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Corrugated Web Girder Fabrication

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Corrugated Web Girder Fabrication

Work Area 2
Pennsylvania Innovative High Performance Steel Bridge Demonstration Project

Report to
Commonwealth of Pennsylvania
Department of Transportation
Contract No. 359810

by

Richard Sause

ATLSS Report No. 03-19
August 2003
**1. Title and Subtitle**
Corrugated Web Girder Fabrication: Work Area 2, Pennsylvania Innovative High Performance Steel Bridge Demonstration Project

**4. Author(s)**
Richard Sause

**5. Report Date**
August 2003

**6. Performing Organization Code**
4D371 (CAGE)

**7. Performing Organization Name and Address**
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**9. Performing Organization Report No.**
ATLSS Report No. 03-19

**10. Work Unit No. (TRAIS)**

**11. Contract or Grant No.**
359810

**12. Sponsoring Agency Name and Address**
The Pennsylvania Department of Transportation
Bureau of Planning and Research
Commonwealth Keystone Building
400 North Street, 6th Floor
Harrisburg, PA 17120-0064

**13. Type of Report and Period Covered**
Final Report

**15. Supplementary Notes**
COTR: Thomas P. Macioce
See Report Nos.: FHWA-PA-2004-005-98-10 (a), (c), (d), and (e) for related work.

**16. Abstract**
The Pennsylvania Department of Transportation (PennDOT) has proposed to design and construct a high performance steel demonstration bridge using HPS-485W (HPS-70W) steel in combination with I-shaped girders with corrugated webs. Toward this goal, a coordinated program of design and fabrication studies, and applied laboratory research (testing and analysis) has been conducted to develop details and design criteria for the bridge. This program, titled the "Pennsylvania High Performance Steel Bridge Demonstration Project", consisted of the following Work Areas: (1) corrugated web girder corrugation shape and strength criteria; (2) corrugated web girder fabrication; (3) fatigue resistance of corrugated web girders; (4) corrugated web girder field splices; and (5) diaphragms with flange rotational restraint braces. This report addresses Work Area 2, corrugated web girder fabrication.

The report describes work that was conducted to investigate the technical challenges involved in fabricating corrugated web girders. The corrugated web girder test specimens fabricated for the laboratory research component of the program provide the basis for many aspects of this investigation. The report also provides information on issues that were not important for the corrugated web girder test specimens (e.g., cambering). The report discusses the major steps taken to fabricate the corrugated web girder test specimens including procurement of corrugated web plate, assembly of corrugated web girders, welding of corrugated web girders, and fitting and welding bearing stiffeners. In addition, the major fabrication considerations for corrugated web bridge girders are discussed.

**17. Key Words**
Steel bridge, steel bridge girder, steel bridge girder fabrication, corrugated web, corrugated web girder, corrugated web girder fabrication, high performance steel

**19. Security Classif. (of this report)**
Unclassified

**20. Security Classif. (of this page)**
Unclassified

**21. No. of Pages**
17

**22. Price**
Reproduction of completed page authorized
Corrugated Web Girder Fabrication

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Richard Sause
Professor of Structural Engineering

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Acknowledgements

This work was sponsored by the Pennsylvania Department of Transportation. Support was also provided by the Federal Highway Administration and the Pennsylvania Infrastructure Technology Alliance (funded by a grant from Pennsylvania Department of Community and Economic Development).

The Pennsylvania High Performance Steel Bridge Demonstration Project is a partnership of the ATLSS Center at Lehigh University with Drexel University (M. Elgaaly), High Steel Structures, Inc. (S. Kopp, R. Kase), and Modjeski and Masters, Inc. (W. Wassef), and involves many individuals (the primary contacts are given in parentheses). In particular, the author is grateful for the contributions of individuals from High Steel Structures, Inc. to this report on Work Area 2, Corrugated Web Girder Fabrication. The contributions of Dr. Hassan Abbas, Dr. Alan Pense, and Dr. John Fisher of the ATLSS Center, Lehigh University, and Dr. Robert Driver of the University of Alberta are also acknowledged. The author is grateful for the input and support of Tom Macioce, Bob Horwhat, Dave Wilhelm, and Joe Bracken from the Pennsylvania Department of Transportation.

The contents of this report reflect the views of the author, who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Commonwealth of Pennsylvania at the time of publication. This report does not constitute a standard, specification or regulation.
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Abstract

The Pennsylvania Department of Transportation (PennDOT) has proposed to design and construct a high performance steel demonstration bridge using HPS-485W (HPS-70W) steel in combination with I-shaped girders with corrugated webs. To assist PennDOT, a coordinated program of design and fabrication studies, and applied laboratory research (testing and analysis) has been conducted to develop details and design criteria for the bridge. This project, titled the “Pennsylvania High Performance Steel Bridge Demonstration Project”, is being conducted by the following team: (1) the ATLSS Center at Lehigh University, (2) Modjeski and Masters, Inc., (3) High Steel Structures, Inc., and (4) Drexel University. The program consists of the following Work Areas: (1) corrugated web girder corrugation shape and strength criteria; (2) corrugated web girder fabrication; (3) fatigue resistance of corrugated web girders; (4) corrugated web girder field splices; and (5) precast deck and diaphragms with flange rotational restraint braces. This report addresses Work Area 2.

The report describes work that was conducted to investigate the technical challenges involved in fabricating corrugated web girders. The corrugated web girder test specimens fabricated for the laboratory research component of the program provides the basis for many aspects of this investigation. The report also provides information on issues that were not important for the corrugated web girder test specimens (e.g., cambering). The report discusses the major steps taken to fabricate the corrugated web girder test specimens including procurement of corrugated web plate, assembly of corrugated web girders, welding of corrugated web girders, and fitting and welding bearing stiffeners. In addition, the major fabrication considerations for corrugated web bridge girders are discussed.
1. Introduction

The Pennsylvania Department of Transportation (PennDOT) has proposed to design and construct a HPS demonstration bridge using HPS-485W (HPS-70W) steel in combination with innovative bridge design concepts. The site of the bridge is to be determined. The demonstration bridge will be a steel girder bridge with four or more I-shaped girders. The girders will be fabricated with corrugated webs, and may be braced with cross frames that include compression flange rotational restraint braces. Precast high performance concrete panels may be used to construct the deck without extensive use of field-placed concrete. To assist PennDOT with the development of the demonstration bridge, a coordinated program of design and fabrication studies, and applied laboratory research (testing and analysis) has been conducted to develop details and design criteria for the bridge. This project, titled the “Pennsylvania High Performance Steel (HPS) Bridge Demonstration Project”, is being conducted by a team composed of the following participants: (1) the ATLSS Center at Lehigh University, (2) Modjeski and Masters, Inc., (3) High Steel Structures, Inc., and (4) Drexel University.

The coordinated program of design and fabrication studies, and applied laboratory research (testing and analysis) consists of the following Work Areas: (1) corrugated web girder corrugation shape and strength criteria; (2) corrugated web girder fabrication; (3) fatigue resistance of corrugated web girders; (4) corrugated web girder field splices; and (5) precast deck and diaphragms with flange rotational restraint braces. This report addresses only Work Area 2, corrugated web girder fabrication.

The objective of this report is to describe work that was conducted to investigate the technical challenges involved in fabricating corrugated web girders. The corrugated web girder test specimens fabricated for the laboratory research component of the Pennsylvania HPS Bridge Demonstration Project provided the basis for many aspects of this investigation. The fabricator of these test girders, High Steel Structures, Inc., also provided information on issues that were not important for the test girders (e.g., cambering). In addition, High Steel’s experience gained in fabricating test girders for Drexel University for a separate research project was utilized in this report.

The report begins with a general description of the corrugated web girder fabrication experience of High Steel Structures, Inc. Then, the report discusses the major steps taken to fabricate the corrugated web girder test specimens for the laboratory research component of the project, including procurement of corrugated web plate, assembly of corrugated web girders, welding of corrugated web girders, and fitting and welding bearing stiffeners. Then, the major fabrication considerations for corrugated web bridge girders are discussed. The report ends with a summary and conclusions.
2. Description of Corrugated Web Girder Fabrication Experience

The fabricator, High Steel Structures, Inc., fabricated eight large-scale corrugated web girder test specimens for the project. These eight girders utilized a trapezoidal web profile and consisted of six girders designed for fatigue tests and two girders designed for shear strength tests. The fabrication of these eight girders is described in some detail in Sections 3 through 5 of the report and provides the experience base for most of the descriptions and conclusions of this report.

In addition, High Steel Structures, Inc. fabricated twelve smaller-scale corrugated web girder test specimens for a prior research project conducted at Drexel University. Six of these girders had a trapezoidal web profile and six of these girders had a sinusoidal web profile. The fabrication of these twelve girders provides an additional experience base for the descriptions and conclusions of this report.

2.1. Corrugated Web Girders Fabricated for the Project

Six 7.4m (24ft) long fatigue test girders were fabricated with a web depth of 1,200mm (3.9ft) and a web plate thickness of 6mm (1/4in). Top and bottom flange plates were 20mm (13/16in) thick with a width of 225mm (8.9in). Two 11.6m (38ft) long shear test girders were fabricated with a web depth of 1,500mm (4.9ft) and a web plate thickness of 6mm (1/4in). Top and bottom flange plate thickness was 50mm (2in) with a width of 450mm (18in). 8mm (5/16in) fillet welds were typically used to attach the webs to the flange. All of the web and flange plate material was ASTM A709, grade HPS-485W (HPS-70W); the stiffener plate material was ASTM A709, grade 345W (50W).

The trapezoidal web profile for these girders was developed as part of Work Area 1 of the project. Figure 1 shows the details of the web profile. Figure 2 shows the fatigue test girders and Figure 3 shows the shear test girders.

![Figure 1. Corrugated web profile for girders fabricated for the project.](image-url)
Figures 1, 2, and 3 show stiffeners attached to the corrugated web test girders. These stiffeners are bearing stiffeners that are needed for the laboratory tests at both the load points and the reaction points to inhibit local web distortion. In a typical corrugated web
bridge girder, stiffeners are needed only at the bearings. Figure 2 shows that simple plate stiffeners were used for the fatigue test girders. Figure 3 shows that tee-shaped stiffeners were used for the shear test girders. The tee stiffeners were used because of the large concentrated forces that were applied to the shear test girders, and the initial uncertainty about the performance of simple plate stiffeners on corrugated webs. Bearing stiffeners were studied in Work Area 4 of the project.

2.2. Corrugated Web Girders Fabricated for Drexel Project

The twelve smaller-scale corrugated web girder test specimens fabricated for the previous Drexel University research project had a web depth of 500mm (20in) and a web plate thickness of 3mm (1/8in). The typical girder length was 6.08m (20ft). The webs were formed in Canada by Apex Industries. High Steel Structures, Inc. was responsible for fabricating the flanges and welding the corrugated web plate to the flange. The top and bottom flanges were 12.7mm (1/2in) thick and 150mm (5.9in) wide. 5mm (3/16in) fillet welds were used to attach the webs to the flange. The web, flange, and stiffener plate material was ASTM A-709, grade 345.

3. Procurement of Corrugated Web Plate

The corrugated plate used to fabricate the corrugated web girder test specimens for the project was not available to High Steel Structures, Inc. through its usual suppliers. High Steel searched directories of domestic steel suppliers and contacted domestic steel manufacturing organizations. They also investigated European material and equipment suppliers. Domestic suppliers of corrugated steel materials were identified, however, the available corrugated materials had the corrugations running in the longitudinal direction of the material, and the available corrugated materials were thin gauge. No corrugated web plate suppliers were identified that could supply material in the required thickness (6mm (1/4in)), width (1500mm (4.9ft)), and grade (ASTM A709, grade HPS-485W (HPS-70W)).

High Steel Structures, Inc. investigated possible methods of forming the corrugated web plate from flat plate material in the required thickness, width, and grade. The process of incrementally moving the plate through a press brake was determined to be a viable process, and studied further. From the corrugation profile and the plate thickness, width, and steel grade selected for the project, the press brake requirements were determined. The process of incrementing the plate through the press brake was considered; computer controlled incrementing was desirable, but manual incrementing of the plate was used.

High Steel Structures, Inc. determined that a custom-made die was needed to form the corrugation profile. A die that forms a full corrugation wave in a one-stroke process (Figure 4 (a)) was found to be the most effective (in terms of accuracy and efficiency) but also the most expensive. A two-stroke process with manual incrementing of the web plate, using a die that forms one half of a full corrugation wave was also found to be
feasible and less expensive (Figure 4 (b)). For the project, a die requiring a four-stroke process with manual incrementing was used, as discussed below.

(a) One-stroke process with die to form complete corrugation wave.

(b) Two-stroke process with die on left side and inverted die on right side of brake press.

Figure 4. Single-stroke and two-stroke processes to form corrugation.

Various fabricators with required press brake equipment, crane capacity, and in-feed/out-feed length capabilities were identified and visited by High Steel. Their equipment and capabilities were audited during these visits. Johnstown Welding and Fabricating, Inc. (Johnstown, PA) was selected to corrugate the plate material.

A custom-made die, based on input from Johnston Welding and Fabricating was made for the project. Trial corrugations were made on scrap material. The die required a four-stroke process with manual incrementing to form a single corrugation wave. The inability to corrugate the plate in a single stroke required rolling the plate over in the transverse direction as shown in Figure 5. As a result, the plate length was limited to 6m (20ft) to eliminate handling difficulties. During the trial corrugations, spring-back was noted and corrections were made to the depth of stroke of the press brake. Initially, the die was used as shown in Figure 5 (a), which required the plate to be rolled two times to form a single corrugation. Later, the die was cut in half and placed on opposite sides of the press brake (Figure 5 (b)), which eliminated the need to roll the plate. This method worked for the fatigue test girders, with a web depth of 1,200mm (3.9ft), but the shear test girders, with a web depth of 1,500mm (4.9ft), required a longer die.
(a) Four-stroke process with rolling of plate.

(b) Four-stroke process with die on left side and inverted die on right side of brake press.

**Figure 5.** Four-stroke processes with single-bend dies to form corrugation.
4. Assembly of the Corrugated Web Girders

High Steel Structures, Inc. assembled the corrugated web girder test specimens for the project. For all the test specimens, the top and bottom flange plates were blast cleaned prior to assembly to remove mill scale and rust. At the beginning of the project, the web plates were not blast cleaned or de-scaled prior to assembly. Mill scale that would be in contact with the web to flange fillet weld was to be removed with a small hand grinder prior to assembly. However, due to the lack of flat surfaces on the web plate, this method of mill scale removal proved to be difficult and time-consuming. The process was changed and the web and flange assembly was blast cleaned after assembly and prior to welding.

Layout lines were placed on the top and bottom flange plates. The lines were used to center the web on the flange plate surface. In addition, a perpendicular line was placed on the flange plate at the location of the first bearing stiffener. The intersection of the perpendicular bearing stiffener line and the centerline of the flange plate was used as a working point. All layout dimensions for the placement of stiffeners, location of the web plate, and so on, were made in reference to the working point. During the project it was determined that the preferred method of locating the web on the flange was to locate the intersection of the center-line of the flange plate with the center-line of the inclined folds of the corrugated web plate.

To begin assembling the flange plates and the web into a girder, the bottom flange was placed in the horizontal position on leveling blocks. Using the established working point, the web was placed vertically on the bottom flange. The web was secured to the bottom flange using clamping devices. A framing square was used to insure that the web was perpendicular to the flange. Using small steel blocks and a hammer or hydraulic jack, each corrugation was moved into position on the flange plate. The web was then tack welded to the flange using shielded metal arc welding with an E7018 (3mm (1/8in) diameter) electrode. Initially, the tack welds were placed at the corners of the corrugations. Since this area is a location of stress concentration, the process was changed, and the tack welds were placed on only the longitudinal fold of the corrugation. After completing the tack welds of the bottom flange to web, the girder was inverted onto the top flange and clamped in position. The top flange was properly positioned and made perpendicular to the web plate and then tack welded to the web.

The web to bottom flange fillet welds were made with the web oriented vertically. Both sides of the web were welded simultaneously using a hand-held, semi-automatic gas metal arc welding process (as discussed below). For several girders a robotic gas metal arc welding process was used (as discussed below). At the completion of the web to bottom flange fillet welds, the girder was inverted and the web to top flange fillet welds were made in a similar manner.
At the completion of the web to flange fillet welds, the girder was rotated so the web was oriented horizontally. Stiffeners were fit in place and welded using a semi-automatic flux-cored arc welding process. The stiffeners were placed on the inclined folds of the corrugated web plate, perpendicular to the longitudinal centerline of the flange. Figure 1 shows that the placement of a stiffener on an inclined fold results in an acute angle between the web and stiffener at the upper stiffener to web fillet weld and an obtuse angle between the web and stiffener at the lower stiffener to web fillet weld. The obtuse angle fillet weld was difficult due to the thin web plate and out-of-position welding. Therefore, it is suggested that bearing stiffeners and cross frame connection plates be located on the longitudinal folds, when possible, to avoid these difficult obtuse angle fillet welds.

5. Welding of the Corrugated Web Girders

The corrugated web girder test specimens for the project were welded primarily by High Steel Structures, Inc. The web to flange fillet welds were made with a semi-automatic gas metal arc welding process. The stiffener to web fillet welds were made using a semi-automatic flux-cored arc welding process. The thin web plate required the use of low heat input welding processes. Starts/stops of the web to flange fillet welding process were not permitted on the bend regions and inclined folds of the corrugated webs. The starts/stops were limited to the longitudinal folds of the corrugations. Periodic checks of these welds were made to insure proper fillet weld size and weld integrity. Welders were qualified according to the AWS D1.5-96 Bridge Welding Code. Weld procedure specifications for fillet welds made with semi-automatic gas metal arc welding are given in Appendix A.

The use of submerged arc welding for the web to flange fillet welds was considered, but was rejected because of the potentially negative consequences of the high heat input on the thin web plate. In addition, submerged arc welding does not offer significant potential for robotic welding of the web to flange fillet welds.

For several girders a robotic gas metal arc welding process was used for the web to flange fillet welds. In particular, the robotic process was used for part of one of the web to flange fillet welds on one of the shear test girders. In addition, two of the fatigue test girders were returned to High Steel Structures, Inc. after fatigue testing, and High Steel replaced the cracked bottom flanges with new flanges welded to the web using a robotic process. First, the new flanges were tack welded onto the webs by High Steel Structures, Inc., and the assembled girders were sent to Panasonic Factory Automation in Franklin Park, Illinois. Then, the corrugation shape was programmed into the robotic welding system, and the web to flange (new bottom flange) fillet welds were made by the robotic welder using a gas metal arc welding process (Figure 6). The tracking system of the robotic welding system was able to compensate for minor variations in the corrugated web shape.

Web splicing was performed using the gas metal arc welding process and the submerged arc welding process. The full penetration welds made by both welding processes were
inspected using radiography. Both welding processes were equally effective. However, care was required during grinding of the weld reinforcement to assure that the final web thickness at the splice was not substantially reduced.

**Figure 6. Robotic welding of corrugated web girder.**

6. **Fabrication Considerations for Corrugated Web Bridge Girders**

This section of the report presents a general discussion of corrugated web girder fabrication considerations. The discussion is based on the experience gained from the large-scale test girders fabricated for the project, as well as the smaller-scale test girders fabricated for the Drexel University research project. The fabricator for the project, High Steel Structures, Inc., also considered issues that were not important for the test girders (e.g., cambering).

6.1. **Engineering and Detailing**

Software for calculating the camber, actual web length, and so on, is needed for corrugated web plates. Currently, calculations are performed manually. The calculations for camber of corrugated web girders will be more time consuming than the calculations for flat web girders. Camber for a straight flat web girder is calculated in a single plane from point to point. If the camber of a corrugated web girder is to be cut into the web plate prior to forming the corrugations, additional calculations are needed, and these calculations would not be in a single plane. Additional calculations may be needed to compensate for changes to the web plate shape that may accumulate by the conclusion of the forming operation.
If the camber for a corrugated web girder is cut into the web plate after forming the corrugations, or if the camber is achieved by heating the web plate after forming the corrugations, then the camber calculations will be similar to the calculations for a flat web girder. If the camber for a corrugated web girder is created by fanning the corrugations, the final length of the top of the web plate will be different than the final length of the bottom of the web plate. The detail drawings will have to note the beginning and the end of the fanned region.

Camber calculations will be more challenging for girders with a sinusoidal web profile than for girders with a trapezoidal web profile. The trapezoidal web profile has distinct points and angles that can be used in camber calculations. The sinusoidal web profile has only continuous curves; all points along the web profile lie along a curve. The absence of distinct working points will also make the detailing of sinusoidal web girders more difficult.

New detail drawings, provided by the fabricator, are needed to show the fit-up and assembly of a corrugated web girder. A corrugation profile detail, showing the dimensions of the typical corrugation wave is needed. Additional details showing the location of the corrugation waves along the length of the girder and the relationship of the corrugation waves with respect to the stiffeners are needed to ensure that the stiffeners and corrugations are placed at the correct location along the girder. Other detail drawings by the fabricator may be needed, for example, a web plate corrugation forming detail drawing may be needed.

### 6.2. Handling and Forming of Corrugated Web Plates

The following discussion of handling and forming equipment is based on the web thickness, girder depth, and corrugation profile used in the project. The web plate was extremely flexible, which resulted in handling difficulties. The handling difficulties are attributed to the web plate thickness being only 6mm (1/4in). Due to the flexibility of the web plate, it is recommended that a single crane with a spreader beam be used to move and position the web plate. Also, care must be taken to prevent relaxation of the corrugations during shipping and handling of the web plate.

The equipment required to form web plate corrugations of the type shown in Figure 1 is a 1000 ton, two post, brake press. This brake press is capable of forming one complete corrugation wave per stroke. The cost of the brake press, including shipping and installation, is approximately $625,000. The corrugating die would be custom made for a given corrugation profile. The cost of the custom-made die is approximately $60,000. Due to the cost of the corrugating die, it would be necessary to develop a standardized corrugation profile.

Flat plate material that is to be corrugated should be purchased and corrugated in lengths of fifty feet. A material handling system, which would include in-feed and out-feed
rollers to move the plate material through the brake press is needed. To assure accuracy and repeatability of the corrugation profile, an incremental feeding system is needed. The approximate cost for the material handling system is $150,000.

Critical parameters in controlling the corrugated web geometry are:

1. Spring back, which occurs when web plate is bent and tends to return back slightly to the unbent position, and which affects the angle of the corrugations.
2. Precise incrementing of the corrugated plate as it passes through the press.

Forming of the corrugations is critical and should be monitored closely. Excessive force in the brake press will result in deformations in the plate surface. Insufficient force will result in a corrugated plate that will not conform to the required corrugation profile due to material spring back. In addition, if a bend is not perpendicular to the longitudinal axis of the plate, a conical shape will result that cannot be corrected in the girder assembly operation. Recommended tolerances for an assembled trapezoidal web girder are shown in Figures 7 and 8. Figure 7 shows the tolerances for a single corrugation wave. Figure 8 shows the tolerances for overall length (between bearings) and for spacing between stiffeners (and cross frame connection plates).

Both trapezoidal web and sinusoidal web profiles were considered in the project and differences in forming should be discussed. If a one-hit die is used to form a complete corrugation wave, there is no significant difference in forming sinusoidal and trapezoidal corrugations. Increased machining costs are expected for a sinusoidal shaped die (compared to the trapezoidal shaped die). However, the accuracy of the sinusoidal corrugations and trapezoidal corrugations would be similar.
Finally, if corrugations are formed using a two-stroke or four-stroke process with manual incrementing to form a single corrugation, the forming process relies heavily on the brake press operator’s skill for corrugation accuracy. The last corrugation at the end of each web plate is difficult to bend accurately in this process. It is difficult to fix an incorrectly formed fold in the web splicing operation or in the girder assembly process. Therefore, when ordering the flat web plate material, material for one additional corrugation (½ wave) should be ordered at each end of the plate, which can be cut off after the girder is assembled.

![Figure 8. Overall length and stiffener spacing tolerances.](image)

6.3. Corrugated Web Girder Assembly

The preferred method of locating the web on the flange is to locate the intersection of the center-line of the flange plate with the center-line of the inclined folds of the corrugated web plate. The intersection of a bearing stiffener with the centerline of the flange plate can be used as a working point and all dimensions for locating the web plate, other bearing stiffeners, and cross frame connection plates can be made in reference to the working point. The zinc marking system in the automatic burning machine used to cut the flanges can be used to locate the web plate, bearing stiffeners, and cross frame connection plates.

The test girders were assembled by fitting the web to the flanges, which were placed in a horizontal position on leveling blocks. The process is as follows. The web is clamped and made perpendicular to the bottom flange, and each corrugation is properly located with respect to the flange and tack welded to the flange. The tack welds should be placed on only the longitudinal folds of the corrugations. After tack welding the web to the bottom flange, the girder is inverted onto the top flange, the top flange is properly positioned and made perpendicular to the web plate and then tack welded to the web. The web to bottom flange fillet welds are made with the web oriented vertically. A hand-
held, semi-automatic welding process or a robotic welding process can be used. At the completion of the web to flange fillet welds, bearing stiffeners are fit and welded in place with the girder rotated so the web is oriented horizontally. This assembly process was successfully used for girders with trapezoidal web profiles and girders with sinusoidal web profiles.

Assembly of girders with trapezoidal web profiles is more efficient for shop personnel than assembly of comparable girders with sinusoidal web profiles. For the test girders, hydraulic jacks were often used to move the trapezoidal web plate into position on the flange plate. Movement of the web plate was fairly easy. To move the sinusoidal web plate into position, a custom-made device (softener) that conforms to the shape of the web is needed. The softener is used to move the sine wave web into position on the flange. The softener is needed since the web has no flat regions that can be used to move the web into position.

A difference between the assembly of a corrugated web girder and a flat web girder has been noted. A flat web plate girder can be assembled with both the top and bottom flange plates positioned and tack welded to the web in a single set-up. The corrugated girder must be inverted after the bottom flange is tack welded to the web. This “T” section (corrugated web and bottom flange) is then placed on the top flange and tack welded. Inverting the assembly permitted the web plate to be moved into position using the hydraulic jacks.

After the welding is complete, a visual inspection of the completed girder is performed, including camber and sweep. Camber is difficult to assess, because specifications for the angle between the corrugations and the flange have not been developed. The corrugations may be required to be 90° to the horizon or the corrugations may be fanned to camber the web. If the corrugations must be 90° to the horizon, then the cambering must be considered in the corrugation forming operation. Girders with trapezoidal corrugations that can be fanned to camber the girder can be cambered using existing shop fabrication methods.

### 6.4. Corrugated Web Girder Welding

Welding of the web to flange fillet welds can be performed using a flux-cored arc welding process or a gas metal arc welding process. The thin web plate section requires the use of a low heat input welding process. The use of submerged arc welding for the web to flange fillet welds is not considered to be appropriate because of the effect of the high heat input on the thin web plate. Stiffener to web fillet welds can be made using a flux-cored arc welding process or a gas metal arc welding process.

Web splices can be made using the gas metal arc welding process or the submerged arc welding process. High Steel Structures, Inc. has found both welding processes to be equally effective. However, because of the thin web plate, care is required during
grinding of the weld reinforcement to maintain the correct final web thickness at the splice.

Many owners currently specify the submerged arc welding process for steel bridge girders. Often, gas metal arc welding is permitted for only cross frames or bearing assemblies. The gas metal arc welding process has disadvantages. For example, the welder must wear a hood, sleeves, gloves, and neck protection, and the welds must shielded from air movement that would result in a loss of gas coverage at the weld puddle. The advantages include a visually acceptable weld with good penetration (using the spray arc mode of transfer), and significantly increased potential for the use of robotic welding because the flux is omitted, enabling better robotic tracking due to the absence of flux and/or slag covering the weld area. The gas metal arc welding process has been used successfully in many industries (naval vessels, building construction, etc.) for many years. The specifications of AWS D1.5 should be used to help insure that gas metal arc welding is performed according to standard specifications. Weld procedure specifications used in the present project for welds made with semi-automatic gas metal arc welding are given in Appendix A.

Preparations for welding and preheat requirements for trapezoidal and sinusoidal corrugated web girders are similar those for the flat web girders. Web to flange fillet welds should be started and stopped on longitudinal folds of trapezoidal webs to avoid compromising the fatigue performance of corrugated web girders. Stop/start locations should not be placed on the bend regions or the inclined folds. Robotic welding could significantly reduce the number of start/stop locations.

6.5. Splicing of Web Plates

If web splices require full penetration groove welds, the trapezoidal corrugation profile is preferred over the sinusoidal corrugation profile. The longitudinal folds of a trapezoidal corrugation profile provide locations where the web plates can be aligned. If the full penetration groove welds are located on the inclined folds of the trapezoidal corrugation profile, these welds would be as difficult as full penetration groove welds on the sinusoidal web profile. An alternative web splice is a fillet-welded lap joint on the inclined fold of a web with trapezoidal corrugations. Bolts could be used to assure web flatness in the lapped region. Further research on this type of web splice is needed.

6.6. Attachment of Bearing Stiffeners and Cross Frame Connection Plates

The attachment of bearing stiffeners to web plates with a sinusoidal corrugation profile is difficult, because when the forming process is not accurately controlled, the corrugations take on a conical shape and the stiffeners must be custom-made for each location. For webs with a sinusoidal or a trapezoidal corrugation profile, welding the stiffeners to the web is difficult when the stiffeners are located on the inclined regions of the web plate.
Stiffeners located on longitudinal folds (where the web runs perpendicular to the stiffener) are easier to weld to the web.

When cross frame connection plates are located on the inclined regions of webs with a sinusoidal or a trapezoidal corrugation profile, the cross frame bolt holes will not be in the expected locations if the web is not accurately placed along the length of the girder from the working point. Webs with trapezoidal corrugations have long regions with a longitudinal orientation (the longitudinal folds), compared to webs with sinusoidal corrugations, and if the cross frame connection plates are located on these longitudinal folds, the bolt hole locations will not be sensitive to inaccuracies in the location of the web along the length of the girder.

For webs with trapezoidal corrugations, fitting and welding the bearing stiffeners and cross frame connection plates to the longitudinal folds are similar to fitting and welding stiffeners and connection plates to a conventional flat web. However, if they are located on the inclined folds, fitting and welding the bearing stiffeners and cross frame connection plates are more difficult. Recommended tolerances for bearing stiffener and cross frame connection plate spacing are shown in Figure 8.

In general, it is suggested that bearing stiffeners and cross frame connection plates be located on the longitudinal folds, when possible, to simplify the fitting and welding of these plates to the web, and to reduce the sensitivity of connection plate bolt hole locations to inaccuracies in the web location, as discussed above. However, studies conducted in Work Area 1 of the project recommend that bearing stiffeners be located at the center-line of inclined folds so that these stiffeners (and the reactions at the bearings) are centered transversely on the girder. Therefore, it is recommended that only the cross frame connection plates be located on the longitudinal folds.

6.7. Inspection

Weld inspection for corrugated web girders with a sinusoidal or a trapezoidal corrugation profile is similar to weld inspection for a flat web plate girder. Difficulties were not encountered in magnetic particle inspection or visual inspection of welds.

To assure accuracy of the depth of corrugations and the location of corrugations along the girder length, dimensional checks must be made during the corrugation forming process, and during fitting of the web to the flanges during girder assembly. The dimensional accuracy of corrugated webs with a sinusoidal corrugation profile is difficult to inspect due difficulty in establishing working points. It is critical that the location of the web plate in relation to the designated working points be checked at frequent intervals during girder assembly. If this inspection is not performed, the accumulated fabrication tolerances will result in a web corrugation mislocation.
7. Summary and Conclusions

This report describes an investigation of the challenges involved in fabricating corrugated web bridge girders. The corrugated web girder test specimens fabricated for the laboratory research component of the Pennsylvania HPS Bridge Demonstration Project provided the basis for many aspects of this investigation. The fabricator of these test girders, High Steel Structures, Inc., also provided information on issues that were not important for the test girders but may be important for bridge girders (e.g., cambering). High Steel’s experience gained in fabricating test girders for Drexel University for a separate research project was also utilized in this report.

Conclusions are as follows:

The technical challenges involved in fabricating corrugated web girders can be managed in a commercial steel bridge fabrication shop. The recommended tolerances for corrugated web geometry are shown in Figures 7 and 8.

The corrugated web girder test specimens fabricated for the present project made effective use of gas metal arc welding. Gas metal arc welding is recommended for use in corrugated web girder bridge projects. Weld procedure specifications used in the project for semi-automatic gas metal arc welding are given in Appendix A.

Based on shop fabrication of girders with both sinusoidal and trapezoidal corrugations, trapezoidal corrugations offer distinct advantages over sinusoidal corrugations. Accurate forming of the corrugations, and the ease of handling, assembly, and welding were major factors in this evaluation. In addition, the fabrication of girders with trapezoidal web profiles has similarities to the fabrication of girders with conventional flat webs.

It is recommended that cross frame connection plates be located on the longitudinal folds to simplify the process of fitting and welding these plates to the web. Bearing stiffeners, however, should be located at the center-line of inclined folds so that these stiffeners (and the reactions at the bearings) are centered transversely on the girder. Unfortunately, this bearing stiffener location will increase the challenges of fitting and welding these stiffeners to the corrugated web.

Standardization of corrugated web thickness, depth, and corrugation profile is critical to the efficiency of corrugated web girders and to the future success of corrugated web girders in the bridge market. Deviations from these standards will have a negative effect on cost of the corrugated web girder bridges.

To fully gain the economical advantages of corrugated web girders, web thickness as small as 6mm (1/4 in), which is less than permitted by current bridge design specifications, and gas metal arc welding should be permitted. The use of cross frames should be minimized. The project has assumed that corrugated web girders will be unpainted weathering steel, and painting of corrugated webs has not been investigated.
Appendix A. Weld Procedure Specifications for Gas Metal Arc Welds

WELDING PROCEDURE FOR AWS PREQUALIFIED JOINTS

GMAW - METRIC

PROCEDURE SPECIFICATIONS

| MATERIAL SPECIFICATION | ASTM A-709M, HPS GRADE 465W AND GRADE 50W |
| WELDING PROCESS | GAS METAL ARC WELDING |
| MANUAL OR MACHINE | SEMIAUTOMATIC |
| POSITION OF WELDING | 2F |
| FILLER METAL SPECIFICATION | AWS A5.16 |
| WELD METAL CLASSIFICATION | ER70S-6 |
| WIRE/FLUX | NATIONAL STANDARD NS-115 |
| WIRE DIAMETER | 1.1mm |
| SINGLE OR MULTIPLE ARC | SINGLE ARC |
| POLARITY | DC+ |
| ROOT TREATMENT | MANUAL CLEANING |
| PREHEAT AND INTERPASS TEMPERATURE | SEE PREHEAT CHART |
| ELECTRICAL STICK-OUT | 19mm |
| SHIELDING GAS | 92%AR/8%C02 |

WELDING PROCEDURE

| PASS NO. | WELDING CURRENT |
| AMPS | WIRE FEED SPEED | VOLTS | TRAVEL SPEED (mm/m) | GAS FLOW (l/min) | JOINT DETAIL |
| 1 | 244-305 | 7.3-10.2 | 22.5-26.0 | 334-445 | 14-17 | 8mm FILLET WELD |

NOTE:
WEB TO FLANGE FILLET WELDS MUST BE MADE IN A SINGLE PASS.

PROCEDURE QUALIFICATION RECORD GMAW-1 (EXPIRES 8/10/05)