STATE OF OHIO
DEPARTMENT OF TRANSPORTATION

SUPPLEMENTAL SPECIFICATION 849

HEAT STRAIGHTENING OF DAMAGED STRUCTURAL STEEL

January 19, 2007

849.01 Description. This work consists of repair and heat straightening of damaged portions of existing steel members. Heat straightening work is to be accomplished in accordance with Item 513 and as noted herein.

General requirements and associated references:

Characteristic	Specification Reference
Site Evaluation & Work Plan	Federal Highway Administration, FHWA Publication, FHWA-HIF-00-008 & FHWA-IF-99-004
Surface Preparation	Society for Protective Coatings, SSPC- SP15 Commercial Grade Power Tool Cleaning or equal
Jacking or Bracing Existing Structure	C&MS 501.05.B.5, Submittal of Construction Plans and Calculations

Characteristic	Specification Reference
Heat Straightening	C&MS 513.11; AASHTO Standard Specifications for Highway Bridges, Division II, Construction, 11.4.12.2; AASHTO LRFD Bridge Construction Specifications, 2nd Edition, 2004, Section 11.4.12.2; and FHWA, Publication, FHWA-IF-99-004; Final Report No. RC-1456 Sponsored by Michigan Department of Transportation, Heat Straightening Repairs of Damaged Steel, Effects Of Multiple Damage-Heat Straightening Repairs On The Structural Properties Of Bridge Steels.
Repairing Damaged Members	ASTM A6; AWS D1.5-2002
Weld Repairs	C&MS 513.21
Nondestructive Testing (Magnetic Particle)	C&MS 513.25.B(4) and (5)
Nondestructive Testing (Radiographic)	C&MS 513.25.A(1) though (6)

849.02 Materials. Furnish material according to Item 711.01. The minimum yield strength of the furnished material shall be equal to or exceed that of the existing material. Submit certified test data, Item 501.06, to the Engineer.

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849.03 Superintendent. In addition to the requirements of Item 105.06 the Superintendent must document experience in conducting heat straightening repairs on highway bridges. Heat straightening experience must satisfy at least one of the following three experience definitions: (1) The Superintendent must have successfully completed at least three heat straightening projects in the preceding five years; (2) The Superintendent must be an Ohio Registered Engineer and must have successfully completed at least one heat straightening project in the preceding five years; or (3) The Superintendent must be an AWS, CWI Inspector in accordance with the provisions of AWS QC-1, Standard for Qualification and Certification of Welding Inspectors and must have successfully completed at least one heat straightening project in the preceding five years.

849.04 Quality Control. Quality control consists of controlling the quality of work in each phase as established by the Quality Control Points (QCPs). Control work quality by inspection, tests, measurements and cooperation with the Engineer.

Quality Control Points (QCP). QCPs are points in time when one phase of the work has been completed and approved by the Superintendent, and is ready for inspection by the Engineer before the next phase of the work can commence. At a QCP, the Superintendent shall provide quality control documents bearing his signature. The Contractor shall provide access to inspect all affected surfaces. If inspection identifies a deficiency, correct the deficiency according to the Contract Documents before starting the next phase of work. Discovery of defective work, material, or the failure of the final product after a Quality Control Point is past, before final acceptance, shall not, in any way, prevent the Department from rejecting the final product or obligate the Department to final acceptance.

	Quality Control Points	Purpose
1	Qualification Verification	Verification of superintendent, sample work plans, welder qualifications, welding procedures, non destructive testing technician and equipment.
2.	Existing Paint Removal	Remove exiting paint to allow visual observation of the heating color, prevent lead exposure or hazardous fumes resulting from burning paint.
3.	Grinding Edges	Round corners to prevent cracking during straightening and improve paint repair.
4	Containment/Waste Disposal	Contain, collect, & dispose of removed paint, abrasives, stripper or power tool cleaning debris
5	Damage Inspection	Visual and non-destructive testing inspection and documentation of all damages to be repaired.
6	Straightening Work Plan	Documentation of Contractor's means and methods including validation of: material replacement or welding repairs to be made, jacking or bracing plans; material certification; surface preparation methods; calculation and control of jacking and pulling forces; heating methods and shapes; heating equipment; and temperature indicating devices.
7.	Repairing Damaged Members	Repair all damaged material to prevent cracking or further damage during straightening.
8.	Straightening Damaged Members	Heat straighten all damaged material using controlled: temperature; and jacking, pulling or restraining forces to prevent hairline fracture cracks, local buckling and protect material properties.
9.	Finished Tolerances, Conditions and Profiles	Check and documentation of dimensional tolerances.
10.	Final Inspection	Final visual and non destructive tests. Collate and check all documentation to assure all requirements have been completed.

849.05 Testing Equipment. For the project duration, provide the Engineer with the test equipment listed below for each work site with ongoing heat straightening work. Maintain the equipment in good working order:

1. One digital camera with at least: 5.0 mega pixel resolution, auto focus, 3 x zoom lens, 512M memory and a built in flash.
2. Provide a handheld portable, Infrared, non contact thermometer capable of reading temperatures from -25 to 1600°F (-30 to 900°C) with temperature sensitivity of ± 1.8°F (1°C)
3. Magnetic Particle Inspection Equipment according to Item 513.25.B Yoke Method with testing particles on the job at all times.
4. Digital light meter capable of measuring illumination from 10 to 200 foot candles with an accuracy of ±5%.

849.06 Pollution Control. Comply with pollution control laws, rules, or regulations of Federal, State, or local agencies and requirements of this specification.

849.07 Safety Requirements and Precautions. Comply with Item 514 for the Safety Requirements and Precautions.

849.08 Inspection Access & Illumination. Comply with Item 514 for the Inspection Access requirements with the following additions.

Illuminate work area with artificial lighting as necessary to supplement natural light and achieve a general work area lighting equal to 20 foot candles throughout the entire work area. Provide additional artificial lighting equal to 100 foot candles measured at work surfaces during times of inspection.

Place and aim artificial light so that lights do not cause glare to the drivers on the roadway. Adjust the positioning and aim of artificial light to the satisfaction of the Engineer.

849.09 Quality Control Point Photographic Verification and Documentation. Take sufficient number of photographs to document the condition of the work at Quality Control Points 2, through 10.

849. 10. Qualification Verification (QCP # 1)
Provide a record of the following: Superintendent's qualifications and work history; sample heat straightening work plans; welder qualifications; welding procedures; Non-destructive testing technician's certification; and a list of equipment to be used and inventoried on each work site.

849.11 Surface Preparation (QCP # 2, 3 and 4)

A. Existing Paint Removal (QCP #2). Remove exiting paint according to SSPC-SP 15 Commercial Grade Power Tool Cleaning or equal. Remove all existing paint except that tight rust or mill scale may remain. Humidity and temperature restrictions do not apply. Remove paint as necessary to perform inspections and straightening work and to the Engineer's satisfaction.

B. Grinding Flange Edges (QCP #3). Round all exposed corners of main members as necessary to achieve a 1/16 inch radius [1.6 mm] or equivalent flat surface at a 45 degree angle. Grind edges at all locations of planned work to prevent edge cracking during the straightening work and to the Engineer's satisfaction.
C. Containment/Waste Disposal (QCP #4). Comply with Item 514 for the Containment/Waste Disposal requirements.

849.12 Damage Inspection (QCP # 5). Visually inspect all areas of damage, suspected damage, yield lines and zones of plastic bending. Also inspect all secondary members and connections between main and secondary members that potentially distributed forces causing damage. Perform this work with inspected surfaces being within approximately 24 inches (610 mm) from the inspector. Use access equipment, illumination, and non-destructive testing as necessary to identify, measure and document the location and

details of: buckling; crimps; misalignment; twists; tears; burrs; damaged edges; punched holes; pull out of secondary members; cracks or other physical distress. Remove existing paint and test using magnetic particle testing, Yoke Method, at all areas of detected and suspected hairline cracking according to Item 513.25.B (4) and (5).

Provide field sketches, non-destructive testing, photographs and inspection access to the satisfaction of the Engineer.

849.13 Straightening Work Plan (QCP # 6) Use field data from the damage inspection to develop a written straightening work plan and have the Superintendent sign and date the straightening work plan. Submit the work plan prior to performing the work.

The written straightening work plan shall include the following details.

A. Framing plan showing areas to be repaired, include results from the Damage Inspection (QCP # 5)
B. Sequence of work
C. Shape, size and temperature of heating patterns
D. Location and limits of jacking, pulling or restraining forces
E. Calculations of member stresses from jacking, pulling or restraining force
F. Location and details of grinding repairs
G. Location and details of drilled or coped holes
H. Location and details of weld repairs
I. Location and details of material replacements
J. Location and limits of paint removal and repair
K. Location, design and details of temporary supports for structural support and stability

849.14 Repairing Damaged Members (QCP # 7). Repair all damaged material including: damaged edges; tears; burrs; sharp edges; punched holes; pull out of secondary members; or cracks by grinding, welding or material replacement as limited by the following table, specification and to the Engineer's satisfaction.

Repair Method	**Limits of Material Damage**
Grinding[1]	Grind[1] out damaged material when the remaining calculated net cross sectional area of the individual plate, flange or web remaining after grinding is greater than 98% of the calculated cross sectional area based upon existing member dimensions. Example; Grind[1] 3/16 inch (5 mm) deep notches in, 1 inch (25mm) X 12 inch (305mm) flange plate. (11.8125 in^2 / 12 in^2) x 100 = 98.44%
Welding [2, 3]	Weld [2] damaged material when the remaining calculated net cross sectional area of the individual plate, flange or web remaining after grinding is less than 98% of the calculated cross sectional area based upon existing member dimensions. Example; Weld [2] 1/4 inch (5 mm) deep notches in, 1 inch (25mm) X 12 inch (305mm) flange plate. (11.75 in^2 / 12 in^2) x 100 = 97.92 % Weld[3] - In lieu of extensive weld repairs and straightening, the Contractor may replace localized portions of main members. Provide a replaced flange or web equal to 100% of the calculated cross sectional area based upon existing member dimensions

Note 1. a) Grind out the damage b) taper to the original surface using a 1:10 slope c) provide a surface finish according to ANSI B46.1 of 250 mil (6.4 μm).

Note 2. a) Prepare the damaged material for welding; b) Perform complete penetration welds according to C&MS 513 using approved electrodes, procedures and welders; c)Grind the completed welds smooth and flush with the adjacent surfaces to provide a surface finish according to ANSI B46.1 of 250 mil (6.4 μm); d) 100% Radiographic and 100% Magnetic-particle testing according to C&MS 513.

Note 3. The Contractor may replace a localized portion of a main member. a) Before cutting any main member, provide bracing and support of the loads in the damaged member. b) Remove localized portions of the structure by cutting and replacing these portions with new steel to match the existing shape and thickness. c) Connect the new steel to the existing structural member using complete penetration welds[2] . d) Grinding the welds smooth and flush with the adjacent surfaces and provide a surface finish according to ANSI B46.1 of 250 mil (6.4 μm). e) Test the welds using 100% Radiographic tests. f) Finish reentrant corners with 1 inch (25mm) radius. g) Provide 2 inch (50mm) diameter (minimum) cope holes in the web, at all weld intersections and at the web to flange intersection.

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Replace all damaged secondary members: cross frames and other attachments to the Engineer's satisfaction. Before cutting any cross frame or attachment, install bracing and supports necessary for structural stability of the main structural members. Condition the main members by grinding or welding at the existing secondary member connection as described in the table listed above. Connect new secondary members by welding or bolting according to the existing detail. Connect cross frames and attachments in the sequence defined in the straightening work plan.
Perform all welding using qualified welders, electrodes and procedures in accordance with Item 513. Perform 100% Radiographic testing for all main member repairs according to Item 513, except submit copies of reports to the Engineer for acceptance. Perform 100% Magnetic Particle testing for all secondary member fillet welds to main members and flange to web fillet welds according to Item 513. Provide material according to this specification.

849.15 Straightening Damaged Members (QCP # 8). Perform straightening using methods which will not permanently damage the metal's material properties. Sharp kinks and bends may be cause for rejection of the work. Heat members using: controlled jacking, pulling or restraining forces; specified heating patterns; and controlled temperatures that result in controlled shrinkage to straighten the member. Do not heat members then use: large jacks or pullers which mechanically hot work the material. Mechanical hot work permanently damages the metal's material properties. Prior to straightening a damaged compression member, install adequate bracing to support loads and prevent buckling.

A. Restraints or preloads. Apply jacking, pulling or restraining forces to the damaged member in the direction that tends to straighten the member. Position jacks, pullers, or restraining forces such that heat straightening shrinkage will relieve the force during the cooling cycle. Do not allow jacks, pullers or restraining forces to subject any part of the structure to unit stresses that exceed 50 percent of the material's nominal yield (F_y) at ambient temperature. Provide pressure gages or load cells to control jacks, pullers or restraining forces. Secure jacks, pullers or retraining forces so they do not dislodge

during cooling. Apply jacks, pullers or restraining forces prior to heating. Do not apply additional jacking, pulling or restraining forces after beginning the application of heat. Do not apply the next cycle of jacking, pulling or restraining forces until the steel has cooled below 200 ºF (93 ºC).

B. Application of Heat. Heat opposite faces of a plate or rolled shape concurrently when the material thickness (t in the figure below) equals or exceeds 1 1/4 inch (30mm). When heating thick plates, it may be necessary to interrupt heating for periods of less than one minute to allow the heat to soak into the flange and avoid surface over-heating. Perform heating using single and multi-orifice (rosebud) heating torches sized according to the following table. Manipulate the torches to avoid overheating. Heat using air-propane or air-natural gas unless other methods are accepted by the Engineer.

Limits on Torch Tip Size		
Steel Thickness	**Orifice type**	**Orifice Size**
less than 1/4inch(6mm)	Single	3
3/8 inches (9.5mm)	Single	4
1/2 inch (13mm)	Single	5
5/8 inch (16mm)	Single	7
3/4 inch(19mm)	Single	8
1 inch (25mm)	Single or Rosebud	8 single, 3 rosebud
1 1/4 inch (32mm)	Single or Rosebud: on both sides*	8 single, 3 rosebud
2 inch (51mm)	Single or Rosebud: on both sides*	8 single, 4 rosebud
3 inch (76mm) or greater	Rosebud: on both* sides	5

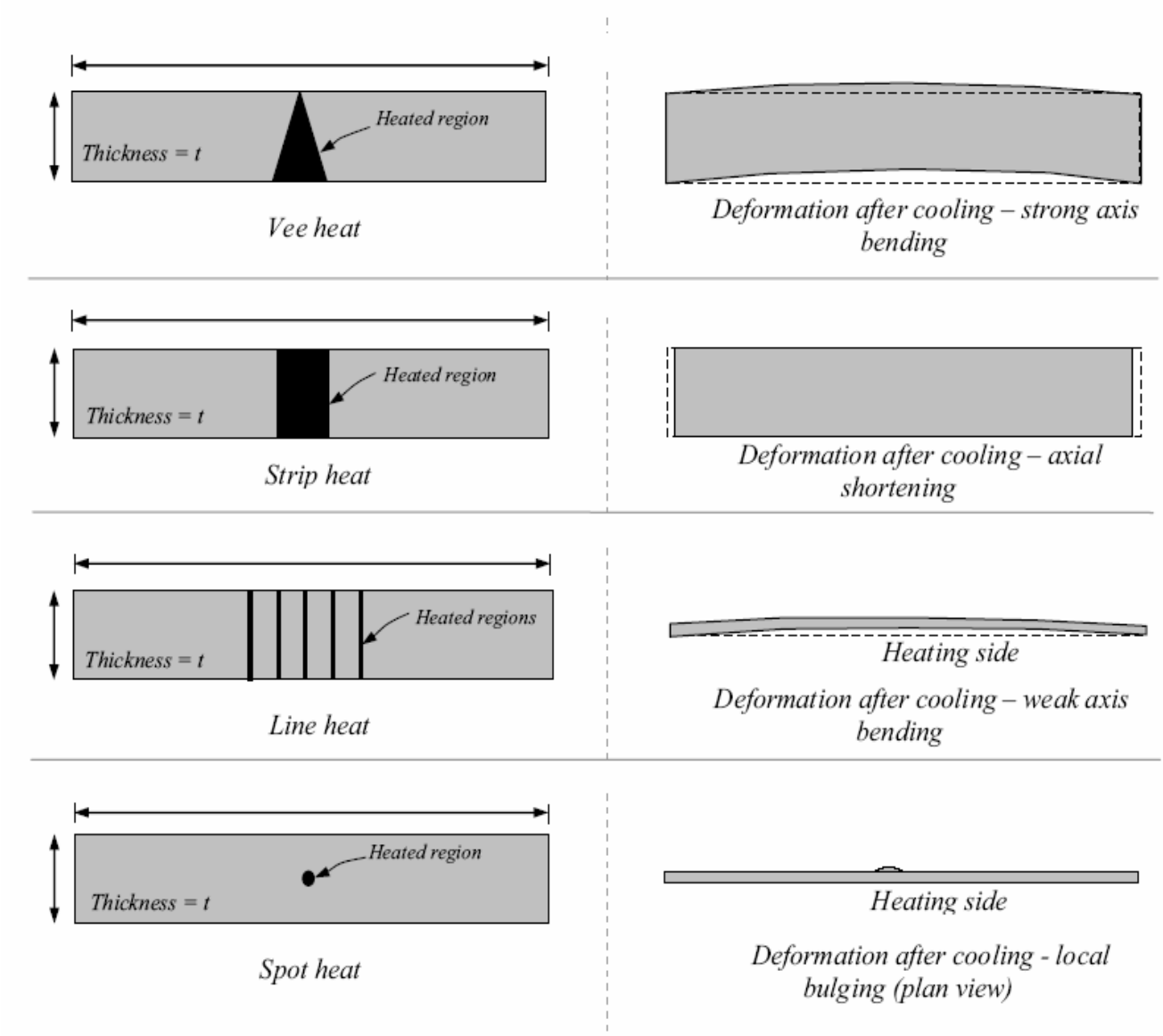
* - Heat applied concurrently to both sides

C. Shape of Heating Patterns. Perform heating using four basic heating patterns: Strip, Line, Spot or "V" as specified below and illustrated in the figure. Prior to applying heat, mark the steel with chalk or soap stone defining: an assigned unique heat number; location; shape and limits of the heating patterns.

1. Strip, Line and Spot heats shall be of sufficient width, length and position to create the required straightening. The maximum temperature shall be prescribed below. If chording or twisting occurs in the member, correct the situation to the Engineers satisfaction.

2. "V" heats consists of triangular areas spaced at regular intervals, not less than a flange width (B_f) apart as measured along the longitudinal dimension of the member. Limit the "V" shape as follows: the distance between the "V" apex and the opposite leg of the "V" shape may equal the width of the plate or shape; do not exceed a 30 degree angle between the adjacent sides of the "V"; and do not exceed a dimension of 10 in. (254mm) for the side opposite the "V" apex as measured long the longitudinal plate edge. Apply heat starting at the "V" apex; manipulate the torch in a serpentine

pattern, progressing toward the side opposite the “V” apex. Once heating proceeds towards the side opposite the “V” apex, do not return heating torches to the “V” apex side of the V heating pattern. The maximum temperature shall be prescribed below. If chording or twisting occurs in the member, correct the situation to the Engineers satisfaction.



Four basic heating patterns

D. Temperature Control. Control heat so the internal temperature of the steel does not exceed the table values below. The internal temperature of the steel is the surface temperature approximately five seconds after passage of the torch.

Control the application of heating so it is confined inside the marked limits of the four basic heating patterns. Bring the steel within the pattern to the desired temperature as rapidly as possible without overheating. Control the application of heat by checking the internal temperature of the steel by frequent use of appropriate temperature range

indicating crayons or an infrared, non contact thermometer. The Department will require investigative testing for damage to the metal's material properties for any procedure which causes the internal temperature of the steel to exceed the specified maximum heating temperature.
Do not accelerate cooling with water, water mist or other cooling accelerants. After the steel surface temperature is less than 600 ºF (315 ºC) cooling may be accelerated with dry compressed air. After completing a planned set of heat patterns along the member, do not apply additional heat until the entire member has cooled below 200 ºF (93 ºC) and the straightening movement has been verified.

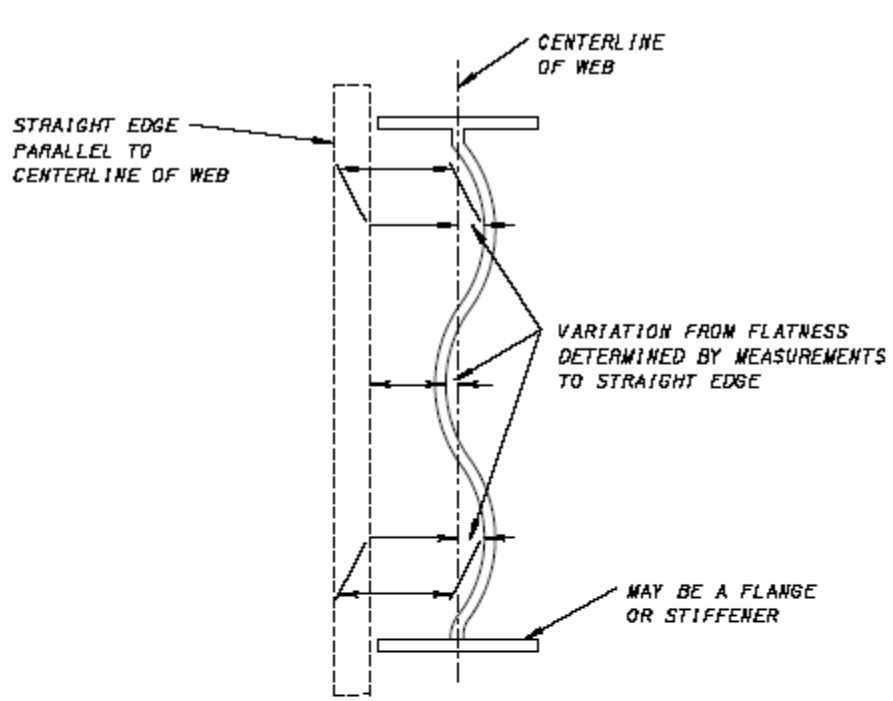
Maximum Heating Temperatures	
ASTM Steel Type and Grade	**Maximum Heating Temperatures**
Mild carbon steel (A7; A373;A36 grade 36; A572 Grade 50; A588 Grade 50W; A709 Grade: 36, 50 and 50W)	1200^{o}F (649 ºC)
Quenched and tempered steel and Thermo mechanical Controlled Process. (A514; A709 Gr. 100/100W; A709: HPS50W and HPS70W)	1100^{o}F (593 ºC)
Quenched and tempered steel A709 Gr. 70W and HPS100W	1050^{o}F (566 ºC)

849.16 Finish Tolerances (QCP # 9). Do not measure dimensional tolerances for final acceptance until all heating and welding operations are completed and the member has cooled to160 ºF (70 ºC) or less. Perform straightening work to meet the table requirements listed below. Check tolerances before any cross frames or other lateral restraint devices are attached. Do not force members into position and then weld in the cross frames to hold members within heat straightened tolerances.

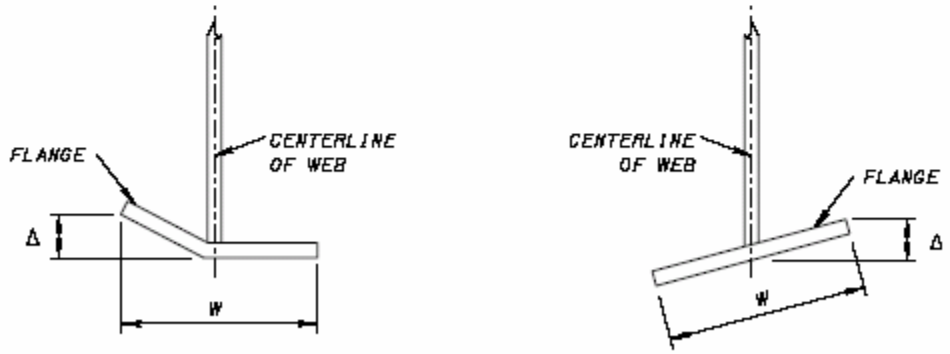
Tolerances for Heat Straightening [4, 5]	
Member Type	**Allowable Tolerance**
Beam, Truss members, or Columns; straightness x and y axis (Sweep and Camber) measured offset from a string line stretched along the longitudinal axis, member center line, true to the original as built condition.	Overall alignment:1/8 inch (3 mm) times the overall member length divided by 10 feet(3m) but not more than 1/2 inch (13 mm), note[1] At point of impact: 1/4 inch (3 mm) times the overall heat straightened length divided by 10 feet but not more than 3/4 inch(22 mm), note[1]

Tolerances for Heat Straightening [4, 5]	
Member Type	**Allowable Tolerance**
Beam, Truss members, or Columns; overall and point of impact straightness (Twist or plumb) measured offset from a string line stretched along the longitudinal axis, center line, true to the original as built condition.	Overall: Permissible difference in the measured offsets (plumb) from a longitudinal center line, at the top and bottom flanges at any point on centerline of member, when measured from a common longitudinal centerline, shall not exceed 1/4 inch (6 mm), note[1] At point of impact: Permissible difference in the measured offsets (plumb) from a longitudinal center line, at the top and bottom flanges at any point on centerline of member, when measured from a common centerline, shall not exceed 3/8 inch (10 mm), note[1]
Flatness of web, measured by off set from a straight edge	D/150 but not greater than 1/4 inch (6mm) , Note [2]
Combined warp or tilt of the flange at any cross section.	W/100 or 1/4 inch (6 mm) which ever is greater except at bearing points not more than 1/16 inch (1.6 mm), Note [3]
Flange Waviness	Waviness, the deviation of the top or bottom surface of a flange from a straight line or plan curvature, shall not exceed 1/4 inch (6 mm) when the number of waves in a 10-foot (3 m) length is four or less, or 1/8 inch (3 mm) when more than four, but sharp kinks or bends shall be cause for rejection.
Surface Finish and Cross Sectional Area	Provide existing members with 98% of the calculated cross sectional area based upon existing member dimensions. Taper to the original surface using a 1:10 slope c) provide a surface finish according to ANSI B46.1 of 250 mil (6.4 μm). Provide new materials with 100% of the calculated cross sectional area based upon existing member dimensions Smooth complete penetration welds to a surface finish according to ANSI B46.1 of 250 mil (6.4 μm).

1. Tolerances for horizontally curved members or vertically cambered members should account for the original shape of the member.
2. Flatness of web measured by offset from a straight edge whose length is not less than the lesser dimension of the distance between stiffeners or the distance between flanges. Position straight edge so that the two ends are touching the web and a mid point offset can be measured using a ruler. Check the offset. Position the straight edge horizontally, vertically and diagonally to determine maximum offset. "D" is the lesser dimension of the distance between stiffeners or the distance between flanges. See illustrative figure below.
3. Determine combined warp and tilt of the flange at any cross section by measuring the offset at the toe of the flange from a line normal to the plane of the web through the intersection of the centerline of the web with the outside surface of the flange. "W" is the width of the flange. See illustrative figure below.
4. Check tolerances before any cross frames or other lateral restraint devices are attached. Do not force members into position and then weld in the cross frames to hold members within heat straightened tolerances.
5. The Contractor may request acceptance of final tolerances outside of the specified values. The contractor may indicate that a point of diminishing return has been reached where additional work will not result in a better final condition.



NOTE 2 FLATNESS OF WEB



Δ = COMBINED WARP OR TILT OF THE FLANGE AT ANY CROSS SECTION
W = FLANGE WIDTH

NOTE 3 COMBINED WARP AND TILT OF THE FLANGE

849.17 Final Inspection (QCP # 10). Perform a final arms length inspection of all surfaces that were repaired or heated. Perform the inspection after the work is complete

and cooled to160 ºF (70 ºC) or less. Perform non-destructive testing at locations of detected or suspected hairline cracking as part of this inspection. Test these areas using magnetic particle testing. Repair any cracks that are found according to Repairing Damaged Members (QCP # 7).

The Department will base final acceptance of the work upon acceptance of the: Surface Preparation; Damage Assessment; Repairing Damaged Members; Straightening Damaged Members; and Final Inspection. The Department will review the reports, progressive project documentation and progressive field measurements to determine the final acceptability of the work.

849.18 Method of Measurement. The Department will measure Damage Assessment, Straightening Damaged Members and Surface Preparation on a lump sum basis. The Department will measure Repairing Damaged Members by Grinding, by each hour expended performing the work. Hours include the cost of all labor, supervision, equipment and materials required to grind damaged members.

849.19 Basis of Payment The Department will not pay for the following:

A. Restoration of property to its original condition if the Contractor causes damage or injury to public or private property.

B. Repairing adjacent coatings outside the surface preparation areas damaged during the repair or straightening operations.

C. Hazardous material testing that is required by a hauler, treatment facility, disposal facility or landfill.

D. Repair of damage to structural members caused by improper jacking or pulling.

E. Investigative testing for damage to the metal's material properties caused by excessive heating temperatures.

The Department will pay for inspection access, inspection, non destructive testing; straightening work plan and final inspection as incidental to Damage Assessment.

The Department will pay for existing paint removal, grinding flange edges and containment/waste disposal as incidental to Surface Preparation.

If repairs require welding, drilling or coping holes, or material replacement according to: Repairing Damaged Members (QCP# 7), the department will pay for these repairs as extra work according to Item 109.05 or as otherwise specified in the contract.

All other requirements of this specification are considered incidental to the work.

The Department will pay for accepted quantities at the contract prices as follows:

Item	Unit	Description
849	Lump Sum	Damage Assessment
849	Lump Sum	Surface Preparation
849	Hours	Repairing Damaged Members by Grinding.
849	Lump Sum	Straightening Damaged Members.

Designer Comments:

Include all pay items.

Designate the existing paint coating and application year.

Designate the existing steel type, grade, minimum yield strength and allowable jacking stress which is 50% of the material yield stress.

When estimating the quantity for Item 849, Repairing Damaged Members by Grinding, unless a more detailed estimate can be determined from field observations and engineering judgment provide one tenth hour for each linear foot of span length multiplied by the number of damaged beams.

When estimating the quantity for Item 849, Repairing Damaged Members by Grinding, and damage is: beyond the limits of grinding; resulted in large cracks or missing sections of material; or resulted in cross frames and attachments replacement. Provide appropriate bidding items: Item 513, Repair of Damaged Main Material by Drilling or Coping Holes as per plan; Item 513, Repair of Damaged Main Material by Welding or Replacement as per plan; or Item 513, Repair of Damaged Secondary Material by Welding or Replacement as per plan. Include applicable notes and plan details as necessary to define the work. See BDM section 600 note #44 for item Item 513 replacement materials for a basis of these plan notes.

Determine the need for associated repair items

Item 202, Portions of Structure Removed, As Per Plan

Item 512, Concrete Repair by Epoxy Injection, As Per Plan

Item 513, Repair of Damaged Main Material by Welding or Replacement As Per plan

Item 513, Repair of Damaged Main Material by Drilling or Coping Holes As Per plan

Item 513, Repair of Damaged Secondary Material by Welding or Replacement, As Per Plan

Item 514, Field Painting of Damaged Structural Steel, As Per Plan (April 19, 2006)

Item 516, Jacking and Temporary Support of Superstructure, As Per Plan

Item 519, Patching Concrete Structures

Item 614, Maintaining Traffic

Item 624, Mobilization