The Importance of Tension Chord Bracing

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The importance of tension chord bracing for joists, joist-girders and fabricated trusses must not be overlooked. Reasons often given for tension chord bracing or bridging are:

1. To control the slenderness ratio of the tension member as required by the American Institute of Steel Construction (AISC) and the Steel Joist Institute (SJI)
2. To stabilize members during the erection process and to hold them in alignment
3. In roof structures, to brace the bottom chord for uplift requirements imposed upon the structural system

None of these directly address the requirements of providing bracing to stabilize the compression diagonals on the verticals in a truss system. Examine the simple king post truss shown in Fig. 1.

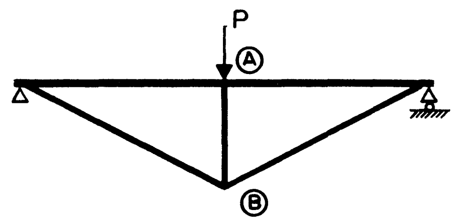

Fig. 1. King post truss

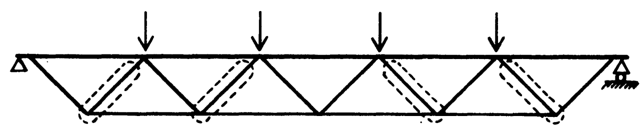

Figure 2

The designer of this truss, in all likelihood, would assume the column **A–B** to be pin-ended and restrained laterally at points **A** and **B.** In most cases, roof deck, floor deck or some other bracing means provide for lateral bracing at point **A.** If a lateral brace is not placed at point **B,** only the lateral stiffnesses of the tension diagonals are available to provide the lateral bracing.

Most engineers recognize the need for a tension chord brace for this situation. However, if one examines the more typical situation, shown in Fig. 2, similar stability requirements exist. All of the encircled compression diagonals are typically designed as pin-ended columns and require lateral bracing at their ends.

The bottom chord flexural strength and stiffness (into the plane of the paper), coupled with any bottom chord braces, must provide the required bracing for the compression diagonals. The tension diagonals of a joist or truss may contribute to the stability of the compression diagonals; however, to determine analytically the amount of contribution is beyond the scope of this paper. The opinion of the authors is that, in most ordinary situations, adequate bracing has been provided by default, because designers have followed bridging and bracing requirements based on the slenderness criteria of AISC and SJI, which may inherently provide the necessary bracing strength and stiffness. Without further study and evaluation, it is not known when these slenderness criteria will also satisfy the bracing requirements discussed here. Unfortunately, stability calculations are not fully understood by the practitioner or the theorist today; however, sufficient information does exist to perform rudimentary calculations.

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BRACING REQUIREMENTS

If the compression elements of a joist, joist girder or fabricated truss are designed using an effective length factor (K) equal to unity, then the ends of the compression element must be braced adequately so that the buckling mode of the column is consistent with the K equal to unity assumption. The bracing must satisfy both strength and stiffness criteria. Figure 3a illustrates a column buckled in the familiar sine curve shape.

The brace shown in Fig. 3b has a given strength F_{br} and a given stiffness β (kips/in.). The brace must prevent sidesway of the column in order for the column to reach P_{cr}. For the ideal column shown in Fig. 4, Yura[1] and others[2] have illustrated the strength and stiffness requirements as outlined.

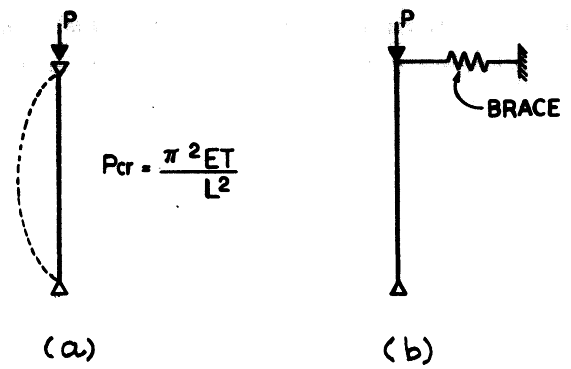

Figure 3

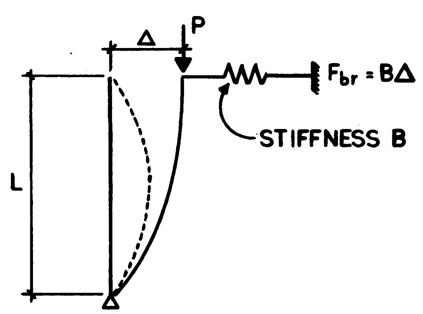

Figure 4

The stability of the column can be determined by displacing the column and then checking equilibrium of the deformed column. Thus, taking moments about the column base:

$$P\Delta = FL$$

$$P\Delta = \beta \Delta L$$

thus,

$$\beta L = P$$

This equation simply means that if β, the brace stiffness, is greater than P/L, then sidesway will not occur, and K can be assumed equal to one. If, however, β is less than P/L, then sidesway will occur, and K must be taken greater than one. For real columns, initial displacements are present and should be assumed as shown in Fig. 5.

Again, by displacing the structure and checking for equilibrium by summing moments about the column base,

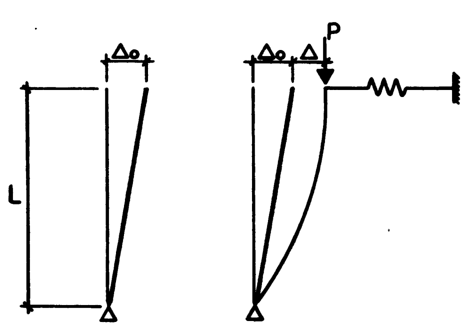

Figure 5

the following equation can be written:

$$P(\Delta_o + \Delta) = \beta \Delta L$$

Solving for β, $\beta = \dfrac{P}{L}\left(1 + \dfrac{\Delta_o}{\Delta}\right)$

The brace force $F_{br} = \beta\Delta$. Then,

$$F_{br} = P/L\,(\Delta + \Delta_o)$$

If one asumes a value for Δ_o of $0.002L$, which is the acceptable AISC out-of-plumbness for a column, and if one also assumes that Δ should not exceed Δ_o, then the stiffness requirement reduces to:

$$\beta = 2P/L$$

and the strength requirement to:

$$F_{br} = 0.004P$$

Using a factor of safety of 2 for stiffness, $\beta_{req} = 4P/L$. The factor of safety on the force requirement would be accounted for in conventional design equations for the brace. These two criteria,

$$\beta_{req} = 4P/L$$

and

$$F_{br} = 0.004P$$

must be achieved in the bracing system for the compression elements in question.

These requirements can best be illustrated in these examples:

Example 1—Determine the adequacy of the bridging system shown in Fig. 6 to laterally brace the end compression diagonal of the 24LH09 joist. Assume the force in the end compression diagonal is 19.5 kips, and that the bottom chord of joist is comprised of two angles with the following properties:

$I_y = 5.04$ in.^{4}

$S_y = 0.882$ in.^{3}

Solution: The strength and stiffness requirements are:

$$\beta_{req} = \frac{4P}{L} = \frac{4 \times 19.5}{3.6 \times 12} = 1.8 \text{ kips/in.}$$

$$F_{br} = 0.004P = 0.004\,(19.5) = 78 \text{ lbs}$$

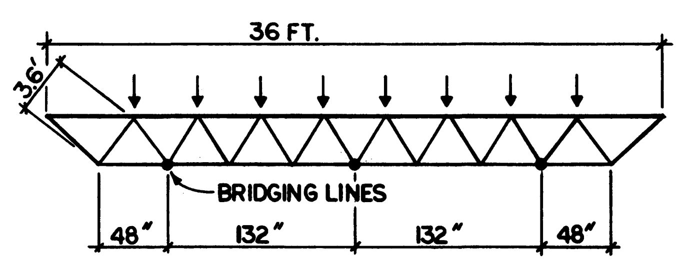

Figure 6

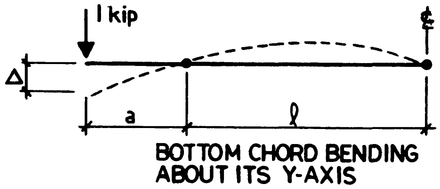

Figure 7

Assuming that the bridging is infinitely rigid and that bracing action is provided only by the y-axis bending of the bottom chord, the furnished stiffness and strength can be evaluated as follows:

Stiffness (see Fig. 7):

$$\Delta = \frac{Pa^2}{3EI}(1 + a) = \frac{1\,(48)^2\,(132 + 48)}{3(29{,}000)\,(5.04)} = 0.946 \text{ in.}$$

$$\beta_{furn} = 1/0.946 = 1.057 \text{ kips/in.} < 1.8 \text{ kips/in.}$$

n.g.

Strength—

Maximum moment about y-axis in tension chord:

$$M_y = 48\,F_{br} = 48(78) = 3{,}740 \text{ lb-in.}$$

$$\text{Bending stress } f_{by} = M_y/S_y = 3{,}740/0.882 = 4{,}500 \text{ psi}$$

The bending stress f_{by} must be added to the chord stress f_a from bending caused by the vertical loading.

Based on these calculations, the stiffness of the lower chord with the bridging spaced as assumed is insufficient to brace the end diagonal. Bridging should be placed at or closer to the junction of the end compression diagonals and the tension chord. If four bridging lines were used as shown in Fig. 8, the *minimum* stiffness of the 120-in. length of bottom chord (based on a simple beam analogy) would be:

$$\Delta = \frac{PL^3}{48EI} = \frac{(1)\,(120)^3}{48\,(29{,}000)\,(5.04)} = 0.246 \text{ in.}$$

$$\beta_{furn} = \frac{1}{0.246} = 4.06 \text{ kips/in.} > 1.8 \text{ kips/in.} \quad \textbf{o.k.}$$

This stiffness requirement is conservative, since the diagonals to be braced are not at the center of the 120-in. span. By inspection, adequate strength and stiffness exist to laterally support all interior diagonals of the joist.

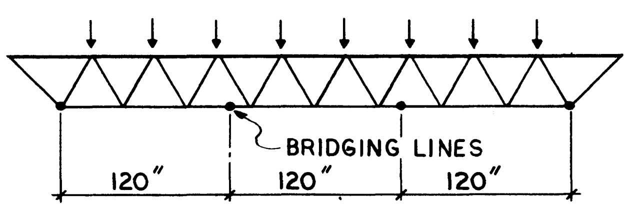

Figure 8

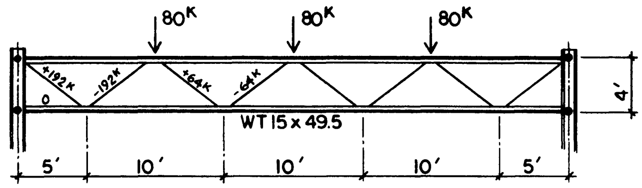

Figure 9

Example 2—For the truss shown in Fig. 9, determine the tension chord bracing requirements. Properties of the WT 15x49.5 are:

$$I_y = 63.9 \text{ in.}^4$$

$$S_y = 12.2 \text{ in.}^3$$

$$r_y = 2.10 \text{ in.}$$

Solution:

Based on the AISC Specification for maximum slenderness ratio of $L/r < 240$, the truss bottom chord would not require lateral bracing.

The reader should note that the bottom chord extension of the truss is shown as a zero force member. This was done here to simplify calculations. If continuity exists between the extension and the columns shown whereby moment could be developed at the joint, then the chord extension would have a compression load. To laterally brace the extension for the compression load, bracing calculations similar to those shown below could be made.

Since no bracing exists on the tension chord, the chord must be checked for its adequacy to brace the compression end diagonals and the interior compression diagonals.

Stiffness:

$$\beta_{req}{}^{192} = \frac{4 \times 192}{6.403 \times 12} = 10 \text{ kips/in.}$$

$$\beta_{req}{}^{64} = \frac{64}{192} \times 10 = 3.33 \text{ kips/in.}$$

Strength:

$$F_{br}{}^{192} = 0.004P = 0.004(192) = 0.77 \text{ kips}$$

$$F_{br}{}^{64} = 0.33 \times 0.77 = 0.25 \text{ kips}$$

For the end compression diagonal, determine the bracing criteria:

Determine furnished stiffness:

Since the tension chord must provide the lateral bracing stiffness for all the compression diagonals simultaneously, the lateral force from each diagonal will affect the stiffness of the tension chord in proportion to its magnitude. Thus, to find the stiffness at the end diagonal location a 1-kip force is used in conjunction with a $\frac{1}{3}$-kip force at an interior diagonal (one-third of the force exists at an interior diagonal). To find the stiffness at an interior location, a 1-kip force could be

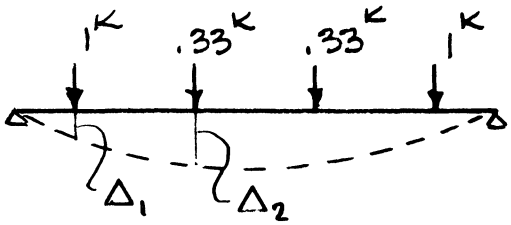

Figure 10

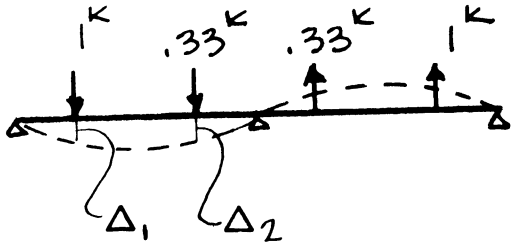

Figure 11

placed at an interior location in combination with 3-kip loads at the end diagonals; however, mathematically, the stiffness can be found from the deflection at the ⅓-kip location.

$\Delta_1 = 0.673$ in.

$\Delta_2 = 1.533$ in.

$\beta_1 = 1/0.673 = 1.486$ kips/in. $<$ 10 kips/in. **n.g.**

$\beta_2 = 33/1.533 = 0.215$ kips/in. $<$ 3.33 kips/in. **n.g.**

Bracing is inadequate by stiffness standards.

Try a lateral brace at midspan:

Determine furnished stiffness:

$\Delta_1 = 0.11$ in.

$\Delta_2 = 0.097$ in.

$\beta_1 = 1/0.11 = 9.091$ kips/in. $<$ 10.0 kips/in. **o.k.**

$\beta_2 = 0.33/0.097$
$= 3.40$ kips/in. $>$ 3.33 kips/in. **o.k.**

Calculate stresses:

Moment at the 1-kip load = 4.166 kip-in. (from statics)

$M_{by} = (0.77/1) \times 4.166 = 3.21$ kip-in.

$f_{by} = 3.21/12.2 = 0.26$ ksi

Add the center brace.

SUMMARY

A calculation procedure has been presented which allows the designer to determine the need for tension chord bracing for joists, joist girders and fabricated trusses.

Based on these procedures, it is apparent that serious consideration should be given to providing bracing to the tension chord of trusses and providing bridging lines at the first bottom chord panel point for steel joists. The equations upon which the calculation procedure is based are predicated upon the assumption that a P-Δ force develops for the compression member. These equations may be overly conservative for certain conditions. For example, since the majority of load is delivered to the end compression diagonals shown in Fig. 2 through the adjacent tension diagonal, when the tension chord displaces laterally the tension diagonal also displaces and delivers the load to the compression diagonal concentrically (see Fig. 12), thus the only P-Δ force that is developed may be that due to the panel point load. It would then appear that to stabilize trusses of the type described here, that one could use only the concentrated panel point loads in the bracing equations, as one would in the case of a Vierendeel truss. Until such time as research indicates this approach is justified, a more conservative approach should be taken.

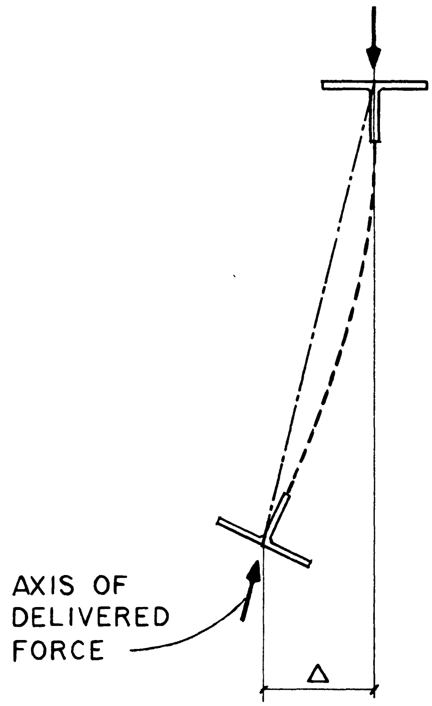

Figure 12

ACKNOWLEDGMENT

The author wishes to thank Prof. T. V. Galambos, University of Minnesota, and Prof. J. A. Yura, University of Texas, for their suggestions on this paper.

REFERENCES

1. *Yura, J. A.* Lecture Notes *AISC lectures on bracing.*
2. *McGuire, William* Steel Structures *Sect. 5.31, "Lateral Bracing of Columns and Beam-Columns," Prentice-Hall, Inc., 1968.*