One Engineer's Opinion

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Q. *For a beam to be considered as compact, AISC Specification Sect. 1.5.1.4.1 requires, in addition to certain cross-sectional geometry, that the compression flange of a beam must be supported laterally at intervals not exceeding* $2400\, b_f/\sqrt{F_y}$ *nor* $20{,}000{,}000\, A_f/dF_y$. *Also, Formulas (4) and (5) of the Specification contains the term* l *which is defined as the unbraced length. The Specification is silent, however, as to the strength requirements for the bracing members; therefore the questions arise: What constitutes adequate lateral support? May points of inflection be considered points of lateral support?*

A. The questions asked are deceptively simple ones for which there is no rational simple answer. However, a qualitative answer may be given which will serve as a starting point for discussion.

If a beam is initially straight and loaded to produce bending about its principal axis only, the bracing forces required to prevent it from twisting and buckling laterally in the elastic range are very small. However, if the beam is permitted to depart from good alignment, then the bracing force to prevent buckling may become appreciable. In other words, the *rigidity* of the bracing is as important as (or perhaps more important than) the *strength* of the members.

The real measure of the requirements for lateral bracing is dependent upon (1) the size, stress intensity, and cross-sectional shape of the member being braced, (2) the design criteria for the member braced; that is, whether the member is designed elastically or plastically, and (3) the stiffness of the bracing system including anchorages and connections.

Thus, a brace directly connected to the compression flange, acting in axial tension or compression and anchored to a rigid support at its far end would be called upon to provide a smaller bracing force than a similar brace anchored to an elastic support.

A brace connected to the tension flange of a deep member, and depending upon knee braces or web stiffeners to transmit the lateral restraining force to the compression flange, would also be called upon to provide a larger bracing force than an axially loaded brace, since the spring constant of member loaded in bending is in general much lower than a member loaded axially.

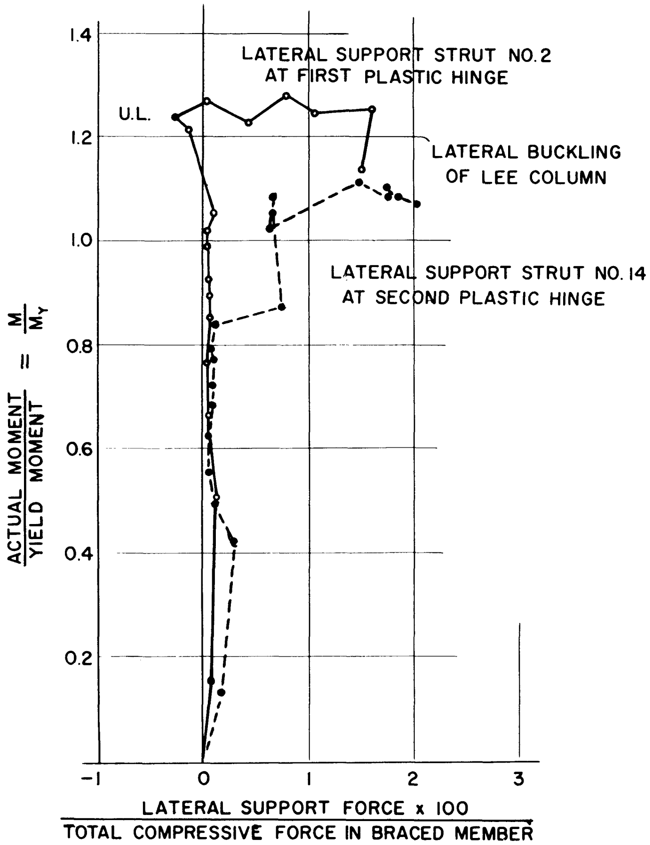

Fig. 1. Moment vs lateral support forces

It is important to remember that the demands placed upon the bracing will depend upon the design criteria used for the braced member. A beam designed according to elastic design criteria will not be stressed up to the elastic limit even when supporting an overload of 65 percent, but a beam designed according to plastic design criteria *is counted upon* to undergo inelastic straining in supporting overloads. Pincus[1] has pointed out that in-

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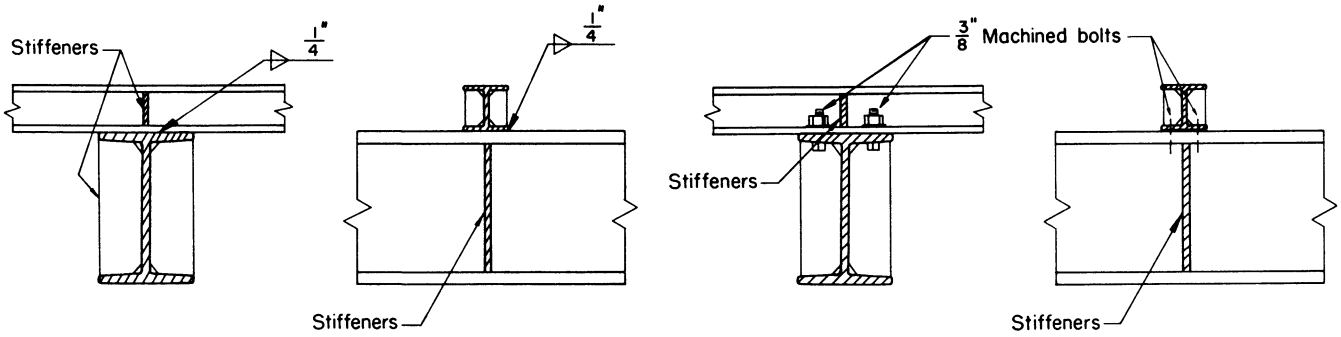
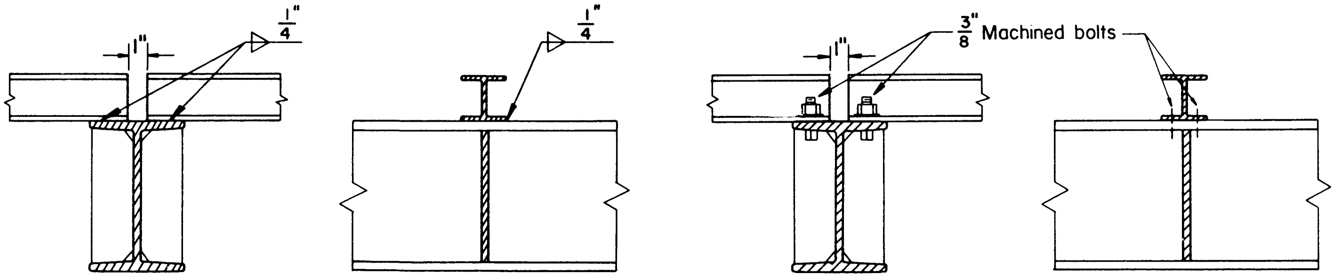
[1] *Pincus, George,* On the Lateral Support of Inelastic Columns, *AISC Engineering Journal, Vol. 1, No. 4, October, 1964.*



(a) WELDED CONTINUOUS CONNECTION

(c) BOLTED CONTINUOUS CONNECTION



(b) WELDED DISCONTINUOUS CONNECTION

(d) BOLTED DISCONTINUOUS CONNECTION

Fig. 2. Typical connection details

elasticity at a given ultimate load requires a greater amount of support than is required to reach the same load in a structure that remains elastic. The fact that the bracing forces are very small in the elastic range but rapidly increase at yielding of the braced beam was demonstrated in the early phases of research on plastic design at Fritz Engineering Laboratory, Lehigh University. Figure 1 is a plot of observed forces in bracing to the compression flange at the knees of rigid frames. The forces in the bracing were observed to be a small fraction of 1 percent of the total compressive stress in the braced member at the point of bracing until loading produced yield point stresses. As straining continued in the braced member, the forces in the braces varied in an erratic manner and increased rapidly several fold.

Since the demands on the bracing will be different for elastic and plastic design, different rules should apply. Consider first elastic design. A widely accepted rule-of-thumb recommends that bracing be designed to resist a force of 2 percent of the resultant compressive force in the braced member. For members designed in accordance with elastic design criteria, this rule is conservative but not uneconomic. Since the calculated required bracing force is very small, a refined analysis to determine more precisely what the required bracing capacity might actually be is unwarranted.

If more than a single brace is provided within the maximum unbraced length permitted for full allowable bending stress, the total required brace capacity may be divided among the braces acting.

Frequently, continuous lateral bracing is effectively provided by the supported roof decking rather than by members specifically installed to provide bracing. In such cases, the required restraint is provided by the shear stiffness of the decking material acting as a diaphragm between adjacent beams. Anchorage to a rigid abutment at the far end is not important, but attachment of the deck to the supported beams and edge connection between adjacent sheets of decking *is* important. A suitable theory for determining the effective shear rigidity of diaphragms is not available. Values must be determined experimentally for each deck configuration. A design procedure suitable for routine office use is yet to be developed.

For beams designed in accordance with plastic design criteria, bracing which is intended to prevent lateral buckling in a region which is counted upon to operate as a plastic hinge before ultimate load is reached must be more conservatively designed. A series of experiments were performed on braced wide flange beams by Lee, Ferrara and Galambos.[2] The test beams were subjected to two-point loading to produce a uniform moment of M_p between braces, which simulated purlins supported on the compression flange. The variables included unbraced length, size and length of bracing members and details of connection between the braces and the braced beam. Figure 2 shows typical connection details. All of the bracing arrangements tested provided adequate support to permit M_p to be developed in the braced beam without failure by lateral buckling.

The report points out that lack of an adequate theory and the limited number of tests completed make it impossible to formulate design rules. However, since all bracing systems tested were adequate, bracing meeting the following criteria will be very adequate:

1. Space lateral bracing so that a brace is provided at the plastic hinge and at a distance of $40r_y$ in both directions away from the plastic hinge.
2. Design bracing members elastically such that no plastic hinge exists in them at the time of failure of the braced member.
3. Select brace purlins such that brace-depth to beam-depth ratio is at most 1/3.5.
4. Attach brace members by welding or bolting to the compression flange of the braced beam.
5. Provide a vertical stiffener for at least half the depth of the web at the bracing point.
6. The weak axis slenderness ratio of the braces should be less than 200 if purlins extend in both directions from the braced beam, or less than 100 if purlins extend in one direction only.

In both elastic and plastic design, points of inflection should not be assumed to be equivalent to braced points when investigating the tendency of a beam to buckle laterally. This statement is contrary to opinions which have been expressed in the past.[3]

Formulas (4) and (5) of the AISC Specification give reasonable approximations of critical bending stress modified by a factor of safety for the more usual cases of loading and are much easier to use in routine calculations than the more correct formulas.* The more exact formulas and Formulas (4) and (5) are based upon the assumption that the beam is positively restrained against rotation about its Z-Z axis at points of support. Points of inflection do provide some support against rotation about the Z-Z axis; however, this restraint is elastic in nature and its effectiveness would be difficult to evaluate. It is better than nothing but is less than the full restraint assumed in the development of the theoretically correct formulas and the approximate Formulas (4) and (5).

The length to be used in Formulas (4) and (5) should be the distance between braces which effectively prevent lateral movement of the compression flange and twisting of the beam about the Z-Z axis at the braced point. If the brace is connected by bolting or welding so as to prevent twisting of the compression flange, bending stiffness of the web will be adequate to prevent twisting of the cross-section in beams designed according to elastic design criteria.

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[2] *Lee, Ferrara and Galambos,* Experiments on Braced Wide-Flange Beams, *Fritz Engineering Laboratory—Report No. 205H.6 (unpublished).*

[3] Modern Steel Construction, *Vol. 2, No. 4, pp. 14 and 15.*

* *See Formula (4.11) in the Column Research Council Guide to Design Criteria for Metal Compression Members.*