PROPORTIONS FOR IMPROVED STIFFNESS OF BOX SECTION BEAMS USED AS LONGITUDINAL ROADSIDE GUARDRAIL BARRIERS

W. V. Brewer, University of Tulsa

ABRIDGMENT

•DIMENSIONS for barrier beam sections cannot be specified in an optimum way without a detailed consideration of the system using the beam. Proportions, however, may be examined with a minimum of information about the system. It is here assumed that the beam is part of a strong-beam, weak-post, high-performance system designed to accept high-speed vehicles with low deceleration rates. As performance requirements increase, a cost-effective system must use greater barrier spans to absorb vehicle energy (1). A high specific stiffness is desirable. The second moment of cross-sectional area about the major section axis divided by the cross-sectional area squared is the stiffness ratio used for comparisons because it is not dependent on section size. Similar ratios are used for minor axis and torsional stiffness.

AISC specifications limiting width-thickness ratios for structural plate elements are used wherever applicable. Simply supported plate conditions are assumed throughout so that all proportions are conservative to this extent. Nomenclature is as shown in Figure 1. Pertinent formulas are as follows:

1. (second moment of area about the major section axis)/(half depth)^4

$$\frac{I}{h^4} = 4\,\frac{a_2}{h}\,\frac{b_2}{h}\left(\tfrac{1}{2}\,\frac{a_1}{a_2}\,\frac{b_1}{b_2}\left(\frac{z_1}{h}\right)^2 + \left[\frac{(z_1/h)^2 + (z_2/h)^2}{2}\right]\left\{1 + \tfrac{1}{3}r\left[\frac{(z_1/h)^3 + (z_2/h)^3}{(z_1/h)^2 + (z_2/h)^2}\right]\right\}\right)$$

for $\frac{z_2}{h} = 2 - \frac{z_1}{h}$ and $\frac{z_1}{h} = \dfrac{1}{1 + \tfrac{1}{2}\,\frac{a_1}{a_2}\,\frac{b_1}{b_2}\left(\frac{1}{1 + r}\right)}$.

2. (second moment of area about the minor section axis)/(half depth)^4

$$\frac{i}{h^4} = 4\,\frac{a_2}{h}\left(\frac{b_2}{h}\right)^3\left[\tfrac{1}{6}\,\frac{a_1}{a_2}\left(\frac{b_1}{b_2}\right)^3 + r\left(1 + \frac{1}{3r}\right)\right]$$

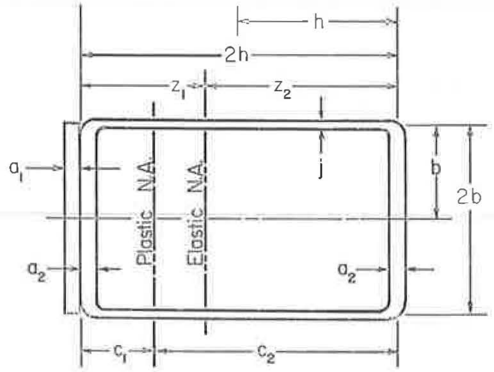
for $r = \dfrac{\frac{j_2}{a_2}}{\frac{b_2}{h}}$.

3. (torsional stiffness for a thin walled tube)/(cross-sectional area)^2

$$\frac{J}{A^2} = \left(\frac{2h}{j_2}\right)\frac{r}{\left(\tfrac{1}{2}\,\frac{a_1}{a_2}\,\frac{b_1}{b_2} + 1 + r\right)^2\left(1 + \frac{1}{1 + a_1/a_2} + 2\,\frac{a_2}{j_2}\,\frac{h}{b_2}\right)}$$

As a point of reference, consider a box section structural tube of uniform wall thickness, compact about its major axis. The maximum width-thickness ratio for flanges (2, p. 102) is

Figure 1.



$$\frac{2b}{a} \le \frac{6{,}000}{f^{1/2}}$$

and for webs is

$$\frac{2h}{j} \le \frac{13{,}300}{f^{1/2}}$$

where f is the yield or plastic stress in psi.

Stiffness for this section is a function of ratio r. The function maximizes for r = 3.

$$r = \left(\frac{j}{a}\right) \Big/ \left(\frac{b}{h}\right)$$

$$\frac{I}{A^2} = \frac{2h}{j} \, \frac{r(1 + \frac{1}{3}r)}{8(1 + r)^2}$$

Maximum stiffness about the major section axis is produced at a flange ratio less than the allowable; however, increasing 2b/a to the limit does not significantly change this performance. Minor axis and torsional stiffness are substantially increased as b/h = 1/r = 0.451.

$$\frac{I}{A^2} = \frac{619}{f^{1/2}}$$

$$\frac{i}{A^2} = \frac{185}{f^{1/2}}$$

$$\frac{J}{A^2} = \frac{443}{f^{1/2}}$$

Elastically designed sections have more desirable stiffness characteristics but cannot be used in guardrail applications because of the prohibitive expense of preventing plastic hinge in the vehicle impact area. It is in this area that the roadside flange is in compression and must be capable of performing plastically without local buckling. The opposite outside flange need not meet the same requirements. It is in tension throughout the plastic impact zone of maximum moment and is therefore stable. Zones of second largest bending moment occur on either side of the vehicle impact area. The discussion that follows applies only to roadside barriers and not to median barriers, which must have identical performance from both flanges. Further, the discussion assumes that the barrier system has been designed to prevent plastic flexure in these areas. (Our studies lead us to believe that this would minimize initial costs as well as reduce replacement costs for high performance systems.) Outside flanges may then be designed elastically to take advantage of superior overall stiffness. Resulting cross sections have only one axis of symmetry.

An asymmetric section that is relatively easy to fabricate from a strip of uniform thickness (by folding or possibly roll forming) has one flange double the thickness of the other. Elastic design of the outside flange to meet AISC specification (2, p. 100) requires a width-thickness ratio somewhat more conservative than the perfect plate theory:

$$\frac{2b}{a} \le \frac{8{,}000}{f^{1/2}}$$

The doubled roadside flange exceeds plastic plate requirements.

Plastic requirements for stability of the webs subjected to combined tension and bending are less severe than for pure bending. Any reasonable estimate of this ratio must depend on relative magnitudes of tension and bending or alternatively on the location of the neutral axis for a plastic section. This cannot be known without specifying section proportions that require the desired ratio 2h/j. An iterative solution is necessary. Values thus obtained produce the following results for the proposed asymmetric section:

$$\frac{a_1}{a_2} = 1 \qquad \frac{j}{a_2} = 1 \qquad \frac{b}{h} = 0.455 \qquad \frac{2b}{a_2} = \frac{8{,}000}{f^{1/2}}$$

$$\frac{I}{A^2} = \frac{765}{f^{1/2}} \qquad \frac{i}{A^2} = \frac{197}{f^{1/2}} \qquad \frac{J}{A^2} = \frac{479}{f^{1/2}} \qquad \frac{2h}{j} = \frac{17{,}600}{f^{1/2}}$$

Stiffness ratios have improved in every category for this section when compared with a symmetric box section structural tube of uniform wall thickness. In volume production fabrication cost would be little if any more than for a symmetric box section. Lighter sections could be used to obtain the same performance levels.

A second asymmetric section that is relatively easy to fabricate consists of a box section tube of uniform wall thickness with the roadside flange augmented by a plate. The tube flanges satisfy the elastic criterion. Thickness a_1 of the plate augmenting the roadside flange can be adjusted so that the plastic criterion is satisfied where the possibility of different maximum stress levels in the component parts has been taken into account.

$$\frac{a_1}{2b} = \frac{f_1^{1/2}}{6{,}000} - \frac{f_2^{1/2}}{8{,}000}$$

for $f_1 \geq f_2$. When $f_1 > f_2$, then a_1 is sized conservatively as if the entire composite roadside flange would develop plastic stress f_1.

If component parts are made of the same material and the largest elastic stress is equal to the plastic stress, then

$$\frac{2b}{a_2} = \frac{8{,}000}{f^{1/2}} \qquad \frac{i}{A^2} = \frac{246}{f^{1/2}} \qquad \frac{a_1}{a_2} = \frac{1}{3}$$

$$\frac{I}{A^2} = \frac{665}{f^{1/2}} \qquad \frac{2h}{j} = \frac{14{,}800}{f^{1/2}} \qquad \frac{j}{a_2} = 1$$

$$\frac{2b}{a_1} = \frac{24{,}000}{f^{1/2}} \qquad \frac{J}{A^2} = \frac{552}{f^{1/2}} \qquad \frac{b}{h} = 0.542$$

Stiffness ratios are improved in every respect when compared with symmetric section but are superior to the single-component asymmetric section only about the minor axis and in torsion.

Performance about the major axis is enhanced as a result of a shift in the plastic neutral axis. The greater shift in single-component section is a result of greater augmentation of material to the roadside flange. A more pronounced effect can be obtained by increasing the strength of the augmenting material. As an example in the extreme, let $f_1 = 2f_2$.

$$\frac{a_1}{a_2} = 0.886 \qquad \frac{2b}{a_2} = \frac{8{,}000}{f_2^{1/2}} \qquad \frac{i}{A^2} = \frac{188}{f_2^{1/2}}$$

$$\frac{j}{a_2} = 1 \qquad \frac{I}{A^2} = \frac{936}{f_2^{1/2}} \qquad \frac{2h}{j} = \frac{20{,}800}{f_2^{1/2}}$$

$$\frac{b}{h} = 0.384 \qquad \frac{2b}{a_1} = \frac{9{,}030}{f_2^{1/2}} \qquad \frac{J}{A^2} = \frac{492}{f_2^{1/2}}$$

SUMMARY

Asymmetric box beam cross sections, formed by adding material to the roadside flange, have superior specific stiffness characteristics when compared with symmetric sections designed to meet similar stability criteria. Stiffness about the major section axis can be increased by as much as 50 percent while minor axis and torsional stiffness are maintained at levels comparable to a symmetric section. Alternatively minor axis and torsional stiffness can both be increased 25 percent by accepting a marginal 7 percent increase about the major axis.

CONCLUSIONS

Current barrier systems employing box section beams use unnecessarily conservative section proportions. A roadside barrier system designed to employ asymmetric box sections could translate superior stiffness into reduced overall cost for a high-performance system.

ACKNOWLEDGMENTS

This investigation was supported by the National Science Foundation and by the University of Tulsa.

REFERENCES

1. Brewer, W. V. Energy-Absorbing Barrier Beams Suspended From Linear Supports (Abridgment). Highway Research Record 460, 1973.
2. Brackenbrough, R. L., and Johnston, B. G. Steel Design Manual, 2nd Ed. United States Steel Corp., Nov. 1968.