Classic Papers from AISC's
Engineering Journal

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While all papers in the AISC *Engineering Journal* make a contribution to the state of knowledge of steel design and construction, some papers rise above the rest and stand as seminal in their importance. This regular feature in *Modern Steel Construction* magazine will highlight those most notable of works in the AISC *Engineering Journal*.

Cambering Steel Beams

By David T. Ricker
From the 4th Quarter 1989 issue

The following highlights can be examined in greater detail by reading the full paper, available at **www.aisc.org/epubs**.

Types of Camber: The author distinguishes between natural camber (the out-of-straightness remaining after the initial rolling, cooling, and straightening of the member at the mill) and induced camber (the curvature that is applied subsequent to the initial rolling and straightening process, usually in the fabricating shop).

The Camber Curve: The deflection curve for a horizontal, uniformly loaded member of constant cross section theoretically approximates a parabola. However, since the sag ratio for beams, that is, the ratio of mid-ordinate to chord, is so small, it generally is accepted that adequate accuracy results if the camber curve is considered to be a segment of a circular curve. Some camber calculations are based on circular curves. Camber usually is expressed in terms of the maximum ordinate at midspan. The full paper gives a method to determine the approximate camber at other points along this curve.

Sage Advice, with Humor to Boot: Once the deflections are determined, the desired amount of camber can be selected. The selection of camber is often arbitrary. The methods of cambering are relatively crude, and the results are less than precise. There is little need nor justification in meticulous mathematical manipulation or methodical multifarious meditation when it comes to determining camber requirements.

Cold Cambering Using Force: The types of steel used for structural purposes are ductile, that is, they have the property of deforming extensively under substantially constant stress…When we cold-camber a beam, the extreme fibers reach stresses and deformations that are on the horizontal portion of the stress-strain curve. With most cold-cambering devices, it is impossible or difficult to maintain a constant stress. The rams which deliver the force advance when the button is pushed and halt when the button is released. When the ram is halted, the deformation and stresses come to balance in a brief moment, and equilibrium is reached. When the ram is retracted, the beam relaxes and some residual deformation is evident by the fact that the beam is no longer straight. This essentially is the cold-cambering process.

We all know that bending a wire back and forth enough times will weaken it to the point where it will fail with very little effort. What about the cold-cambered beam, which we bent in one direction to make the camber curve and are now loading in the opposite direction with its service loads? Another of the seemingly endless wonderful properties of structural steel is that, if allowed to rest for a few hours at room temperature, steel has the tendency to recover its elastic properties. The application of mild heat, about 225°F for a few minutes, will accelerate the period of recovery.

Mention should be made here of the term "strain hardened." This consists of an alteration of the elastic properties of cold-worked steel and a raising of the proportional-limit stress, as a result of the aforementioned aging or application of mild heat. Two facts emerge from this brief discussion of cold bending:

1. The same allowable stresses (or load factors) can be applied to cold-cambered beams as to uncambered beams, provided that they are allowed to "age" for a few hours.
2. Never attempt to reduce the camber in an overcambered beam by immediately applying force in the opposite direction. If this caution is ignored, strain weakening will result and the elastic-limit will be lowered. If normal, allowable stresses subsequently are assigned to the member, the factor of safety will be reduced.

When a beam is to be cold-cambered by force, it is usually mounted in some type of rigid frame which holds the beam secure while the force is delivered. The ends of the beam must be laterally supported in addition to the compression flange. The fulcrums must be devised so that the ends are free to rotate because of the severe arc to which the beam is forced in order to produce the residual strain. There are usually two points at which the load is delivered to the beam. These points might be about 6′ or 8′ apart, while the resisting supports can be 22′ or so apart. This will produce a curve that is very close to duplicating a parabola.

When the operator activates the cambering device, the rams advance and the beam deflects, often as much as two or three times the amount of desired camber. The rams are halted and kept in place for a few seconds, during which the steel microstructure undergoes rearrangement and the stresses relax somewhat. When the rams are retracted, the beam springs back, stresses drop to zero, and a permanent set is left in the beam. If the deformation is insufficient, the rams can be immediately reactivated to add more camber. Contrary to popular belief, cold cambering does not result in significant residual stresses, at least in the flange areas. A bar shape, if bent cold to a tight radius, will contain residual stresses but, when a beam is bent, the radius of the bend is so large that the tension flange undergoes nearly pure tension while the compression flange is subject to nearly pure compression. Pure tension "stretching" and compression "squeezing" do not produce residual stresses; therefore, there should be no concern over this phenomenon when cold-cambering beams.

Cambering Using Heat: The heat application must not exceed 1100°F for ASTM A514 steel nor 1200°F for other structural-type steels. The temperatures should be monitored by heat-sensitive crayons or other suitable means. There is no reason to exceed these temperatures. In fact, most cambering can be done at temperatures lower than these maximums. The consequences of overheating are not readily apparent to the naked eye, but nonetheless they are present in the form of microstructure changes in the steel.

Most heat cambering is accomplished by heating wedge-shaped segments at intervals along the length of the member. The number of wedge-shaped heated segments varies depending on length and size of the member and the amount of camber required. For starters, try two heated areas at the 3/8 and 5/8 locations. Experience will be the best teacher. Before heating, install a plumb line or other device so that the movement can be monitored. Once the heating starts, it should not be interrupted until the serpentine path described below is completed. As the heating proceeds, the member will start to bend in the direction opposite to that intended. However, after the heating is finished and the beam starts to cool, the beam will commence to straighten and then continue to bend in the desired direction... For best results, let the heated member cool by itself... Heat also can be used to straighten members. The heat source can be anything that works—natural gas, propane, and oxy-acetylene mixtures all work well. A commonly used torch nozzle is a medium to large (approximately 1½" diameter) "rosebud" type.

Members that Lend Themselves to Cambering: Filler beams, girder beams, composite floor beams, and members with uniform cross section.

Members that Do Not Lend Themselves to Cambering: crane beams or crane girders, spandrel beams, especially those supporting facia materials, c. beams with single or double cantilevers, beams braced with knee braces, beams with full moment connections or significant semi-rigid moment connections, beams with welded cover plates, especially if the cover plate does not extend full length, members of non-uniform cross section, beams with significant non-symmetrical loading, short beams—less than 20′ in length, shallow beams—wide-flange shapes less than nominal 14" depth and standard beams less than 12" depth, beams subject to significant torsion loads, and beams which would require less than 1" of camber. (Small camber requirements can often be satisfied by natural mill camber.)

Establishing the Amount of Camber: Beams can be cambered to accommodate part of the dead-load deflection, the full dead-load deflection, or dead-load deflection plus part of the live-load deflection, at the discretion of the engineer. This can be influenced by the relative percentages of dead and live load, the probable frequency and intensity of live load, the performance history of similar members, aesthetics, or other pertinent factors.

As previously mentioned, determining the amount of camber is a very inexact process. After the cambering process, performance of the member often is not according to the script. In general, the anticipated amount of beam deflection does not occur. This probably is due to some degree of end fixity of the beam connections.

When to Camber: Usually the cambering, if performed by the fabricator, is done after the member has been cut to length and punched or drilled. Beams that require square and parallel ends, such as for end-plate or welded-moment connections, must be cut after cambering. Any interior hole groups will be perpendicular to the flanges at their locations. The fact that the beams that frame to these hole groups will not be exactly vertical is of small consequence.

Camber Cautions

a. Don't over-camber beams which receive shear studs for composite action. The over-cambering could result in the heads of the studs protruding from the top of the concrete slab.

b. Don't cold-camber beams to which a cover plate will subsequently be welded. The heat thus generated at one flange will generally be enough to significantly alter the camber curve.

c. When cold-cambering by force, make sure that there is sufficient length of bearing at the load points in order to prevent local flange and web buckling. The fulcrums must be free to rotate so as to conform to the camber curve.

d. When heat cambering, do not overheat the steel.

e. Do not force-cool heated members with water or air spray if their temperature is greater than 700°F.

f. Columns comprised of section sizes normally associated with beams should, when ordered from the mill, be noted "no camber permitted." Otherwise, the mill may provide the members with a small amount of "natural" mill camber.

g. Heat cambering should be performed only on low-carbon steels. Application of heat to medium-and high-carbon steels increases the danger of embrittlement. ASTM A36, A572 Gr. 50, A588, A441, and A242 are popular low-carbon steels. [Note ASTM A992 is also a low-carbon steel.]

h. When using the heat-cambering method, it is not necessary to reheat previously heated areas when following the serpentine path. Allow the steel to cool naturally behind the torch. ★