# The Road to Repair

BY MARTIN ANDERSON

## Heat straightening can be an effective tool in working with damaged steel members.

**DESPITE EVERYONE'S BEST EFFORTS,** structural steel members can become damaged in the field. Forklifts may hit unprotected columns, overheight trucks can strike bridge girders, and so on. Fortunately, in many instances the damaged steel can be repaired (brought back into acceptable tolerances) in the field with a technique known as heat straightening. It is an appealing method of repair for structural steel as it can be performed in-place, does not require adding material to the member, and may not require temporary shoring, potentially saving both time and money.

Heat straightening is the process of applying heat in conjunction with passive restraint to produce permanent localized deformation that counteracts undesired deformations. The keys are that hot steel has a lower yield point than cold steel, that steel expands when heated and contracts when cooled, and that this expansion/contraction can be made asymmetric through judicious use of passive restraint.

Passive restraint can be (and often is) provided by jacks. However, the most important mode of restraint occurs within the steel itself, as an internal restraint caused by thermal gradients within the material. Cooler areas of steel tend to impede the thermal expansion of heated areas, causing plastic deformation in the heated area and corresponding changes in the shape of the member. Controlling the deformation is largely a matter of setting up and controlling thermal gradients in the steel; rather than directly shaping the member by applying force to it, the steel shapes itself as it reacts to temperature differences created by applying heat.

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Consider the example of applying heat to a triangular region across the width and roughly in the middle of a short steel bar, laid flat. As the heated area attempts to expand the colder areas will prevent it from doing so. The base of the triangle will expand more than the apex, causing the bar to bend toward the apex of the heated region. As the steel cools, greater contraction will occur at the base of the triangular heated region, resulting in a permanent bend without the application of external force. If desired, this bend can be enhanced by using additional external passive restraints during the heating phase.

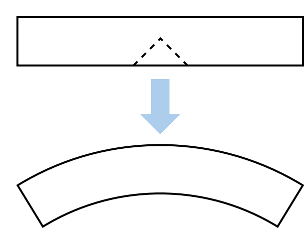

**Fig. 1**

You may wonder, at this point, if we couldn't accelerate the process further by aggressively tightening the clamp (by using active jacks, for example) and using more heat to lower the yield point even further. These are both bad ideas. First, heating must be done judiciously, especially in the field, because it may change the material properties of the steel. It must stay safely below the lower phase transition temperature (which is about 1,300 °F/700 °C, depending on material). Second, applying significant force while the steel is hot risks pushing the steel well beyond yielding, potentially resulting in rupture, unexpected crimps, buckling, and other undesirable distortions.

"Hot mechanical straightening" and "hot working" are different from heat straightening. They may be acceptable in some applications but not as unplanned variations on heat straightening in the field. Hot mechanical straightening generally involves application of large forces, attempting to straighten the deformation in a single heating cycle. While this can be an effective repair method for structural steel, it risks rupture or localized distortion and is difficult to perform in the field. Hot working, meanwhile, involves very high heat and the application of large forces. Because temperatures greater than 1,300 °F (700 °C) can change the properties of some steels, they are not permitted by the AISC *Specification*.

## Damage Patterns

Before designing a repair methodology, one must first analyze the damage. Most of the research on heat straightening recognizes the same four fundamental types of damage, each with a corresponding shorthand designation:

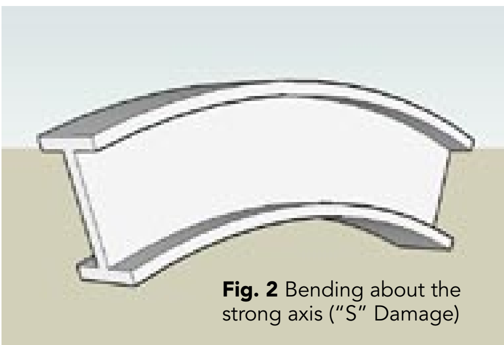

**Fig. 2** Bending about the strong axis ("S" Damage)

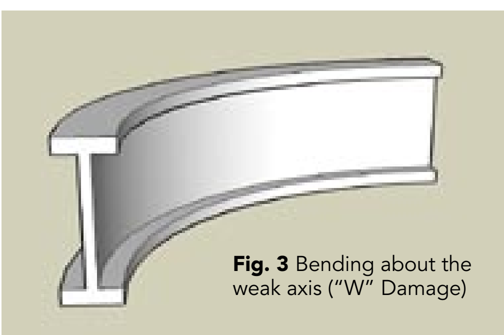

**Fig. 3** Bending about the weak axis ("W" Damage)

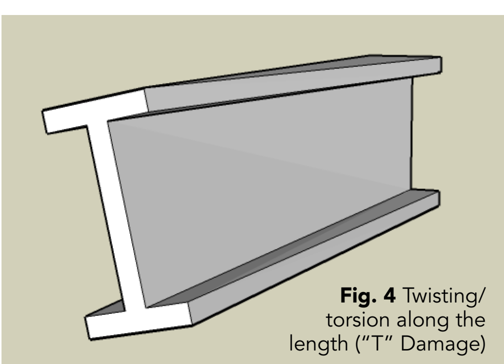

**Fig. 4** Twisting/torsion along the length ("T" Damage)

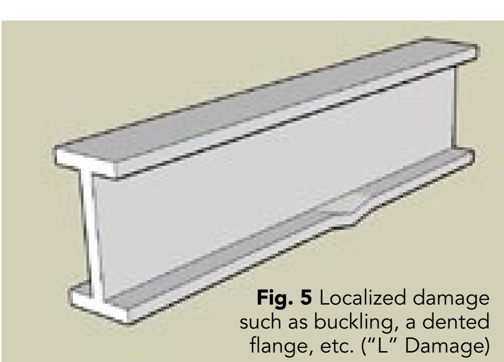

**Fig. 5** Localized damage such as buckling, a dented flange, etc. ("L" Damage)

In most cases the actual damage sustained will be a combination of these basic four damage patterns. For example, a beam struck by a truck may have local bending at the flange as well as torsion and/or weak-axis bending. A crucial step in heat straightening is to correctly characterize the damage so that a suitable repair methodology can be established. Many of the core texts on heat straightening make specific recommendations regarding appropriate repair methodologies for each type of damage as well as how to address the various combinations.

## Heat Patterns

Just as there are four damage categories there are four basic ways to apply heat to a wide-flange section. These can be combined (simultaneously or in sequence) to create complex heating designs for the specific damage being repaired.

- Spot: a small circular area is heated without moving the torch very far. Be warned, it is easy to accidentally overheat the steel with this pattern.

**Fig. 6** Spot Heat

- Line: a straight pass of the torch in one direction. Some refer to an "edge" heat, which is a line heat along the edge of a member (such as along a flange tip).

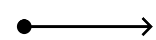

**Fig. 7** Line Heat

- Strip: sometimes referred to as a "rectangular" heat, this pattern involves repeated passes of the torch progressively back and forth across a rectangular area.

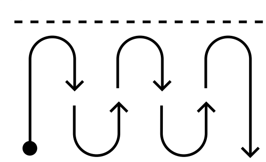

**Fig. 8** Strip Heat

- Vee: perhaps the most-used heating pattern. A small spot is heated, serving as the apex of a triangle. As the torch is swept back and forth, the length of the sweep increases, gradually creating a triangular heated region.

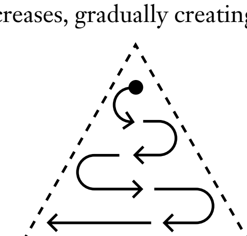

**Fig. 9** Vee Heat

## What About Columns?

Heat straightening is most commonly applied to beams, but it can be used to remove distortion in axially-loaded members as well. However it is important to consider the existing loads before applying heat. Local eccentricity of the axial column load may create a moment that will impede heat straightening or make the distortion worse. To overcome that, you may wish to consider using a jacking force to produce an opposing moment equal to the axial compressive force at the point of damage. In addition, *P*-delta effects should be considered.

### What About Fatigue?

Heat straightening of fatigue-sensitive members requires additional consideration and planning, and should not be undertaken without careful inspection of the damaged area for nicks, cracks, or anything else that could serve as crack initiation points. All such imperfections should be ground smooth before applying heat. Weld toes should be ground smooth to avoid stress concentrations, and nondestructive testing (NDT) should be used throughout the process to ensure that cracks are not occurring during the repair. For best results, these members should not be repaired more than twice in the same damage area.

### Tips & General Suggestions:

- Do not use a cutting torch. This may seem obvious, but it's important.
- Use an appropriate tip on the heating torch. Thicker steel requires more heat, but delivering this heat without overdoing it becomes problematic. The Federal Highway Administration (FHWA) document in the list of resources below includes specific suggestions. The document recommends starting at a single-orifice size 3 tip for steel less than a ¼-in. thick, single-orifice size 8 or multi-flame (rosebud) size 3 for steel up to 1 in. thickness, and multi-flame size 5 for steel 3 in. thick or greater.
- Do not try to heat an excessively large area; because you are relying in part on the restraint provided by cooler sections of steel, heating a very large area will tend to reduce efficiency.
- Do not heat the steel outside the area that yielded during the damaging event. This is pointless, and reduces efficiency.
- Always observe the maximum temperature rules stated in Section M2.1 of the AISC *Specification for Structural Steel Buildings*, as well as the AASHTO/AWS D1.5M/D1.5 *Bridge Welding Code*. For carbon steel, keep the temperature below 1,200 °F (650 °C) at all times; other steel grades may have different temperature requirements, but always stay below the lower phase transition temperature. Using 1,200 °F (650 °C) for carbon steel gives a 120 °F (50 °C) margin of safety in case of operator variability, measurement error, and the like.
- Remember that temperature crayons can burn when exposed to direct flame. You may wish to consider various forms of temperature monitoring. Infrared devices are increasingly affordable and accurate, but be sure you monitor the temperature of the steel, not the temperature of the flame. Measuring temperature is not as easy as it may at first appear, and care should be taken at all times to ensure accurate readings.
- Do not actively cool the steel (for example, by water spray or compressed air) until it has cooled to below 600 °F (315 °C) to keep from creating brittle zones in the member.
- Do not reheat the steel until it has cooled below 250 °F (120 °C) or you risk additional damage.
- When applying restraint with jacks, calibrate and monitor the jacking forces to avoid over-jacking and potentially damaging the member. MSC

### Selected Resources

Additional information on heat straightening repair of structural steel can be found in these documents:


"What You Should Know About Heat Straightening Repair of Damaged Steel," by R. Richard Avent and David J. Mukai, *Engineering Journal*, First Quarter 2001, available online at **www.aisc.org/epubs**.

"Heat-Straightening Repairs of Damaged Steel Bridges: A Technical Guide and Manual of Practice," Report No. FHWA-IF-99-004, U.S. Department of Transportation, Federal Highway Administration, available online at **www.fhwa.dot.gov/bridge/steel**.

"Heat-Straightening Repair of Damaged Steel Bridge Girders: Fatigue and Fracture Performance," NCHRP Report 604, Transportation Research Board of the National Academies, available online at **www.trb.org/Main/Public/Blurbs/160020.aspx**.

"Engineered Heat Straightening Comes of Age," by R. Richard Avent, P.E., *Modern Steel Construction*, February 1995, available online at **www.modernsteel.com/backissues**.