E-ISSN: 2707-8299
P-ISSN: 2707-8280
Journal's Website
IJSDE 2024; 5(2): 25-27
Received: 11-06-2024
Accepted: 19-07-2024

Young Sohn
Department of Engineering, Central Connecticut State University New Britain, CT 06050, United States

Corresponding Author:
Young Sohn
Department of Engineering, Central Connecticut State University New Britain, CT 06050, United States

Evaluation of heat straightening repair field application on damaged steel girder bridges

Young Sohn

DOI: https://doi.org/10.22271/27078280.2024.v5.i2a.32

Abstract
Heat straightening field visit to a repair site revealed that real heat straightening repair process violated the limits and guidelines provided by FHWA due to time and economic issues. These violations include but are not limited to: (a) under heating below 1200°F, (b) over heating above 1200°F, (c) over straining above the restraining force limit (0.5 M_p), (d) multiple heat straightening of the same location more than two times, (e) No measurement of applied forces, (f) unclear temperature measurement, and (g) short cooling time. There is a lack of knowledge of the effects of these imperfections in the heat straightening repair process on the damaged-repaired steel beams. The fact that this is an ongoing concern suggests that further research, particularly field studies, is needed to evaluate the impact of these procedural imperfections on the repaired beams. Future studies could provide crucial data on how these variances affect the mechanical properties of steel, fatigue resistance, and the overall lifespan of repaired structures.

Keywords: Heat straightening, heating temperature, restraining force

Introduction
Over-height trucks occasionally collide (Impact) with steel highway bridges causing structural damage to the steel beams. This permanent deformation can be repaired by heat straightening, which is a structurally efficient and cost-effective repair process. However, in the real field implementation of heat straightening, the repair process violated the limits and guidelines presented by various state highway agencies and the FHWA. In this research, the realistic implementation of heat straightening repair (With imperfections) is determined and evaluated.

Backgrounds
Guidelines for conducting the heat straightening repair have been developed by the NCHRP (Shanafelt and Horn 1984) [1] and the FHWA (Avent and Mukai 1998). These guidelines present procedures for estimating the damage magnitude and identify heating patterns and locations for repairing different types of damage.

The guidelines establish limits for: (a) the maximum damage that can be repaired (100 times the yield strain), (b) the maximum restraining force (50% of the section plastic moment), (c) the maximum heating temperature (650 °C/1200 °F for mild steels and 595 °C/1100°F for quenched and tempered steels), and (d) the number of damage-heat straightening cycles at the same location (2 cycles of damage-heat straightening). The FHWA guidelines also identify the effects of damage and heat straightening repair on the residual stresses and the steel structural properties. These guidelines have been developed based on studies conducted over the years.

Field Visit to Heat Straightening Repair Site
The heat straightening repair project on Allisonville road, crossing over I-465 eastbound near Indianapolis, was visited. One of the heat straightening companies conducted heat straightening repair on the east-end girder (Eastbound) damaged by an over-height truck as shown in Fig. 1. The damaged part of the steel girder had previously experienced another damage-repair process before this heat straightening repair. Two eastbound lanes on I-465 were blocked for the repair process during nighttime work procedures.

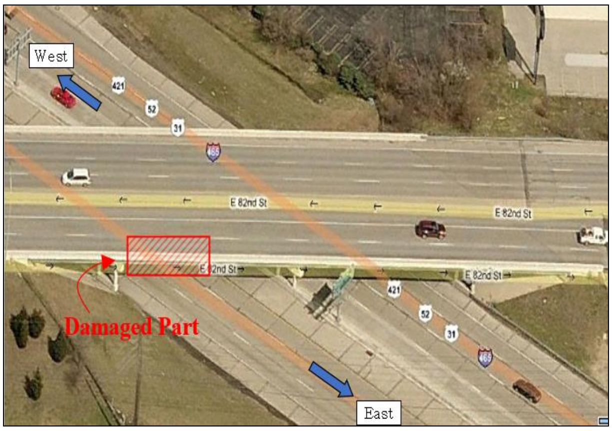

Fig 1: Damaged girder location

As shown in Fig. 2, the east-end composite beam was hit by an over-height truck at 37 ft. from the south abutment and various types of damages were found around the impact point. These damages included a 6 in. out-of-plane displacement (Combined with distortion) of the bottom flange, formation of the web yield line, and the girder-to-diaphragm connection failure (Including bolt fracture and bearing shear failure of the crossbeam).

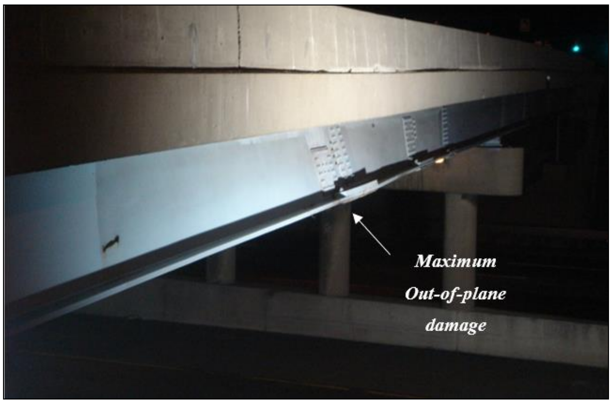

Fig 2: Damage on Allisonville Road Bridge

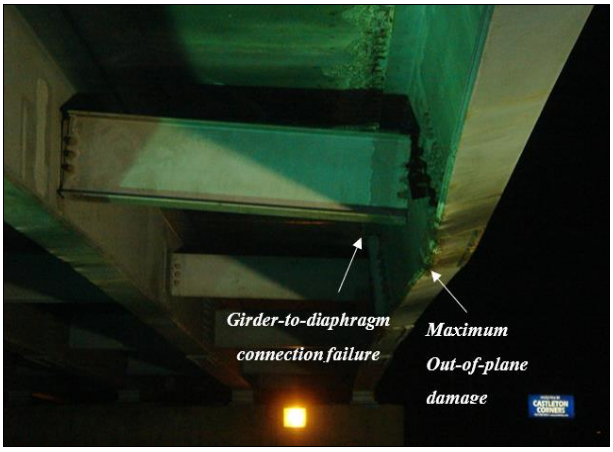

Fig 3: Close-up view of damaged region

The maximum out-of-plane damage occurred at the location with an additional cover plate, which was added in the previous damage-repair process. This is seen more clearly in Fig. 3. Bearing shear failure that occurred in the end connection of one diaphragm is also shown in Fig. 3. Yield lines also formed in the girder web close to the concrete slab following the girder direction.

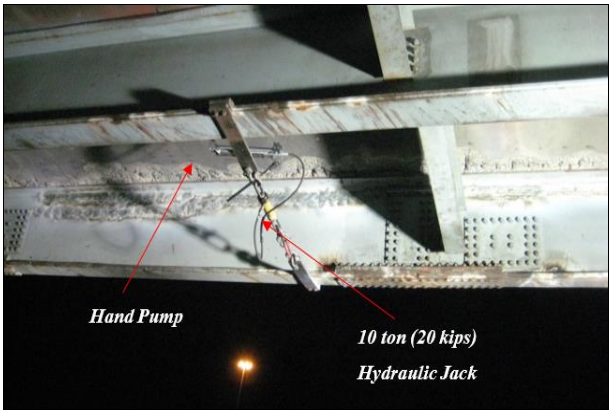

Fig 4: Hydraulic jack system for restraining force

Fig. 4 shows a hydraulic jack system installed by heat straightening repair technicians. They used a 10-ton (20 kips) jack with a hydraulic hand pump to provide a restraining force prior to heating cycles. However, no pressure gages were attached to the system. They just assumed that the applied restraining force with the no-gauged hand pump was close to 10 kips.

An oxygen-propylene torch was used for the heating process. Initially, line heats were applied on the web of the girder close to the concrete slab. Fig. 5 shows the line heat process being applied by a technician. After the line heat, Vee heats were applied on several damaged points of the beam as shown in Fig. 6. As seen in Fig. 6, half-depth and full-depth Vee heats were properly applied following the deformed shape of the bottom flange. The Vee angle was computed to be approximately 55º.

Fig 5: Line heat on the web of the girder

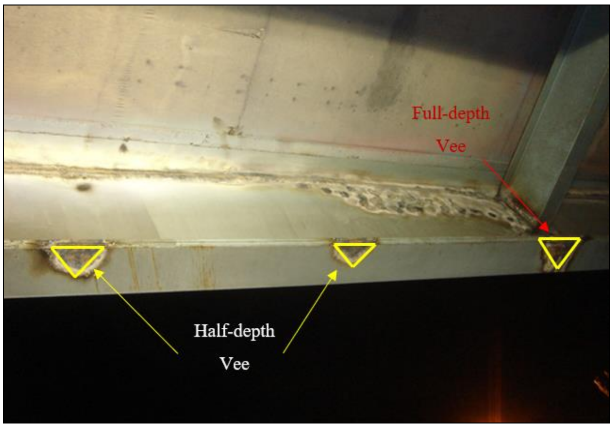

Fig 6: Vee heat locations of the bottom flange

Three technicians performed the heating process using the oxygen-propylene torches. During the heating, the technicians did not use any temperature monitoring equipment like temperature indicating crayons or infrared thermometers. Technicians totally relied on their experience to reach their target temperature of 1200 ºF.

The heating temperature was measured by the researchers using an infrared thermometer gun. In most of the heating cycles, technicians reached 1300 ºF - 1530 ºF as their maximum heating temperatures. These temperatures are higher than 1200 ºF, which is the maximum heating temperature recommended by the FHWA heat straightening guidelines.

The FHWA recommendation (1998) allowed the steel to cool down to 250 ºF before relieving the restraining force applied on the heated steel. But in this heat straightening process, the cooling temperature was not measured by any temperature measurement device. Technicians assumed 20 minutes was enough time to cool the steel down below 250 ºF.

After nine heat straightening repair cycles, the damaged beam was almost straight with a 1/4 in. tolerance. The damaged diaphragm was replaced with a new one after the heat straightening process was finished.

Discussion

Based on the findings of this research, several serious violations were performed in the heat straightening repair site. More site visits are necessary to address recurring field application issues. These visits enable engineers to identify and document specific challenges that arise during the repair process, such as material distortions, improper heating techniques, or unanticipated structural behaviors. By increasing site visits, professionals can ensure better adherence to repair guidelines and improve the overall effectiveness and safety of the heat straightening process. Future studies could provide crucial data on how these variances affect the mechanical properties of steel, fatigue resistance, and the overall lifespan of repaired structures.

Conclusion

As mentioned in the previous section, there were several deviations from the FHWA recommendations for heat straightening repair at the actual site. These included the followings.

Unreliable restraining force

At the site, applied restraining forces were not measured. FHWA heat straightening guideline strongly emphasis that the restraining force must be kept below 50% of plastic moment force. This is done to manage the stress caused by the restraining force during heat straightening.

Adjusting restraining force during the heat application

Once the restraining force was applied, no additional force adjustment should be applied to prevent force-straightening. Even with no force measurement system, over-straightening forces could be easily achieved by field technicians to accelerate the repair process.

No temperature measurements-Overheating (Heating temperature over 1200 ºF)

To avoid the formation of martensite, which can cause brittle behavior of the repaired steel, the maximum heating temperature of mild carbon steel (e.g. A7, A36, A588 steel) must be limited to 1200 ºF (Below the phase transition temperature of mild carbon steel – 1340 ºF). At the site, the heating temperature was reached 1300 ºF - 1530 ºF as their maximum heating temperatures.

Inaccurate cooling time to cool down below 250 ºF (No temperature measurement)

Ambient air cooling is recommended as the safest cooling method for heated steel. Rapid cooling can be detrimental if the steel is overheated and may produce brittle “hot spots”. Rapid cooling by compressed air or water mist can be applied when steel surface temperature is lower than 600 ºF. However, field technicians repeatedly applied sequential repair cycles above 800 ºF of steel surface temperature.

References

1. Shanafelt GO, Horn WG. Guidelines for evaluation and repair of damaged steel bridge members. NCHRP Report No. 271. Washington, DC: Transportation Research Board, National Research Council; c1984.
2. Federal Highway Administration (FHWA). Heat straightening repairs of damaged steel bridges - A technical guide and manual of practice. Report No. FHWA-IF-99-004. Washington, D.C: FHWA; c1998.
3. Putherickal J. Effects of heat straightening structural steel. Final Report for MLR-91-3. Ames, Iowa: Iowa Department of Transportation; c1992.
4. Till RD. Effect of elevated temperature on fracture critical steel members. MDOT Research Report No. R-1344. Michigan Department of Transportation, Materials and Technology Division; c1996. p. 1-17.
5. Varma AH, Kowalkowski KJ. Effects of multiple damage-heat straightening repair on the fundamental properties of bridge steels. MDOT Report No. RC-1456. Lansing, MI: Michigan Department of Transportation, Construction and Technology Division; c2004. p. 418.
6. Kowalkowski KJ. Effects of multiple damage-heat straightening repair cycles on the structural properties and fracture toughness of steel beam bridges. Ph.D. dissertation. West Lafayette, IN: Purdue University, School of Civil Engineering; c2005.
7. Connor RJ, Kaufmann EJ, Urban MJ. Heat-straightening repair of damaged steel bridge girders: fatigue and fracture performance. NCHRP Report No. 604. Washington, D.C: Transportation Research Board, National Research Council; c2008.
8. Sohn YM. Effects of realistic heat straightening repair on the properties and serviceability of damaged steel beam bridges. Ph.D. dissertation. West Lafayette, IN: Purdue University, School of Civil Engineering; c2012.