Design Charts for Bolts with Combined Shear and Tension

HANS WILLIAM HAGEN AND RICHARD C. PENKUL

MECHANICAL FASTENERS which are subject to a combined shear and tensile stress occur most frequently in connections for diagonal bracing systems. Although the force in a diagonal may be reversible, the axial tensile force is more critical relative to the type of connections being discussed here. To facilitate calculations and to give the designer a feeling for the size of joints to be anticipated, it would be desirable to develop typical design charts.

DEVELOPMENT OF EQUATIONS

The AISC Specification recommends combined stress design equations for various fasteners used in either bearing- or friction-type connections. Only two of these cases will be considered here, viz., A325 bolts in bearing-type joints with threads excluded from the shear planes, and A325 bolts in friction-type joints. However, design charts similar to the ones included herein could readily be constructed for other fastener and joint-type combinations.

For the first case, the stress limitations are given as follows:

$$F_t = 50 - 1.6f_v \leq 40 \text{ and } f_v \leq 22 \quad (1)$$

where F_t = allowable tension stress, ksi
f_v = shear stress caused by shear component of applied force, ksi

This stress equation will be converted to a force equation by multiplying it by the total bolt area, A_b, to be used.

$$F_tA_b = 50A_b - 1.6f_vA_b \quad (2)$$

$$T = 50A_b - 1.6V \quad (3)$$

where $T \leq 40A_b$ = tensile component of applied force, kips
$V \leq 22A_b$ = shear component of applied force, kips

Hans William Hagen and Richard C. Penkul are Structural Engineers, LeMessurier Associates, Inc., Boston, Mass.

Hence, the required bolt area may be determined by

$$A_b = \frac{T + 1.6V}{50} \quad (4a)$$

or, when

$$T = 40A_b, \quad A_b = V/6.25 \quad (4b)$$

or, when

$$V = 22A_b, \quad A_b = T/14.8 \quad (4c)$$

See Fig. 1 for the force envelope corresponding to a unit bolt area.

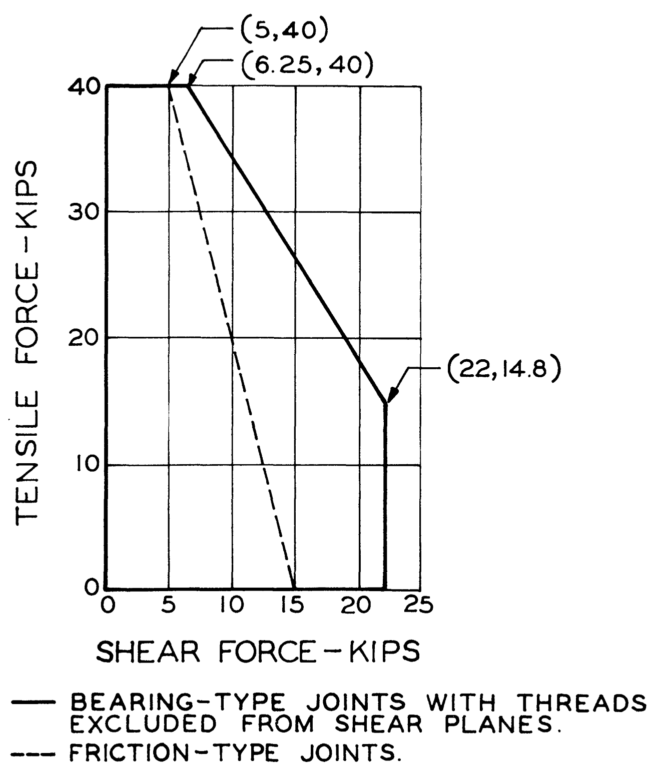


Fig. 1. Force envelope for A325 bolt area (A_b) = 1.0 in.²

In the second case, the stress requirements are as follows:

$$F_v \leq 15(1 - f_t A_b / T_b) \quad (5)$$

where f_t = tensile stress caused by tensile component of applied force, ksi

T_b = proof load of bolt, kips

This kind of equation would be readily adaptable for use in the construction of general design charts for bolts such as the A490 variety which exhibit a constant stress at the proof load for bolt diameters ½ in. to 2½ in. In the case at hand, however, Equation (5) does not offer sufficient flexibility since the proof load stress levels of A325 bolts decrease as the bolt diameters increase. The "average nominal proof load tensile stress," i.e., T_b/A_b, is approximately 60 ksi for bolt diameters ⅝- to 1¼-in. inclusive. If this value is substituted into Equation (5), the result is

$$F_t = 60 - 4f_v \leq 40 \text{ and } f_v \leq 15 \quad (6)$$

where F_t and f_v represent values previously defined. Again, the stress equation will be transformed into a force equation.

$$F_t A_b = 60A_b - 4f_v A_b \quad (7)$$

$$T = 60A_b - 4V \quad (8)$$

where $T \leq 40A_b$ = tensile component of applied force, kips

$V \leq 15A_b$ = shear component of applied force, kips

The required bolt area may then be obtained by

$$A_b = \frac{T + 4V}{60} \quad (9a)$$

or, when

$$T = 40A_b, \qquad A_b = V/5 \quad (9b)$$

See Fig. 1 for the force envelope corresponding to a unit bolt area.

Although the modified equation is adequate for bolt diameters up to and including 1 in., it is somewhat unconservative for 1⅛ and 1¼ in. diameter bolts — 12.6 and 5.5 percent, respectively—working at the maximum allowable tensile stress. Of course, this differential should be taken into account in an actual design. It should be noted, however, that this error diminishes as the ratio of shear to tension increases.

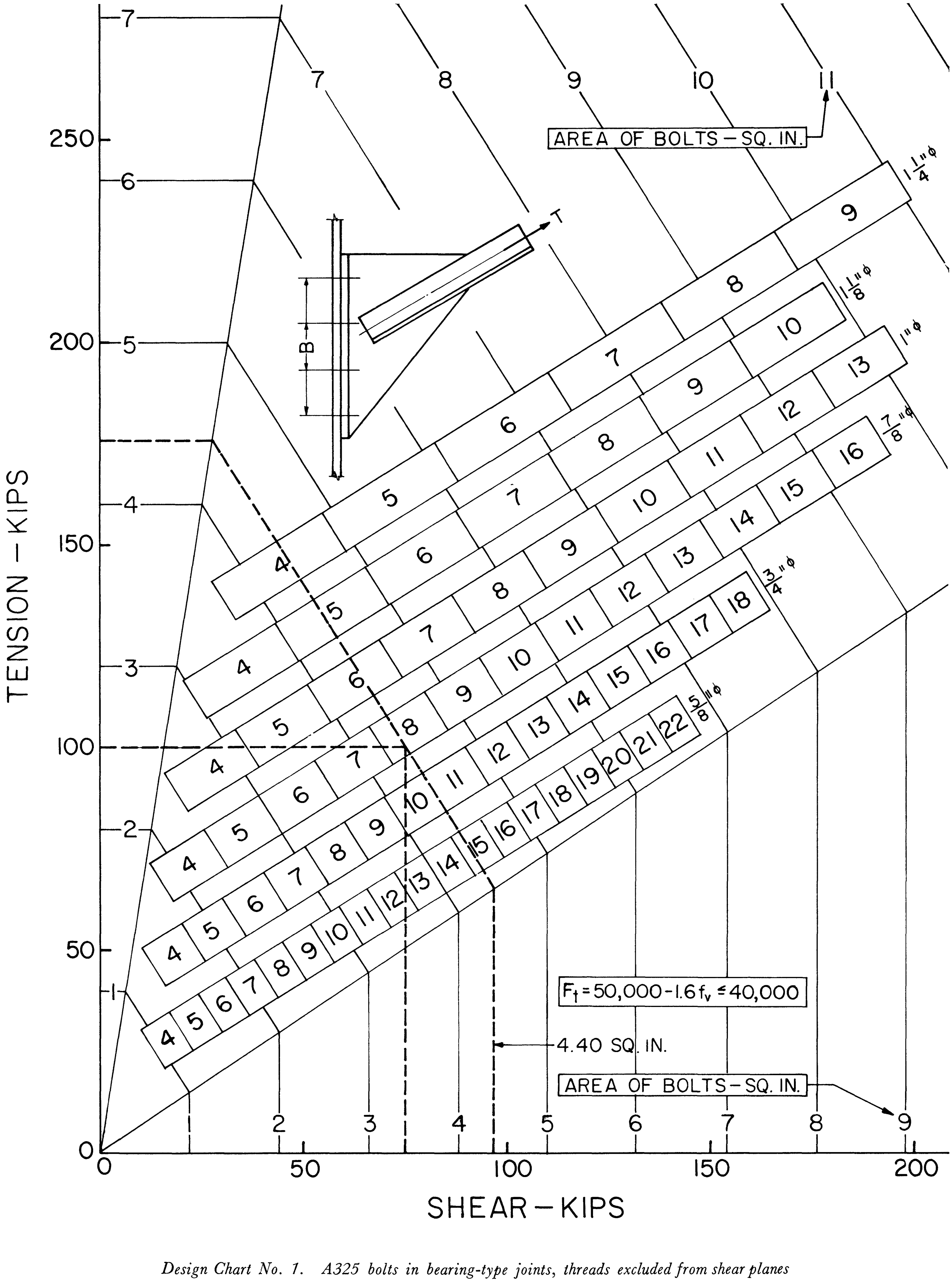
USE OF DESIGN CHARTS

Use of the design charts is quite simple. Suppose that it is required to design the column connection at the lower end of a diagonal member which carries a tensile force of 125 kips and whose slope is three vertically and four horizontally. Resolution of this force yields a shear force of 75 kips in the vertical direction and a tensile force of 100 kips in the horizontal direction. If the top end of the diagonal member is to be connected to a horizontal member, the values for shear and tension would, naturally, be interchanged.

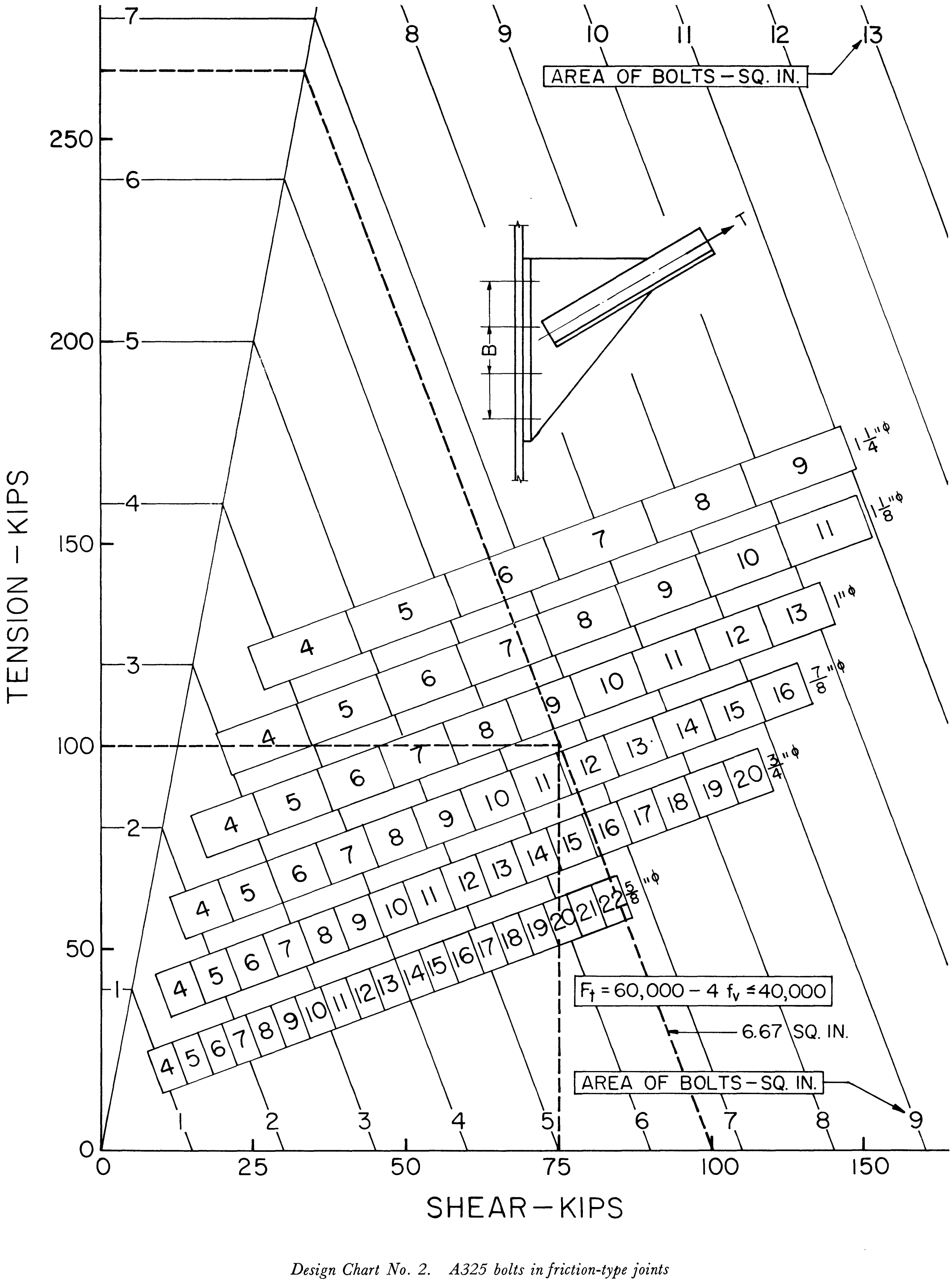
Locate the coordinate point (75, 100)—V, T—as shown on the two design charts. On Design Chart No. 1 this point falls on the outline of the force envelope corresponding to an A_b of 4.40 sq in., whereas on Design Chart No. 2 this point falls on the outline of the force envelope corresponding to an A_b of 6.67 sq in. To determine the size and quantity of bolts, scales of which have been superimposed on the charts, follow the boundary of the appropriate force envelope. When the applied load is to be sustained by a connection using A325 bearing-type bolts with threads excluded from the shear planes, Design Chart No. 1 offers the following choices: four 1¼ in., five 1⅛ in., six 1 in., eight ⅞ in., ten ¾ in., or fifteen ⅝ in. bolts. If a friction-type connection with A325 bolts is to be used, Design Chart No. 2 requires the following: six 1¼ in., seven 1⅛ in., nine 1 in., twelve ⅞ in., sixteen ¾ in., or twenty-two ⅝ in. bolts.

APPLICABILITY

It must be strongly emphasized that the validity of this design chart approach assumes that the external loads are applied at the centroid of the fastener groups. The existence of prying action in the connection materials may cause additional tensile forces in the bolts which must be added to those due to the external load. Also, no attempt has been made here to incorporate the plate thickness requirements; this must be done independently by the designer. Therefore, caution and judgment must be exercised as to applicability of these charts.



Design Chart No. 1. A325 bolts in bearing-type joints, threads excluded from shear planes



Design Chart No. 2. A325 bolts in friction-type joints