Bending Considerations in Steel Construction

BY RUSS BARNSHAW

Incorporating curved members in structures adds value—and flare.

IT HAS BEEN POSSIBLE AND PRACTICAL, especially since the mid-1980s, to curve structural sections to form arches and curved elements for steel structures. This has given architects and consulting engineers greater freedom to design buildings that are both functional and attractive.

By definition, the act of bending steel changes the member's geometric properties. However, it also changes its mechanical properties, as well as its cost and value. Let us consider the effects some of these changes individually.

Metallurgical Changes

The most common question that arises is what happens to the steel when it has been rolled into a curve. When steel is cold rolled, it is taken past the yield point to create a permanent change in shape. This results in some strain hardening and subsequently the material properties are changed. The material shows some loss of ductility with a reduced percentage elongation and a reduction in the Charpy V-notch impact values. However, the steel exhibits the same elastic characteristics in the elastic range as it did before the bending process.

Therefore, the way to quantify the degree of strain hardening is to calculate the percentage of strain.

For example, the percent strain created when a section of depth D is curved is

$$\frac{D \times 100}{2R}$$

where R = mean radius
and D = the section depth.

Thus, an 18-in.-deep beam rolled to an 80-ft radius gives a percent strain of

$$\frac{18 \times 100}{2 \times 80 \times 12} = 0.94\%$$

From our experience you can curve steel sections up to approximately 3% strain before the properties are reduced below those of the specification of the unworked sections. This is about as small a radius as can normally be achieved for steel beams about the major axis.

Minimum Radius and Tolerances

We often are asked what the minimum radius is for a curved section. This apparently simple question does not have a simple answer, however. The actual minimum radius depends on many factors. For example, does the application of the curved member permit any distortion of the cross section, or is none allowable?

Each wide flange beam series has a range of flange and web thicknesses and it is generally easier to bend the heavier sections. General guidance is provided in Table 1. For specific advice, talk directly to a steel fabricator or bending specialist.

Table 1
Typical Steel Sections Curved about the Major Axis (50 ksi)

W-Shapes (Wide Flange Beams)	Minimum Bend Radius
W 24 x 176	70 ft
W 21 x 73	50 ft
W 18 x 60	42 ft
W 12 x 136	20 ft

Beams naturally can be curved more easily about the minor axis than the major axis, although bending about the major axis is the way most curved beams are used in steel construction. It is always advisable for consulting engineers to check with a steel fabricator or bending company to confirm that they can curve a section of a particular size.

It is easy to get confused about the way a section is bent. Using such terms as hard-way, easy-way, toe-in-angle, toe-out-angle and so on can give rise to errors. The best solution is to send a drawing or sketch to the bender and this usually clarifies what is required.

In our experience the typical tolerance on a curve is ⅜ in. on the radius. For cambers the tolerance is ± ¼ in. up to 24 in. deep and ± ⅜ in. on larger beams. There is, incidentally, no truth in what is sometimes said about cambers opening back to straight beams due to a journey by truck. The bending forces required to bend the beam in the shop are far greater than any of those caused by any jostling about in transit.

Costs of Curved Steel

Much of the steel construction industry figures costs in terms of price per unit weight. That creates a problem for the bending company because it takes a similar amount of time to curve a heavy weight and a light weight beam. The heavier beam can therefore be curved at a much lower price per unit weight.

It is much better to think in terms of bending as a cost per curved section. Naturally, in the end you can convert the cost to dollars per unit weight, but you will see a big variation between projects when it is expressed in this way.

The Architect's Pleasure

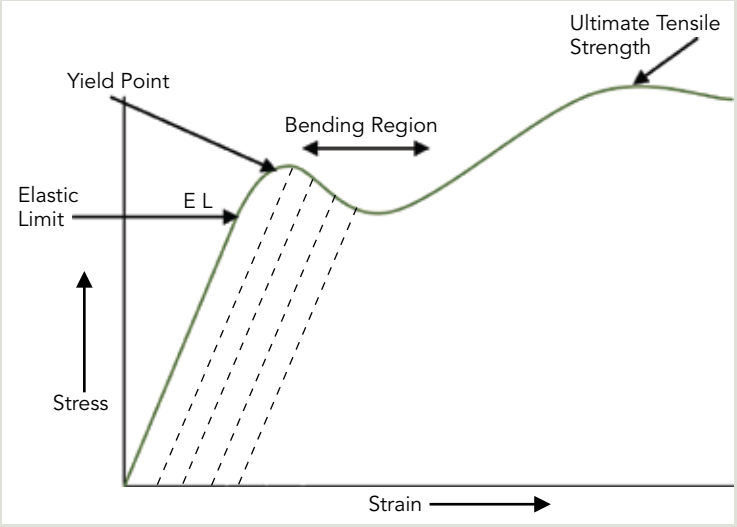
Curved steel sections have been employed in many structures and many award-winning structures involve curved elements as one of their main features. You do not need many curved pieces to make a considerable change in the appearance of a structure.

Curved structures are ideal for certain types of structures, for example, railway stations, airport terminals, exhibition halls, shopping malls and sports stadia. It is these structures that are required in a modern world—As people-holding structures they are seen mainly from the inside and the curved elements create ceiling forms that enhance the experience of being in the building.

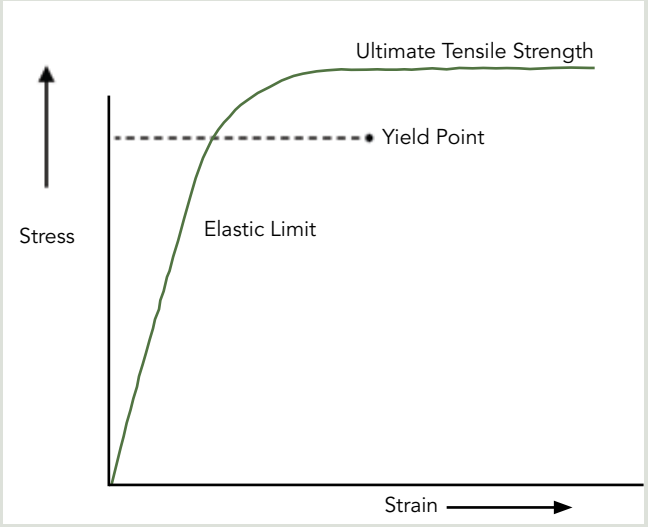
Architects are of course aware of steel's essential properties and characteristics, but AISC and other industry groups continually work to increase awareness of why steel framing is an attractive solution. Steel-framed buildings are generally light, which reduces foundation loads. The buildings also are

Russ Barnshaw is chairman of Barnshaws Section Benders, based in the U.K., has been involved in section bending for more than 50 years. Barnshaws Group (www.barnshaws.com) has six bending plants in the U.K., employing 180 people, and has a turnover of around $25 million (U.S.).

During bending, the steel section must be subjected to a stress that exceeds both the elastic limit and the yield point. The elastic limit is the maximum stress that the material can be subject to before a permanent change in the material length occurs, either stretching in tension or compaction in compression.



Plastic bending takes place in the zone marked "Bending Region." The dotted lines show how the material will spring back when the bending load is removed. The spring back reduces as the strain is increased.



After bending, the stress-strain curve takes a different shape. The yield plateau disappears and you see an increase in both the yield point and the Ultimate Tensile Stress (UTS).

much quicker to erect and require less site work. The material is almost 100% recyclable and is sustainable.

The introduction of accurate, smooth curved elements adds to this attraction, so the roller bender plays an important part in the steel construction industry and in its ability to compete with other forms of construction.

Closing Notes on Communication

With the increasing use of e-mail communication bending companies can receive early structural designs and quickly respond regarding the bendability of the sections proposed. This requires greater skill sets within the bending companies, including having sales people who are familiar with the use of CAD in order to respond electronically to inquiries—sometimes relating not only to the section but to the profile evaluating shapes being proposed. It also facilitates substituting alternative, more easily bendable shapes at an early point in the design.

As in all facets of design and construction, clear and open communication among the participants throughout the project is a keystone of success. And including curved structural sections often makes that success even better. MSC