Perform heat straightening according to AWS D1.7 *Guide for Strengthening and Repairing Existing Structures*. Consider using an AWS Certified Welding Inspector to provide quality assurance for heat straightening work.

Limited information on the heat straightening of wrought iron is provided in Purdue University's *Evaluation and Repair of Wrought Iron and Steel Structures in Indiana*.

6.11—WELDING

Welding can be a valuable tool for bridge preservation and rehabilitation; however, it should only be used when welding is the best alternative based on technical merit. There are many additional challenges that must be overcome to successfully weld existing bridge steel, which include but are not limited to:

- Unknown chemical composition;
- Unknown heat treatment condition;
- Unknown existing residual stresses;
- Unknown carbon content (i.e. weldability);
- Unknown grain size;
- Unknown degree of cold work in existing condition;
- Unknown fracture properties of existing steel, i.e. Charpy impact toughness and fracture toughness;
- Structural restraint which can resist large residual stresses;
- Dimensional changes due to welding;
- Creation of fatigue crack initiation sites;
- Cooling cracks; and
- Presence of diffusible hydrogen.

C6.11

An example of the importance of chemical composition is the tendency of silicates, alumina, and sulfides to cause lamellar tearing.

Perform welding of existing steel according to AWS D1.7 *Guide for Strengthening and Repairing Existing Structures* and AASHTO/AWS D1.5M/D1.5.

Do not weld on the pins in pin-connected trusses. Do not weld counters or other members together to eliminate noise or vibration.

Welding can create high residual stresses and crack initiation sites in the base metal. Welding in structural connections can change the way loads are transferred and introduce forces that the connection was not designed for.

Due to the structural risks of field welding, avoid field welding unless the structural risks are higher with other options. Control the risks of field welding by:

- Verifying alloy according to AWS D1.7 *Guide for Strengthening and Repairing Existing Structures* prior to welding;
- Eliminating traffic loads during field welding when possible;
- Verifying carbon content of existing steel prior to welding;

See AWS D1.7 *Guide for Strengthening and Repairing Existing Structures* Article 4.4 for further information on determining the weldability of existing steels.

- Following the requirements of AWS D1.7 *Guide for Strengthening and Repairing Existing Structures* and AASHTO/AWS D1.5M/D1.5;
- Following the requirements of AASHTO/AWS D1.5M/D1.5 Clause 12 for fracture critical members, including preheat and post-weld thermal treatments and electrode selection and storage;
- Conservatively, when working with unknown steels or with steels prone to hydrogen-induced cracking or lamellar tearing, provide post-weld thermal treatments according to AASHTO/AWS D1.5M/D1.5 Annex G; and
- Verifying weld quality by appropriate NDT, according to AASHTO/AWS D1.5M/D1.5 Clause 6.

6.12—REPAIR AND STRENGTHENING

Repair or strengthening may be required to address degraded original members, impact damage, or inadequate load capacity as shown by a load rating.

In some cases, angles, bent plates, channels, fish plates, or doubler plates can be installed to strengthen the member to meet the required load capacity. Design and detail these repairs according to AASHTO LRFD. Account for increased stresses caused by stiffness changes or by eccentricities of repair members. When the repair is installed on pitted original steel or when fastener details do not comply with AASHTO LRFD Article 6.13.2.6, design and detail it as non-slip-critical and provide fay surface sealing.

In some cases, new cover plates can be installed in sections with bolted splices, such as when an end post is damaged by impact and must be repaired while carrying dead load or while live traffic is allowed on the bridge. Perform structural analysis as needed to determine the length of original cover plate that can be removed safely. Design and detail these repairs according to AASHTO LRFD. Account for increased stresses caused by stiffness changes or by eccentricities of repair members. When the repair is installed on pitted original steel or when fastener details do not comply with AASHTO LRFD Article 6.13.2.6, design and detail it as non-slip-critical and provide fay surface sealing.

In some cases, auxiliary members may be added adjacent to or within existing members to increase the member capacity. Add the auxiliary members in the least conspicuous location possible. Design new connections for the auxiliary members to structurally connect them into the existing pinned connections or riveted connections.

C6.12

Use temporary shoring unless analysis shows that the structure is stable during installation of the repair. Sometimes stability can be provided by removing some or all traffic from the structure during repair work.

Built-up sections, i.e. vertical posts; upper and lower chords; and end posts made from angles, channels, and plates lend themselves to strengthening by adding material to flanges and webs.

For tension members, post-tensioning can be used to increase the capacity of the member. A high-strength cable or rod is fastened to both ends of the member and tensioned to counteract some of the dead load carried by the member FHWA-HRT-14-063.

Bridges with steel stringers and non-composite concrete decks can be strengthened without affecting historical integrity by making the deck composite with the stringers. In some cases, this has been accomplished by coring, welding shear studs, and patching.

Welding should only be used in repair and strengthening work when it is the best alternative based on technical merit. When welding is a part of repair and strengthening work, perform the work according to Article 6.11.

Post-tensioning is best suited for longer trusses with more significant dead load. Post-tensioning also can be used to provide redundancy.

6.13—GUSSET PLATES

Analyze gusset plates when load rating riveted, welded, or bolted steel truss bridges. Strengthen according to Article 6.12 as needed to fulfill the intended level of service.

Gusset plates are a common location for pack rust. Remove pack rust and treat according to Article 6.8.

C6.13

Detailed information on the load rating and analysis of gusset plates is provided in FHWA-HRT-14-063, *Guidelines for Design and Rating of Gusset-Plate Connections For Steel Truss Bridges*.

6.14—VERTICAL CLEARANCE IMPROVEMENT

Consider vertical clearance improvement for bridges that have enough over-height impacts to justify an intended level of service that will accommodate higher vehicles. Also consider the risk of catastrophic failure in the event of over-height impacts that can cause chain-reaction failures.

Vertical clearance of through-trusses can often be improved by rebuilding sway braces and portal braces.

The quality of field measurements is critical for vertical clearance projects as actual truss measurements often vary from the values shown on as-built plans. Some truss measurements may change when original braces are removed, i.e. vertical members often have built-in stresses that are relieved when sway bracing is removed.

Sway braces can ordinarily be removed and replaced one at a time without shoring. Portal braces normally require some temporary shoring to resist wind loads during removal and replacement.

C6.14

Generally, under applicable historic preservation laws, minimal visual changes are preferred when this type of work is performed. Sway bracing can usually be rebuilt at the higher elevation using the same cross-sections as original, with minimal visual impact. Portal braces are more challenging since many of them have minimal depth as originally built. If space allows, a “V” portal brace arrangement can be rebuilt into a “W” portal brace arrangement that is about half the original depth using the same cross-sections as original. Other vertical clearance projects have replaced shallow “V” or “X” portal bracing with box beams or curved braced members with a web for bracing in the shallowest areas.

Consider limiting sway bracing removal and replacement to periods when winds are forecast at less than 35 mph.

Vertical clearance projects can benefit from the use of 3D CAD modeling to verify theoretical fit-up of parts, and of Lidar point clouds as a source of field measurements.

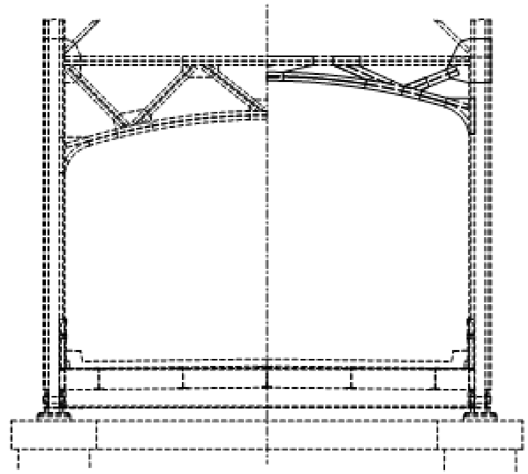

Figure C6.14-1—Before and After View of Portal Bracing Reconstruction.

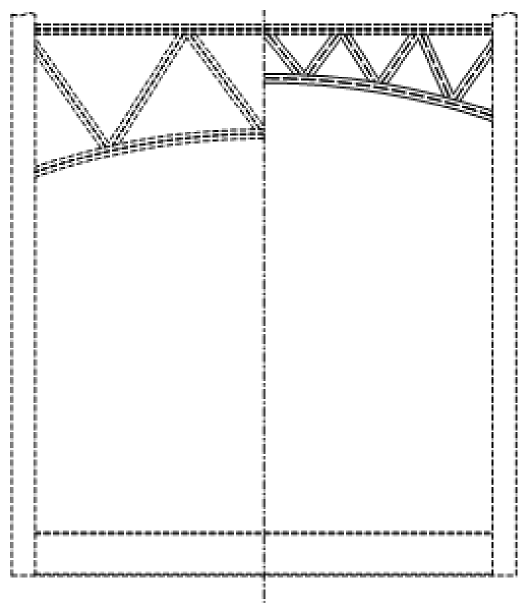

Figure C6.14-2—Before and After View of Portal Bracing Reconstruction, “W” Bracing Arrangement.

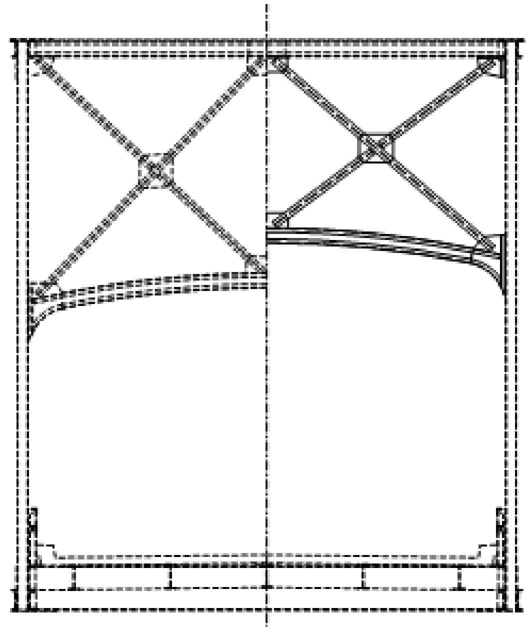

Figure C6.14-3—Before and After View of Sway Bracing Reconstruction.

6.15—WROUGHT IRON

Use of wrought iron for structural members was primarily limited to the 19th century, though it was used in limited cases into the early 20th century, where it is primarily seen in tension members of truss bridges. It is comprised of very low carbon iron with strings of slag which can be detected visually after polishing and etching with a solution of muriatic acid.

The tensile capacity of wrought iron is identified in AASHTO MBE Article 6A.6.2.3, with coupon testing encouraged to confirm the mechanical properties.

Wrought iron is more corrosion resistant than steel, but should still be protected from aggressive conditions using similar coatings to steel structures.

Like steel, wrought iron should not be cold worked, though limited information is available about the requirements of heat straightening. Due to limited fatigue resistance, members with significant damage should be replaced in kind.

Welding should only be used on wrought iron when it is the best alternative based on technical merit. When welding involves wrought iron, perform the work according to AWS D1.7 *Guide for Strengthening and Repairing Existing Structures*. Consider using an AWS Certified Welding Inspector to provide quality assurance for welding of wrought iron.

C6.15

A detailed discussion of the properties of wrought iron is available in the *Construction Materials Reference Book*.

For more information on the durability of damaged and repaired wrought iron, see *Evaluation and Repair of Wrought Iron and Steel Structures in Indiana*.

When slag inclusions are small enough to permit welding, preheating should always be used, but the inter-pass temperature should not exceed 250 degrees F. Fillet welds are not recommended. Welding of wrought iron should not be performed without a chemical analysis to determine weldability.

6.16—CAST IRON

Historic cast iron was used in bridge construction from 1780 until around 1880, though it may be found in limited applications into the early 20th century. It is often identifiable by the mold lines from its casting.

As formed during this period, cast iron is brittle and weak in tension, with a granular structure when fractured. If needed for load evaluation, samples should be taken for testing as properties are variable.

Intact cast iron has a corrosion resistant layer from the mold process, but may still corrode in aggressive environments. Once cast iron has been abrasive blasted, it will corrode similarly to steel and should be kept coated. When replacing members connecting to cast iron, galvanic corrosion should be avoided through isolation of the materials.

Damaged cast iron can be repaired by braze welding with preheating and slow cooling. "Metal stitching" techniques may also be appropriate in limited cases. Welding should only be used on cast iron when it is the best alternative based on technical merit. When welding involves cast iron, perform the work according to AWS D1.7 *Guide for Strengthening and Repairing Existing Structures*. Consider using an AWS Certified Welding Inspector to provide quality assurance for welding of cast iron.

C6.16

A common use of cast iron was in the fittings on covered bridges, where it is known to have been used through the 1920s.

6.17—SUSPENSION BRIDGES

Consider the following for preservation and rehabilitation of historic suspension bridges:

- Provide effective main cable corrosion protection, according to Article 6.8.
- Suspender cables may need to be re-tensioned or replaced. Tension can be measured by observing the natural frequency of each rope and correlating to tension.
- Provide suspender cable corrosion protection, according to Article 6.8.
- Deck replacement is complicated and must be staged so that deformations are controlled within acceptable limits.
- Traction rods with fusible links may be needed to transfer longitudinal earthquake and braking forces from the stiffening trusses to the main cables. Fusible links limit the force transfer to that which can be carried by the friction clamp connection to the main cable.
- Monitor for wear in pins and connections that are affected by thermal stresses.
- Maintain expansion joints in functional condition.

C6.17

- In some cases, additional main cables have been added adjacent to the existing cables, with their own suspender cables.
- Main cable wire breaks can be repaired using special swaged ferrules to splice new wires into place and tighten them. Typically this would be performed during a main cable internal inspection.

See FHWA-IF-11-045 *Primer for the Inspection and Strength Evaluation of Suspension Bridge Cables* for information on splicing of new wires into the main cable.

6.18—REFERENCES

23 CFR 635.410*, Subpart D, General Material Requirements, Buy America Requirements.* Federal Highway Administration, Department of Transportation, Washington, DC, 2018. Available at: https://www.govinfo.gov/content/pkg/CFR-2018-title23-vol1/xml/CFR-2018-title23-vol1-part635.xml

AASHTO. *AASHTO LRFD Bridge Design Specifications,* 9th Edition. LRFDBDS-9. American Association of State Highway and Transportation Officials, Washington, DC, 2020.

AASHTO. *Guide Specifications for Analysis and Identification of Fracture Critical Members and System Redundant Members.* American Association of State Highway and Transportation Officials, Washington, DC, 2018.

AASHTO. *Guide Specifications for Internal Redundancy of Mechanically-Fastened Built-Up Steel Members.* American Association of State Highway and Transportation Officials, Washington, DC, 2018.

AASHTO. *Manual for Bridge Evaluation,* 3rd Edition. American Association of State Highway and Transportation Officials, Washington, DC, 2018.

AISC. *AISC Shapes Database v15.*0H. American Institute of Steel Construction, Chicago, Illinois. Available at: www.aisc.org/historicshapes [Cited April 2, 2019].

AISC. *Iron and Steel Beams 1873 to 1952.* American Institute of Steel Construction, Chicago, Illinois, 1990.

ASTM. A563-15 *Standard Specification for Carbon and Alloy Steel Nuts.* ASTM International, West Conshohocken, Pennsylvania, 2015.

ASTM. A709/A709M-18 *Standard Specification for Structural Steel for Bridges.* ASTM International, West Conshohocken, Pennsylvania, 2018.

ASTM. F436/F436M-18 *Standard Specification for Hardened Washers Inch and Metric Dimensions.* ASTM International, West Conshohocken, Pennsylvania, 2018.

ASTM. F3125/F3125M-15a *Standard Specification for High Strength Structural Bolts, Steel and Alloy Steel, Heat Treated, 120 ksi (830 MPa) and 150 ksi (1040 MPa) Minimum Tensile Strength, Inch and Metric Dimensions.* ASTM International, West Conshohocken, Pennsylvania, 2015.

AWS. AASHTO/AWS D1.5/D1.5M:2015-AMD1 *Bridge Welding Code*. American Welding Society, Miami, Florida, 2015.

AWS. AWS D1.7/D1.7M:2010 *Guide for Strengthening and Repairing Existing Structures*. American Welding Society, Miami, Florida, 2009.

Bowman, M D.*,* and A M. Piskorowski. *Evaluation and Repair of Wrought Iron and Steel Structures in Indiana*. Purdue University, West Lafayette, IN, 2004. Available at: http://docs.lib.purdue.edu/jtrp/84

Doran, D, and B. Cather. *Construction Materials Reference Book*, 2nd edition. Routledge, London, UK, 2014.

FHWA. *Guide for Heat-Straightening of Damaged Steel Bridge Members,* Publication No. FHWA-IF-08-99. U.S. Department of Transportation, Federal Highway Administration, Washington, DC, 2008. Available at: https://www.fhwa.dot.gov/bridge/steel/heat_guide.pdf

FHWA. *Guidelines for Design and Rating of Gusset-Plate Connections For Steel Truss Bridges,* Publication No. FHWA-HRT-14-063. U.S. Department of Transportation, Federal Highway Administration, Washington, DC, 2014. Available at: https://www.fhwa.dot.gov/publications/research/infrastructure/structures/bridge/14063/index.cfm

FHWA. *Primer for the Inspection and Strength Evaluation of Suspension Bridge Cables,* Publication No. FHWA-IF-11-045. U.S. Department of Transportation, Federal Highway Administration, Washington, DC, 2012. Available at: https://www.fhwa.dot.gov/bridge/pubs/if11045.pdf

Historic Scotland. *Maintenance and Repair Techniques for Traditional Cast Iron.* Historic Scotland, National Conservation Centre, Edinburgh, Scotland, 2013.

NCHRP. *Successful Preservation Practices for Steel Bridge Coatings, Scan Team Report, NCHRP Project 20 68A, Scan 15-03.* National Cooperative Highway Research Program, Transportation Research Board, Washington, DC, 2016. Available at: http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-68A_15-03.pdf

ODOT. *ODOT Historic Bridge Riveting Guidance.* Ohio Department of Transportation, December 27, 2018. Available at: http://www.dot.state.oh.us/Divisions/Planning/Environment/Cultural_Resources/HISTORIC_BRIDGES/Documents/Ohio%20DOT%20Riveting%20Guidance%20and%20Resources%20for%20Historic%20Bridges.pdf

SSPC. SSPC-Guide 6, *Guide for Containing Surface Preparation Debris.* The Society for Protective Coatings, Pittsburgh, Pennsylvania, 2018.

SSPC. SSPC-SP 6/NACE No. 3, *Commercial Blast Cleaning.* The Society for Protective Coatings, Pittsburgh, Pennsylvania, and NACE International, Houston, Texas, 2007.

SSPC. SSPC-SP 10/NACE No. 2, *Near-White Blast Cleaning.* The Society for Protective Coatings, Pittsburgh, Pennsylvania, and NACE International, Houston, Texas, 2007.

Section 7:

ALUMINUM STRUCTURES

7.1—SCOPE

This Section provides guidance for the preservation and rehabilitation of historic aluminum structures. Aluminum structures that may be encountered on historic bridge preservation and rehabilitation projects may include handrails, bridge railings, sign structures, and other components. Refer to Section 1 for the processes that determine permissibility of these alternatives under applicable historic preservation laws.

7.2—DEFINITIONS

Exfoliation Corrosion—A severe type of intergranular corrosion that raises surface grains from metal by forming corrosion products at grain boundaries.

Fay Surface Sealing—Use of silicone sealant between two members in contact, to exclude moisture and oxygen in order to prevent crevice corrosion.

7.3—ABBREVIATION

pH—A scale of acidity ranging from 0 (acidic) to 14 (alkaline).

7.4—DURABILITY

Protect aluminum components in contact with concrete or carbon steel by electrically isolating the aluminum from the concrete or carbon steel, using tar paper, polymer materials, or by fay surface sealing.

6061-T6 and related alloys have performed well in marine environments above splash zone when the aluminum is either anodized or can develop its protective oxide layer prior to salt exposure. Avoid 2000-series alloys as they are particularly susceptible to exfoliation corrosion.

Provide functional expansion joint seals and drainage to prevent deicing salts from contaminating aluminum components.

C7.4

Fay surface sealing is intended to fill pits and gaps to prevent moisture intrusion. Fay surface sealing consists of coating the entire faying surface with silicone sealant and tightening bolts while the sealant is wet.

Contact between aluminum and concrete can be harmful to the aluminum due to the high pH of concrete.

Most aluminum alloys corrode extensively when exposed to chlorides.

7.5—REFERENCES

ASTM. B580-79 *Standard Specification for Anodic Oxide Coatings on Aluminum.* ASTM International, West Conshohocken, Pennsylvania, 2014.

Smith, Frank N. Corrosion Damage Repairs to the Arvida Aluminum Bridge, *Materials Performance*, NACE International, Houston, Texas, 2019.

This page intentionally left blank.