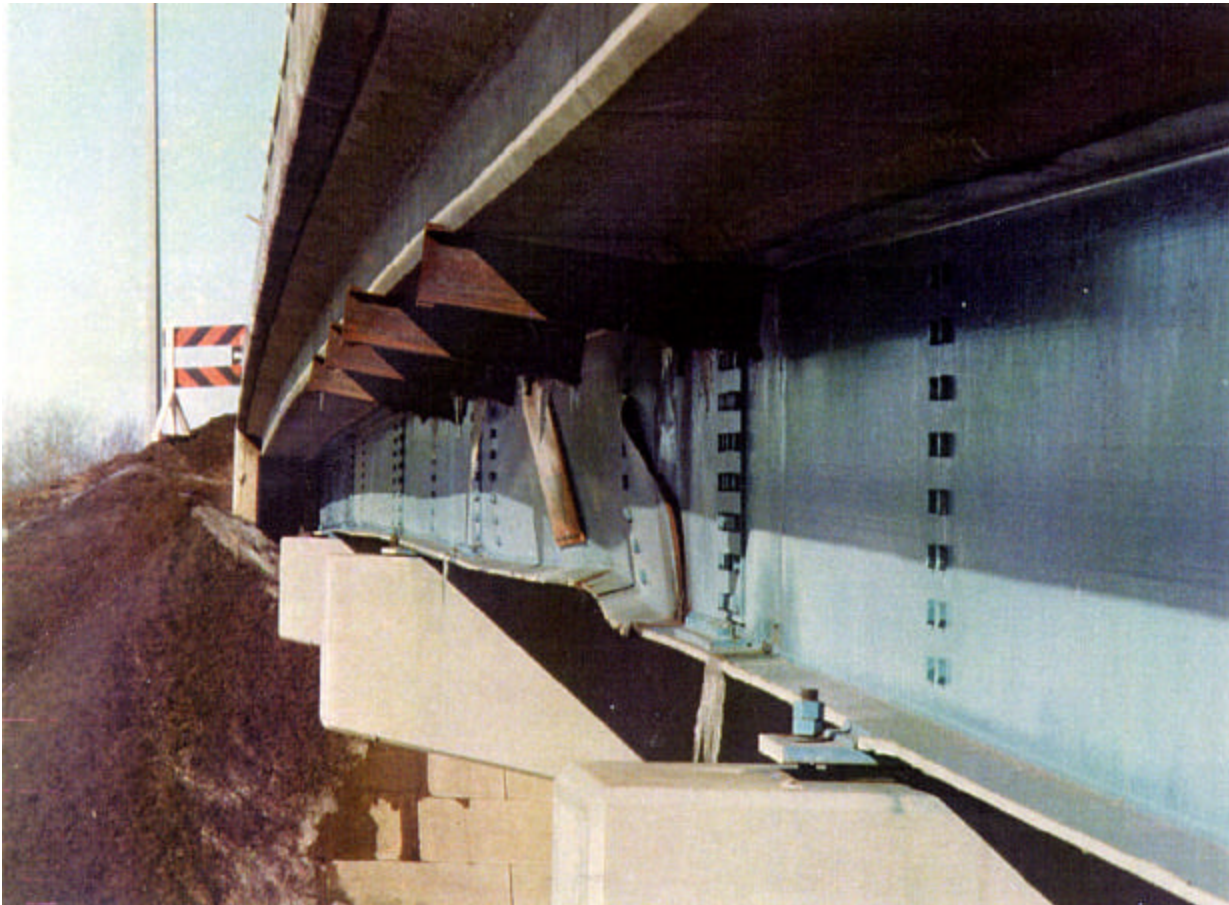


REPAIR OF BRIDGE STRUCTURAL STEEL ELEMENTS MANUAL



Version 1.0

Bridge Engineering Section
Technical Standards Branch
Alberta Transportation

June 2004

Preface to Version 1.0

Technical Standards Branch

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(Release 1.0)

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Printed: June 2004

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1.0 Introduction

Structural steel bridge elements may be damaged by overload, high and/or wide load impacts, vehicle collision, fire, or structural vandalism. If damage to a bridge is left unrepaired, the condition of the components may further deteriorate resulting in a reduction of the bridge's structural capacity. The reduction of this structural capacity could then compromise the safety of the motoring public.

While repair of damaged structural steel bridge elements may be unique and specific to the particular bridge element, standard techniques and procedures are provided for heat straightening, partial member replacement and repair of other defects. These techniques and procedures are carried out with minimal use of costly temporary shoring and supports and little disruption to the traveling public.

The Department has adopted this manual for the repair of structural steel bridge elements. The techniques, procedures and requirements outlined below are based on past Department practices and reference information from other publications such as the Federal Highway Administration's "Heat-Straightening Repairs of Damages Steel Bridges – A Technical Guide and Manual of Practice, Report No.FHWA-IF-99-004, October 1998." Extensive technical experience and judgement is required in the use and application of these techniques and procedures.

The information provided in this document is a supplement to the Federal Highways Heat Straightening Manual. Heat straightening on damaged structures shall be carried out in accordance with the FHWA manual with additions and exceptions described in this document.

2.0 Assessment and Classification of Damage

An initial assessment of the bridge shall be conducted by the consultant to identify all damaged members and to determine if the extent of damage warrants the implementation of load restrictions and signing. The damage shall be classified as follows:

- Rough Holes
- Bullet Indentation/Bullet Holes
- Misaligned Holes/Open Holes
- Nicks and Gouges
- Cracks
- Bending/Buckling/Sweep

2.1 Rough Holes

These are identified in truss members during ultrasonic testing and inspection. These may have occurred during dismantling or erection, or may indicate the start of a fatigue crack.

2.2 Bullet Indentation/Bullet Holes

These holes and indentations can be classified as nicks. They may have fissures around the perimeter and hence are stress raisers.

2.3 Misaligned Holes/Open Holes

Open and misaligned holes shall be assessed to establish if fasteners are required for a structural connection.

2.4 Nicks and Gouges

Nicks, gouges and notches create a discontinuity in the stress flow and are considered to be stress raisers. All nicks, gouges and notches shall be located and depths measured in order to determine the appropriate repair procedure.

2.5 Cracks

All cracks shall be identified and their size and location noted.

2.6 Bending/Buckling/Sweep

Trusses are comprised of both tension and compression members. Distortion in tension members is not as critical as distortion in compression members. The following are guidelines as to when heat straightening repairs should be undertaken:

2.6.1 Trusses

- Main Member (Compression) - Consider heat straightening if the distortion exceeds 20 mm.
- Main Member (Tension) and Secondary Members - Consider heat straightening if the distortion exceeds 50 mm.

2.6.2 Plate Girders

- Flange Bending: Heat straighten when local distortion, or when lateral bending exceeds 10 mm.
- Web Buckling: Heat straighten when the buckling exceeds 8 mm.

3.0 Alberta Transportation's Repair Practice for Damaged Steel Members

3.1 Rough Holes

Members with rough holes are flagged for future inspection. The inspection interval may be reduced from the regular inspection interval.

3.2 Bullet Indentation/Bullet Holes

Bullet indentation/bullet holes are drilled out to eliminate stress raisers and tear cracks when practical. The open holes are filled with fully torqued high strength A325 bolts for compression members, however bolts are not required for tension members.

3.3 Misaligned Holes/Open Holes

Misaligned holes/open connection holes shall be reamed and a high strength A325 bolt installed and torqued if they are a structural connection – if not a structural connection, no action is warranted. Many trusses have open holes where bridgerail and/or bracing modifications were made. These open holes may not require filling. Open holes shall be filled with high strength bolts when structural considerations warrant.

3.4 Nicks and Gouges

Nicks and gouges up to 5 mm deep shall be removed by grinding provided that the net cross-sectional area after removal of the notch is at least 98% of the original cross-sectional area. Notch removal shall be accomplished by fairing to the edge of the material with a slope not steeper than 1:10. Grinding marks shall be parallel to the direction of rolling. Notches deeper than 5 mm shall be repaired by welding.

3.5 Cracks

Truss members with identified cracks under a rivet head are generally monitored. Tension members with cracks extending beyond the rivet head are generally replaced and compression members with cracks extending beyond the rivet head will generally be repaired by field welding. Where replacement is not practical, an alternative suitable repair procedure can be developed. Cracks in rolled beams or plate girders are repaired using approved welding procedures developed for the particular case.

Prior to weld repair, a crack stop hole is drilled at the end of the crack to reduce stress concentration and to avoid further crack growth during welding.

Weld run-off tabs are required on edges of the element at the location of cracks and the crack is prepared for groove welding. Welding extends into the crack stop arrest hole - which is typically 10 mm to 15 mm in diameter. The weld is ground flush and the stop arrest hole is reamed and a 20 mm high strength bolt is installed. When the element to be repaired is comprised of built-up sections, a bronze or copper backing bar shall be used between the material elements during welding. Run-off bars shall be cut off and ground flush following acceptance of the weld.

3.6 Bending/Buckling/Sweep

Severely distorted truss members are generally replaced when they cannot be cost effectively repaired. Steel girder sections are repaired either by a heat straightening method or by partial replacement.

3.7 Repairs by Heat Straightening

The upper limit for heat straightening on steel with plastic strains is 100 times the yield strain ϵ_y . Deformations beyond $100\epsilon_y$ have been successfully repaired by the Department, however engineering judgement is to be applied as to the cost effectiveness of the repairs.

3.7.1 Temperature Range for Heat Straightening

The yield stress, tensile stress and modulus of elasticity for steel reduces significantly at elevated temperatures. However these property changes are reversible upon cooling provided the heating temperature does not exceed the lower critical temperature of 1150°F (620°C), and forced or artificial cooling is not applied when the steel is above 600°F (315°C). After heating, the steel shall be allowed to cool naturally in still air. The temperature of the heated steel must drop below 600°F (315°C) before any artificial cooling is allowed. Cooling can be accelerated by blowing compressed air or cooling can also be achieved by applying a water mist. To maximize movements during heat straightening, a heat cycle should not be repeated before the steel has cooled below 250°F (120°C). Greater movement may be produced by quick heating with a large size Rosebud heating tip. Single orifice heating tips may also be used, however a cutting torch tip should never be used.

Heat straightening shall not be permitted when the air temperature is below -5° C or when winds are excessive unless suitable heating and hoarding is provided.

3.7.2 Effects of Repetitive Cycles of Damage and Repair

Several tests were conducted by the FHWA to determine the effects of repetitive cycles of damage and repair on steel. Their findings showed a large increase in yield stress especially after two or more repair cycles. Tensile strength also increased, but at the apex of the vee (heat pattern), the increase was about half that of the yield stress. Furthermore at the apex region, ductility decreased significantly. The FHWA suggests that heat straightening be limited to two damage/repair cycles because the gap narrows between yield stress and normal tensile strength.

Although Alberta Transportation has performed repeated heat straightening on several damaged structures without any noticeable detrimental effect, it must be recognized that the risk of cracking may increase with multiple heat straightening. It is therefore recommended that multiple heat straightening should be carried out with caution and under the strict supervision of qualified personnel, provided heat straightening is a cost-effective solution for damage restoration.

Key points to consider during heat straightening are:

- Grind out all notches prior to heat straightening.
- Monitor, and ensure that the steel temperature during heating does not exceed 1150°F (620°C).
- Artificial cooling shall not be allowed until the steel has cooled below 600°F (315°C).

3.7.3 Jacking, Pulling and/or Restraining Force

The proper use of an external jacking force can expedite the heat straightening process. It is important to note that over jacking can cause buckling damage and cracks that may lead to brittle fracture. Jacking and/or pulling pressures must be gauged. No forces shall be applied unless they can be measured. Measuring devices shall be calibrated at least once every twelve months.

The Jacking Moment, M_j shall not exceed 50% of the Plastic Moment Capacity (M_p) minus the Residual Moment (M_r).

$$M_j(\text{Jacking Moment}) = 0.5(M_p - M_r)$$

If M_r is unknown, the jacking force shall be limited to 25% of the M_p for the first two heating cycles. For additional heating cycles, the limit of jacking force may be increased to 50% of the M_p .

Preferably, jacking forces are applied adjacent to the area of heat application, and in a direction tending to restore the member. However, it is recognized that there can be situations where it may be practical and effective to apply external force following heat application. Under no circumstances shall external forces be used alone. External force application has a significant effect on the member both in heating and cooling phases of heat straightening cycle.

3.7.4 Tolerances

The dimensions of the heat straightened members shall conform to the following criteria:

Member Type	Maximum Tolerance
Girder, Truss Members, Columns	8 mm over 6 m
Local Flange and Web Deviations	8 mm

3.8 Repair by Partial Replacement

Generally the severity of damage due to high load is in the vicinity of the lower half of the girder. When it is not cost effective to heat straighten the damaged girder in its entirety, the lower half is replaced with a new "T" section. The new section shall be terminated near the

dead load moment inflection point. The “T” section shall not be terminated at a point where the total dead load plus live load moment exceeds 50% of the moment capacity of the original section at that point. Dead load is transferred through hanger support rods to a temporary support girder placed directly above the damaged girder. The strong back beam support on the deck shall bear on or within 0.5 m of the pier or abutment, unless temporary support is added underneath the damaged girder section. A deck support girder, or strong back girder may be required for transferring and carrying dead load when required heat straightening is extensive – even though a section is not being replaced.

The repair equipment and procedure for partial “T” replacement of the lower half of the girder is listed below:

3.8.1 Equipment

- Strong back beam c/w web stiffeners at the bearings and hanger rod locations shall be sized to carry the load of the damaged girder.
- Miscellaneous sizes of shims.
- Hanger rods c/w nuts shall be a minimum of 25 mm ϕ with ultimate strength of 340 kN, unless a larger size is required. These rods shall be placed in pairs at maximum 2.5 m (spacing).
- Temporary post c/w bottom pad to transfer the load to the ground (when required).
- Cap/block for the post to accommodate a jack (when required).
- Hydraulic jack with a capacity to support the deck dead load (when required).
- Back to back channel bracket assemblies - C150x16 minimum, to transfer loads from the damaged girder through the hanger rods to the support girder.
- Heat straightening equipment.

3.8.2 Procedure

- Determine if the structure has sagged due to damage. It is imperative that the damaged structure is restored to the original configuration.
- Place strong back beam directly over the damaged girder. One of the bearings shall be over the pier whereas the other bearing shall be within 0.5 m of the permanent support or a temporary post is added underneath the damaged girder.
- Core 50 mm ϕ holes in the deck for hanger rods – maximum spacing at 2.5 m. Core cable sling holes in the deck - when lowering of the damaged section and lifting of the replacement section is intended to be performed from the deck. Avoid coring through deck rebar.
- Strong back beam shall have web stiffeners at hanger rod and bearing locations.
- Install back to back channel brackets to transfer loads from the damaged girder through the hanger rods.
- Install temporary post beyond the cut out section, centered below the bottom flange of the damaged girder.
- The top of the post shall be at or near an existing girder stiffener and the bottom shall be supported on a pad to transfer the load to the ground.
- The jack over the temporary post shall be snugged tight and secured in place.

- The final cut shall be made using automatic cutting equipment supported on tracks set to match the required cut.
- Straighten the existing remaining section.
- Perform the final jacking to ensure the correct camber is achieved after the “T” section is removed.
- Erect the replacement section and provide temporary support until holes can be field drilled through holes in the new splice plates.
- Install the new “T” section in place and tension the bolts with “Turn-of-Nut” method.
- Pressure inject the epoxy resin to fill and bond all cracks between the top flange and concrete that are 0.3 mm or greater in width. The support girder shall remain installed until epoxy work is complete.
- Patch core holes with approved patching compound.

3.8.3 Replacement of Previous “T” Section

- Install a strongback support beam following procedures prescribed in Section 3.8.
- Remove the old damaged “T” section and retain the splice plates if deemed reusable.
- Straighten the existing remaining section.
- Field drill new “T” section to match existing splice plates while damaged girder is maintained in a no load condition.
- If gap between the top flange and the deck exceeds 0.3 mm, pressure inject epoxy resin to fill any void.
- Patch core holes with an approved material.

3.9 Requirements for Field Welding

All field welding shall be witnessed and supervised by a qualified welding inspector. The following requirements for field welding shall be met:

- Only welders approved by the Canadian Welding Bureau for the process and position shall be permitted to perform weldments. Their qualification shall be current and available for examination by the Consultant.
- Welding procedures approved by the Canadian Welding Bureau shall be submitted to the Department for review prior to welding.
- Low hydrogen filler, fluxes and low hydrogen welding practices shall be used throughout. The low hydrogen covering and flux shall be protected and stored as specified by AWS Standard D1.5. Flux cored welding or use of cored filler wires in the submerged arc process or shielding gas processes, are not considered as conforming to low hydrogen practice. These methods will not be permitted.
- When the air temperature is below 10°C, all material to be welded shall be preheated to 100°C (for known weldable steel) for a distance of 80 mm beyond and on the opposite side the weld and shall be sheltered from the wind.
- When the air temperature is below 0°C, welding will not be permitted unless suitable hoarding and heating, approved by the Consultant, is provided.

- For older steel for which the chemical analysis is unknown, the preheat requirement shall be determined by carbon equivalent, however for material thickness up to 16 mm, preheat of 200°C is generally sufficient.
- All butt welds shall have NDT either by radiographic or ultrasonic inspection.

4.0 Qualifications and Requirements

Due to the specialized nature of these repair techniques and procedures, they must be carried out and inspected by individuals with the appropriate experience and knowledge.

4.1 Qualification of Contractors

The Contractor shall have personnel with experience in conducting heat straightening repairs for damaged steel structures and the work shall be performed by qualified personnel having completed a minimum of five projects. The Contractor shall submit the names and related experience of the personnel performing the heat straightening. Approved personnel shall not be replaced without the written consent of the Consultant.

4.2 Qualification of Consultant Inspectors

- The heat straightening inspector shall be a certified Level III welding inspector as per CSA 178.2 accredited with W47.1/W59 or must have extensive experience in the areas of heat straightening, bridge fabrication and field welding.
- The Bridge Construction Inspector shall be a Certified Civil Engineering Technologist, Professional Engineer or must have extensive experience in the supervision and inspection of bridge construction and bridge rehabilitation work performed by contract.

4.3 Requirements for Inspection by Consultant

- Coordinate and conduct pre-job meeting and other milestone meetings.
- Carry out inspections to ensure compliance to Department standards and specifications.
- Review and approve all traffic accommodation proposals and ensure safety requirements are maintained.
- Conduct survey of deck to establish profiles of damaged and undamaged girder lines.
- Monitor heat application, surface temperature of steel and jacking pressures throughout the course of the heat straightening process.
- Verify jack calibration certificates.
- Verify welder's CWB qualifications.
- Ensure field welding is carried out in accordance with approved procedures.
- Coordinate NDT as required.
- Inspect both strong back beam and support tower and check their placement.

- Ensure holes are to be cored as per the approved layout and properly patched.
- Monitor the removal of the damaged girder section, and the erection of the new girder section
- Monitor epoxy crack injection between the top flange and the deck.
- Inspect material preparation and coating application.
- Check final clean up.

5.0 Contact

Questions or further information on this manual may be directed to Abdul Waheed, P. Eng., Bridge Fabrication Standards Specialist, Alberta Transportation, (780) 415-1019 or Ed Kowal, C.E.T., Bridge Maintenance Technologist, Alberta Transportation, (780) 415-8321.



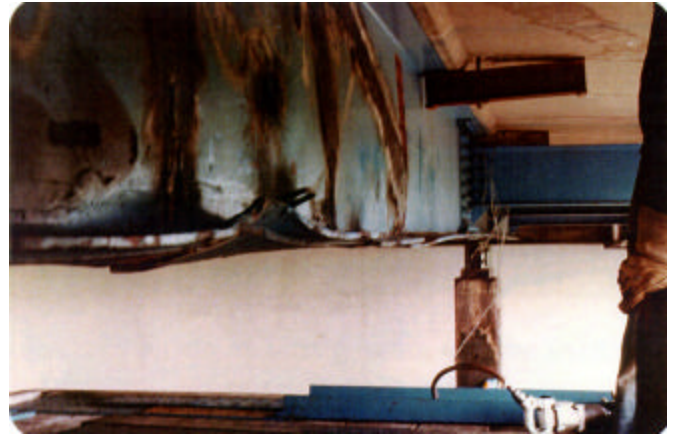
Severe structural damage events – such as with over-height impacts may warrant temporary deck support to keep the structure, or a lane in service...



Temporary strongback deck support girders installed over damaged bridge girders – load transfer rods are installed at maximum 2.5 m spacing.



Intermediate temporary support blocking is required when the strongback deck support girders do not span pier substructure elements.



Severe distortion may require some heat straightening before cutting the girder section for a tee girder replacement.



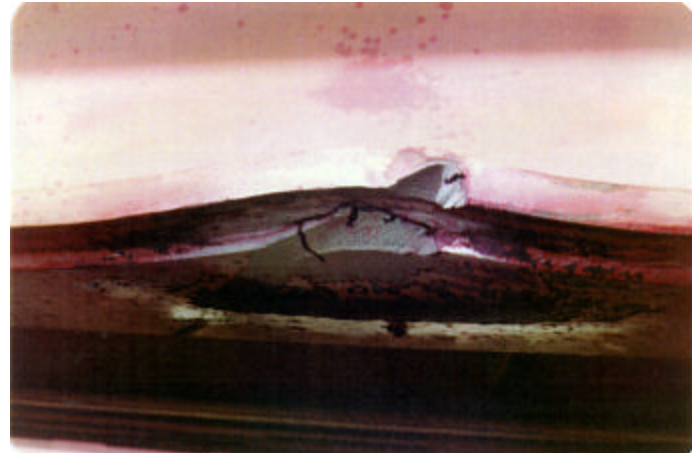
Severely damaged girder can be split and replaced with a tee girder section. A support track is installed, and a radiograph is used to make the section cut.



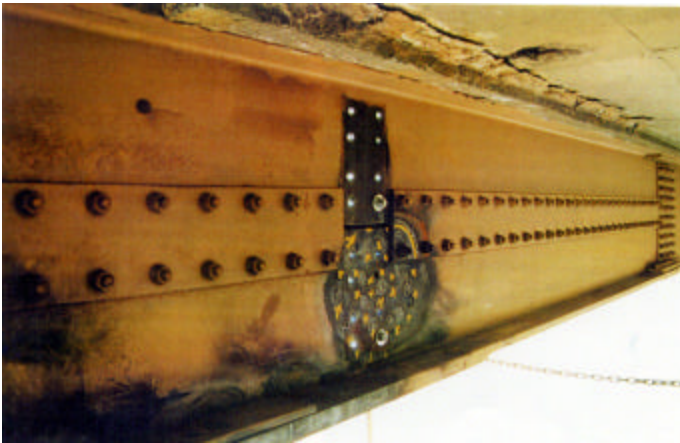
Girder cut-out operations can be performed in sections - allowing one lane of traffic to be maintained, and flowing at this stage of repair.



A hydraulic c-clamp used with heat straightening can be efficient in correcting localized flange distortions.



Notches in the flange and coverplate – with cracks in the flange, coverplate and in the cover plate weld. The flange can be straightened and cracks repaired.



The top flange of a girder can become de-bonded or cracked at the deck interface from an impact event – the continuity and integrity need to be restored...



...loose concrete is removed, the haunch patched and the crack is epoxy resin injected. Installing injection ports.



Drilling crack arrest holes in the flange and web can be effective in stopping the propagation of cracks – the far side of the flange is cracked across in the above photo.



Heat straightening elements on a batterpost. Note the tarp being used to shelter from wind and cold.



Applying water mist, after material has cooled below 315°C (600°F) allows more efficient time for heating cycles.



On compression members, cracks can be effectively repaired by welding. A bronze backing plate is used to separate built-up sections.



A truss tie may be required if repairs are needed for severely damaged tension members.



Jacking frames may be required to accomplish heat straightening effectively and efficiently in some circumstances.



Effective heat straightening procedures may require several combinations of external force application with various heating patterns and techniques.



Jacking pumps require calibration and gages to monitor clamping and jacking forces that are applied. Tension forces on pullers and come-alongs can be measured with calibrated load cell devices.

