SECTION B2

LUGS AND SHEAR PINS

TABLE OF CONTENTS

B 2.0.0 Analysis of Lugs and Shear Pins

The method described in this section is semi-empirical and is applicable to aluminum or steel alloy lugs. The analysis considers loads in the axial, transverse and oblique directions. Each of these loads are treated in Sections B 2.1.0, B 2.2.0, and B 2.3.0 respectively. See Fig. B 2.0.0-1 for description of directions.

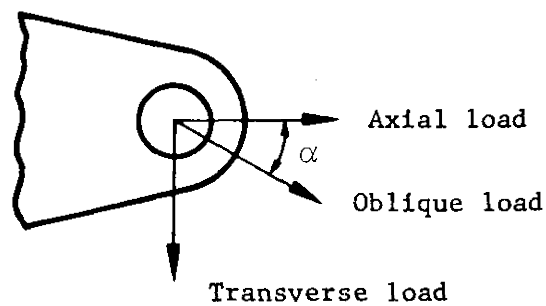

Fig. B 2.0.0-1

B 2.1.0 Analysis of Lugs with Axial Loading

A lug-pin combination under tension load can fail in any of the following ways, each of which must be investigated by the methods presented in this section:

1. Tension across the net section. Stress concentration must be considered.

2. Shear tear-out or bearing. These two are closely related and are covered by a single calculation based on empirical curves.

3. Shear of the pin. This is analyzed in the usual manner.

4. Bending of the pin. The ultimate strength of the pin is based on the modulus of rupture.

5. Excessive yielding of bushing (if used).

6. Yielding of the lug is considered to be excessive at a permanent set equal to .02 times pin diameter. This condition must always be checked as it is frequently reached at a lower load than would be anticipated from the ratio of the yield stress, F_{ty} to the ultimate stress, F_{tu} for the material.

Notes:

a. Hoop tension at tip of lug is not a critical condition, as the shear-bearing condition precludes a hoop tension failure.

b. The lug should be checked for side loads (due to mis-alignment, etc.) by conventional beam formulas (Fig. B 2.1.0-1).

Analysis procedure to obtain ultimate axial load.

1. Compute (See Fig. B 2.1.0-1 for nomenclature)

   e/D, W/D, D/t; $A_{br} = Dt$, $A_t = (W-D)t$

2. Ultimate load for shear-bearing failure:
   Note: In addition to the limitations provided by curves "A" and "B" of Fig. B 2.1.0-3, K_{br} greater than 2.00 shall not be used for lugs made from .5 inch thick or thicker aluminum alloy plate, bar or hand forged billet.

B 2.1.0 Analysis of Lugs with Axial Loading (Cont'd)

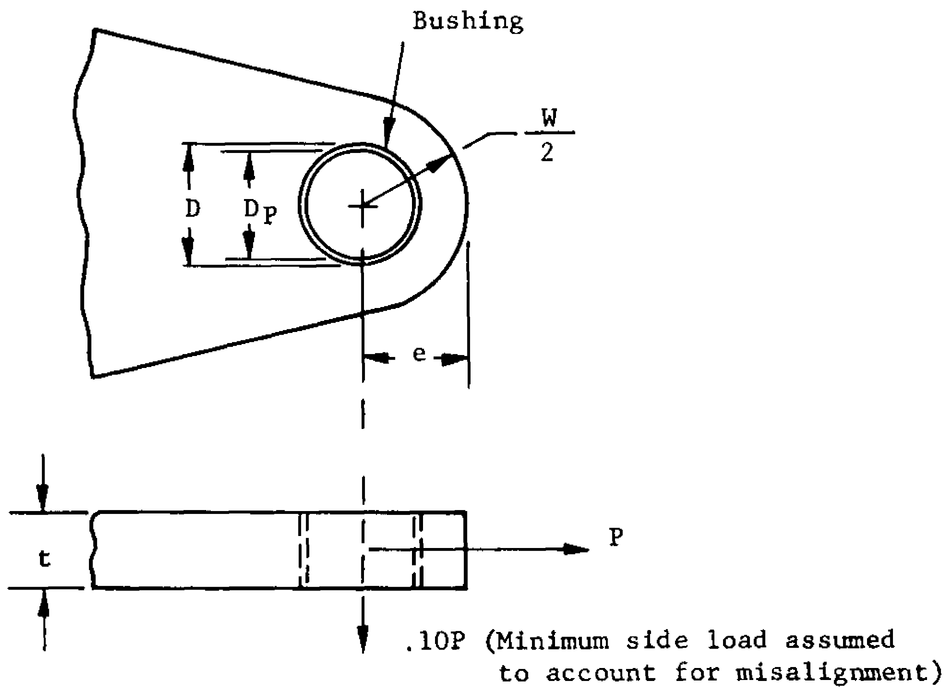

Fig. B 2.1.0-1

(a) Enter Fig. B 2.1.0-3 with e/D and D/t to obtain K_{br}

(b) The ultimate load for shear bearing failure, P'_{bru} is

$$P'_{bru} = K_{br} F_{tux} A_{br} \qquad (1)$$

where

F_{tux} = Ultimate tensile strength of lug material in transverse direction.

3. Ultimate load for tension failure:

(a) Enter Fig. B 2.1.0-4 with W/D to obtain K_t for proper material

(b) The ultimate load for tension failure P'_{tu} is

$$P'_{tu} = K_t F_{tu} A_t \qquad (2)$$

B 2.1.0 Analysis of Lugs with Axial Loading (Cont'd)

where

F_{tu} = ultimate tensile strength of lug material

4. Load for yielding of the lug

(a) Enter Fig. B 2.1.0-5 with e/D to obtain K_{bry}.

(b) The yield load, P'_y is

$$P'_y = K_{bry} A_{br} F_{ty} \quad \text{.........................} \quad (3)$$

where

F_{ty} = Tensile yield stress of the lug material.

5. Load for yielding of the bushing in bearing (if used):

$$P'_{bry} = 1.85 F_{ty} A_{brb} \quad \text{......................} \quad (4)$$

where

F_{ty} = Compressive yield stress of bushing material

$A_{brb} = D_p t$ (Fig. B 2.1.0-1)

6. Pin bending stress.

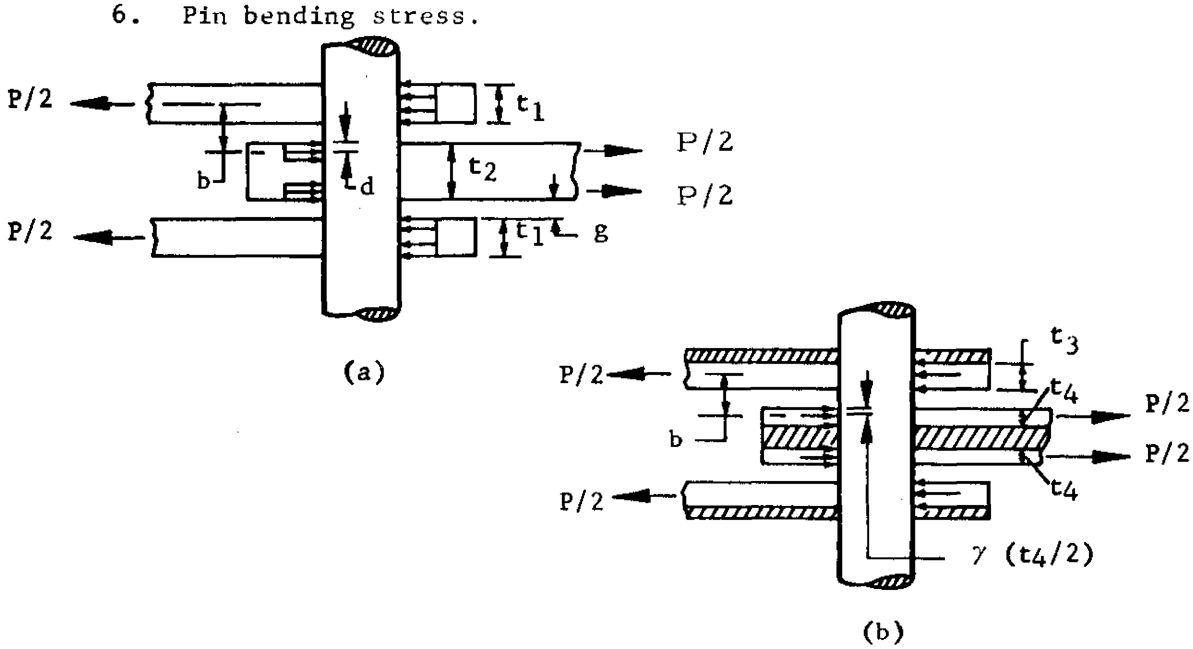

Fig. B 2.1.0-2

B 2.1.0 Analysis of Lugs with Axial Loading (Cont'd)

(a) Obtain moment arm "b" as follows:
(See Fig. B 2.1.0-2a) compute for the inner lug

$$r = \left[\left(\frac{e}{D}\right) - \frac{1}{2}\right] \frac{D}{t_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Take the smaller of P'_{bru} and P'_{tu} for the inner lug as $(P'_u)_{min}$ and compute $(P'_u)_{min}/A_{br}F_{tux}$.
Enter Fig. B 2.1.0-6 with $(P'_u)_{min}/A_{br}F_{tux}$ and "r" to obtain the reduction factor, "γ" which compensates for the "peaking" of the distributed pin bearing load near the shear plane. Calculate the moment arm "b" from

$$b = \left(\frac{t_1}{2}\right) + g + \gamma \left(\frac{t_2}{4}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

Where "g" is the gap between lugs as in Fig. B 2.1.0-2a and may be zero. Note that the peaking reduction factor applies only to the inner lugs.

(b) Calculate maximum pin bending moment M, from the equation

$$M = P \left(\frac{b}{2}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

(c) Calculate bending stress resulting from "M", assuming an My/I distribution.

(d) Obtain ultimate strength of the pin in bending by use of Section B 4.5.2. If the analysis should show inadequate pin bending strength, it may be possible to take advantage of any excess lug strength to show adequate strength for the pin by continuing the analysis as follows:

(e) Consider a portion of the lugs to be inactive as indicated by the shaded area of Fig. B 2.1.0-2b. The portion of the thickness to be considered active may have any desired value sufficient to carry the load and should be chosen by trial and error to give approximately equal Factors of Safety for the lugs and pin.

(f) Recalculate all lug Factors of Safety, with ultimate loads reduced in the ratio of active thickness to actual thickness.

(g) Recalculate pin bending moment, M = P (b/2), and Factor of Safety using a reduced value of "b" which is obtained as follows:

B 2.1.0 Analysis of Lugs with Axial Loading (Cont'd)

Compute for the inner lug, Fig. B 2.1.0-2b

$$r = \left[\left(\frac{e}{D} \right) - \frac{1}{2} \right] \frac{D}{2t_4} \quad \text{.................... (8)}$$

Take the smaller of P'_{bru} and P'_{tu} for the inner lug, based upon the active thickness, as $(P'_u)_{min}$ and compute $(P'_u)_{min}/A_{br}\,F_{tux}$, where $A_{br} = 2t_4\,D$. Enter Fig. B 2.1.0-6 with $(P'_u)_{min}/A_{br}\,F_{tux}$ and "r " to obtain the reduction factor " γ " for peaking. Then the moment arm is

$$b = \frac{t_3}{2} + g + \gamma \left(\frac{t_4}{2} \right) \quad \text{...................... (9)}$$

This reduced value of "b" should not be used if the resulting eccentricity of load on the outer lugs introduce excessive bending stresses in the adjacent structure. In such cases the pin must be strong enough to distribute the load uniformly across the entire lug.

7. Factor of Safety, F.S.
Compute the following Factors of Safety:

(a) Lug

$$\text{Ultimate F.S. in shear-bearing} = \frac{P'_{bru}}{P} \quad \text{...... (10)}$$

$$\text{Ultimate F.S. in tension} = \frac{P'_{tu}}{P} \quad \text{............. (11)}$$

$$\text{Yield F.S.} = \frac{P'_y}{P} \quad \text{......................... (12)}$$

(b) Pin

$$\text{Ultimate F.S. in shear} = \frac{F_{su}}{f_s} \quad \text{............... (13)}$$

$$\text{Ultimate F.S. in bending} = \frac{F_b}{f_b} \quad \text{............... (14)}$$

(c) Bushing (if used)

$$\text{Yield F.S. in bearing} = \frac{P'_{bry}}{P} \quad \text{.............. (15)}$$

An analysis for yielding of the pin and ultimate bearing failure of the bushing is not required.

B 2.1.0 Analysis of Lugs with Axial Loading (Cont'd)

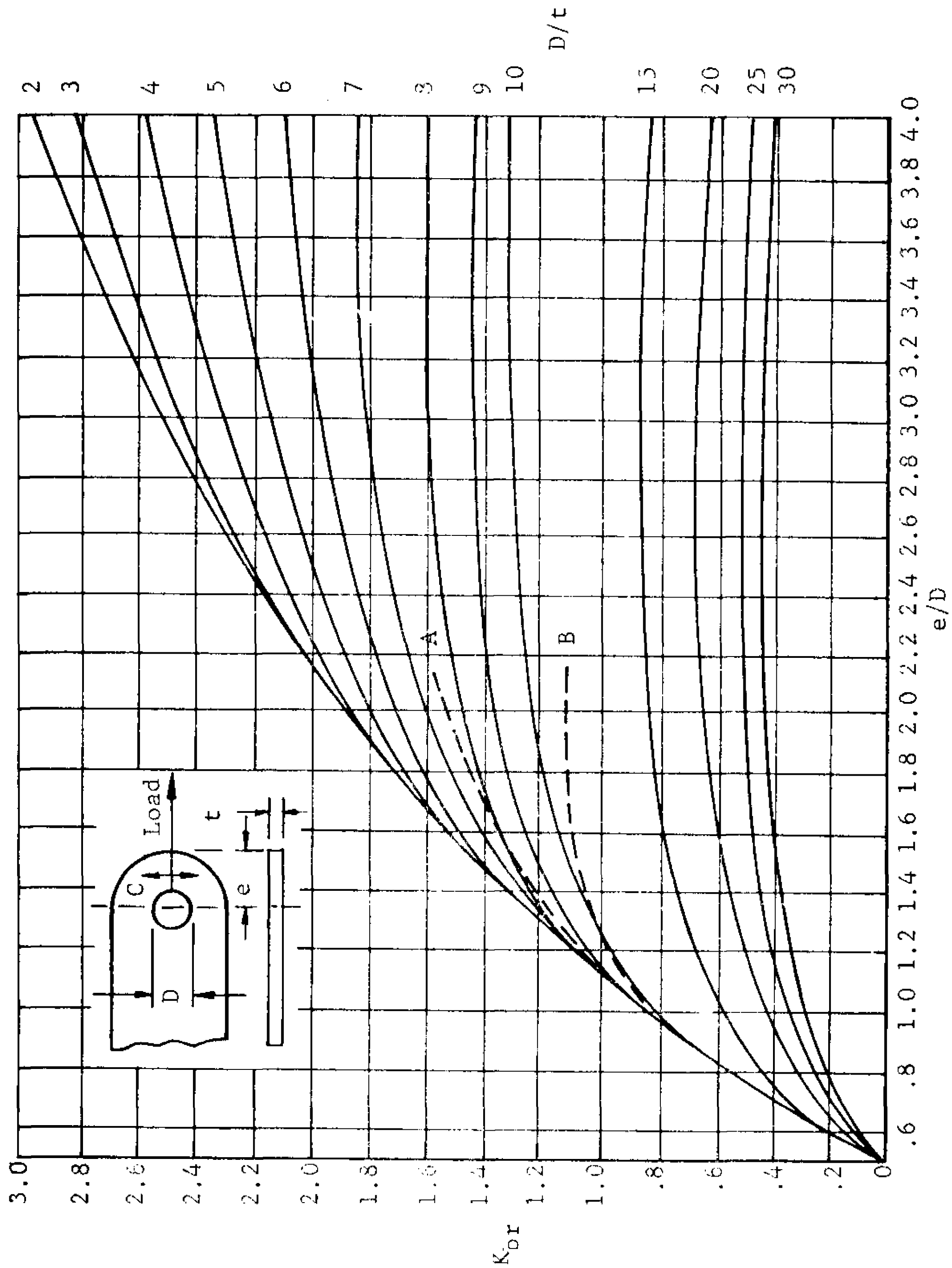

Fig. B 2.1.0-3

See notes on following page.

B 2.1.0 Analysis of Lugs with Axial Loading (Cont'd)

Curve A is a cutoff to be used for all aluminum alloy hand forged billet when the long transverse grain direction has the general direction C in the sketch.

Curve B is a cutoff to be used for all aluminum alloy plate, bar and hand forged billet when the short transverse grain direction has the general direction C in the sketch, and for die forging when the lug contains the parting plane in a direction approximately normal to the direction C.

B 2.1.0 Analysis of Lugs with Axial Loading (Cont'd)

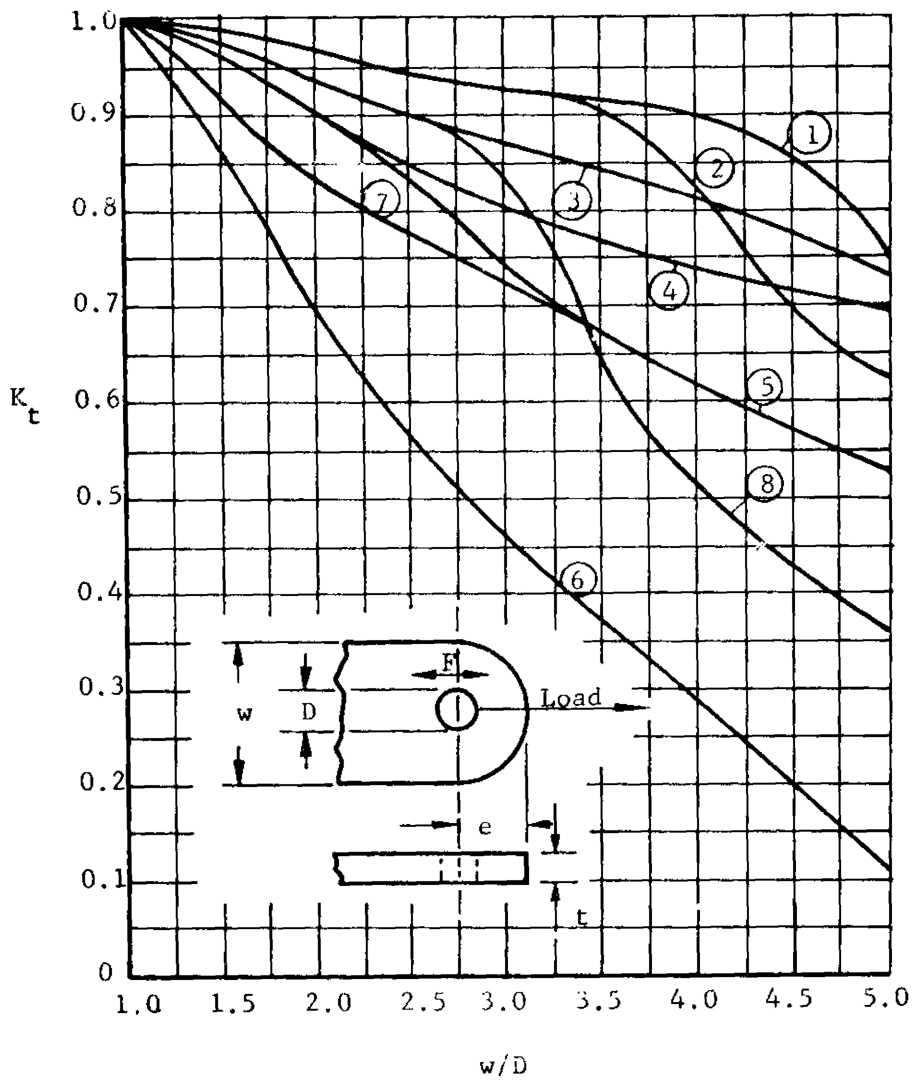

Fig. B 2.1.0-4

Legend on following pages.

B 2.1.0 Analysis of Lugs with Axial Loading (Cont'd)

Legend - Figure B 2.1.0-4 - L, T, N, indicate grain in direction F in sketch

L = longitudinal

T = long transverse

N = short transverse (normal)

Curve 1

4130, 4140, 4340 and 8630 steel
2014-T6 and 7075-T6 plate ≤ 0.5 in (L,T)
7075-T6 bar and extrusion (L)
2014-T6 hand forged billet ≤ 144 sq. in. (L)
2014-T6 and 7075-T6 die forgings (L)

Curve 2

2014-T6 and 7075-T6 plate > 0.5 in., ≤ 1 in.
7075-T6 extrusion (T,N)
7075-T6 hand forged billet ≤ 36 sq.in. (L)
2014-T6 hand forged billet > 144 sq.in. (L)
2014-T6 hand forged billet ≤ 36 sq.in. (T)
2014-T6 and 7075-T6 die forgings (T)
17-4 PH
17-7 PH-THD

Curve 3

2024-T6 plate (L,T)
2024-T4 and 2024-T42 extrusion (L,T,N)

Curve 4

2024-T4 plate (L,T)
2024-T3 plate (L,T)
2014-T6 and 7075-T6 plate > 1 in.(L,T)
2024-T4 bar (L,T)
7075-T6 hand forged billet > 36 sq.in. (L)
7075-T6 hand forged billet ≤ 16 sq.in. (T)

Curve 5

195T6, 220T4, and 356T6 aluminum alloy casting
7075-T6 hand forged billet > 16 sq.in. (T)
2014-T6 hand forged billet > 36 sq.in. (T)

B 2.1.0 Analysis of Lugs with Axial Loading (Cont'd)

Curve 6

Aluminum alloy plate, bar, hand forged billet, and die forging (N). Note: for die forgings, N direction exists only at the parting plane. 7075-T6 bar (T)

Curve 7

18-8 stainless steel, annealed

Curve 8

18-8 stainless steel, full hard, Note: for 1/4, 1/2 and 3/4 hard, interpolate between Curves 7 and 8.

B 2.1.0 Analysis of Lugs with Axial Loading (Cont'd)

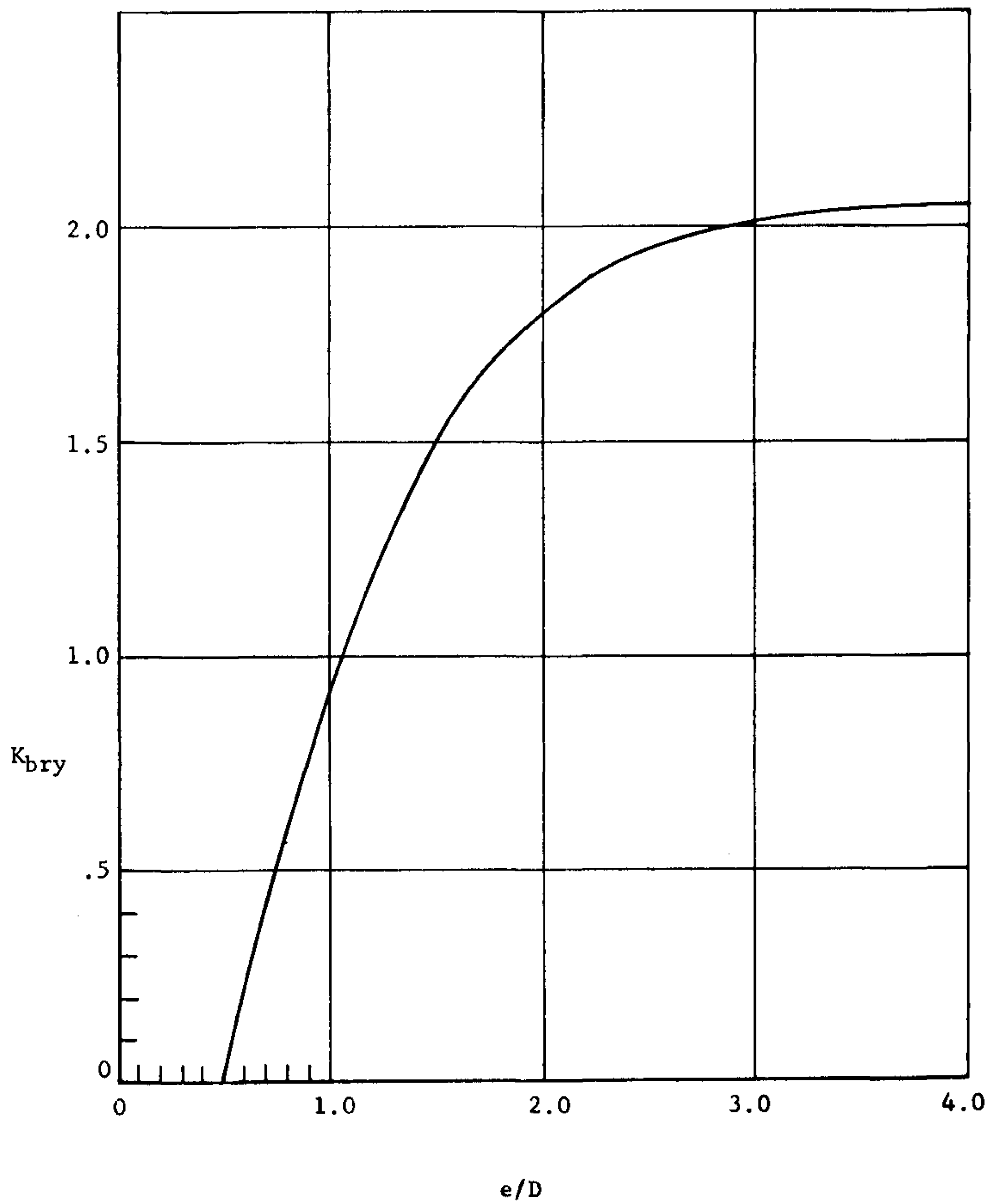

Fig. B 2.1.0-5

Peaking Factors for Pin Bending. Dash Lines Indicate Region Where These Theoretical Curves are not Substantiated By Test Data.

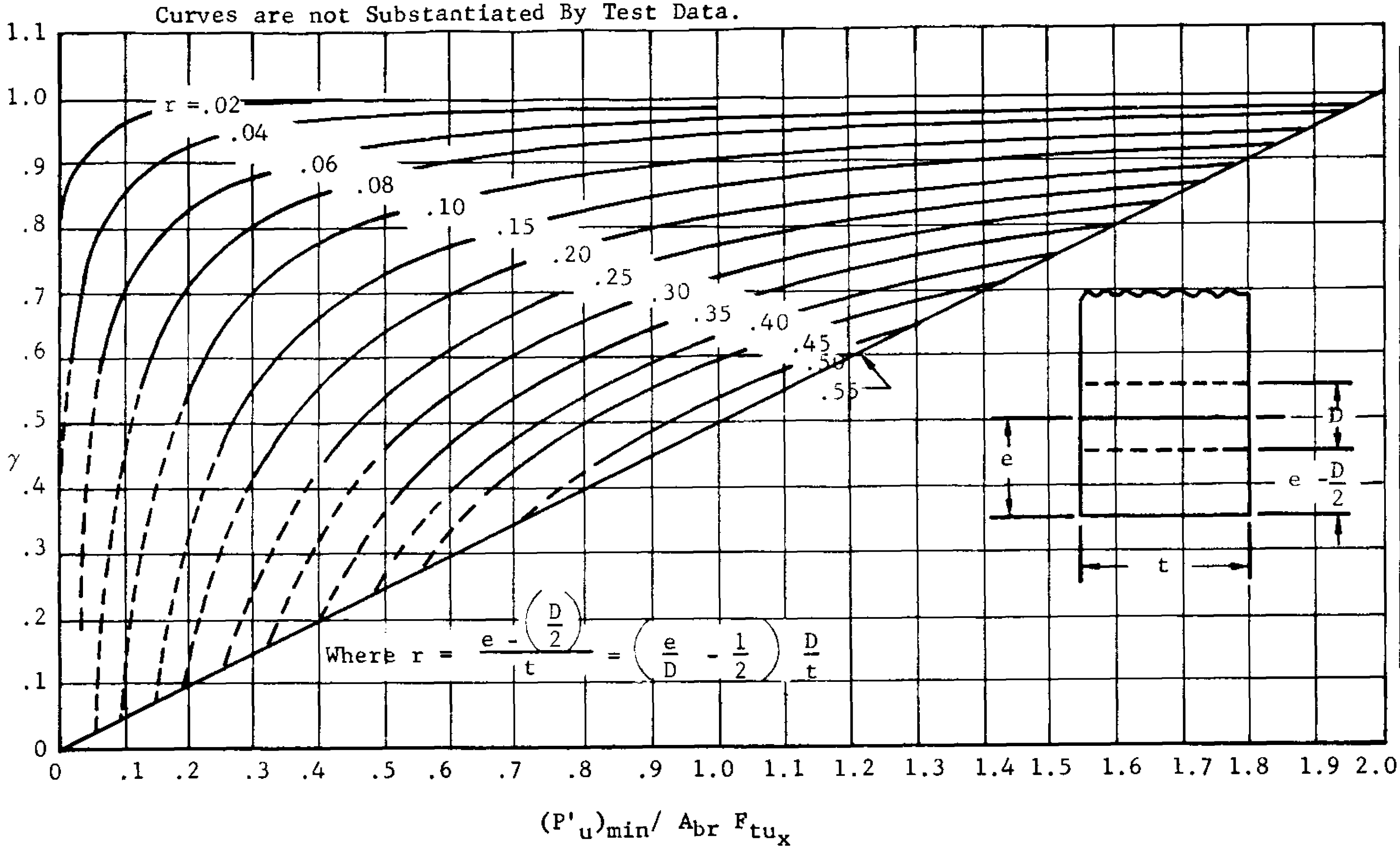

Fig. B 2.1.0-6

B 2.1.0 Analysis of Lugs with Axial Loading (Cont'd)

Special Applications

1. Irregular lug section - bearing load distributed over entire thickness.

For lugs of irregular section having bearing stress distributed over the entire thickness, an analysis is made based on an equivalent lug with rectangular sections having an area equal to the original section.

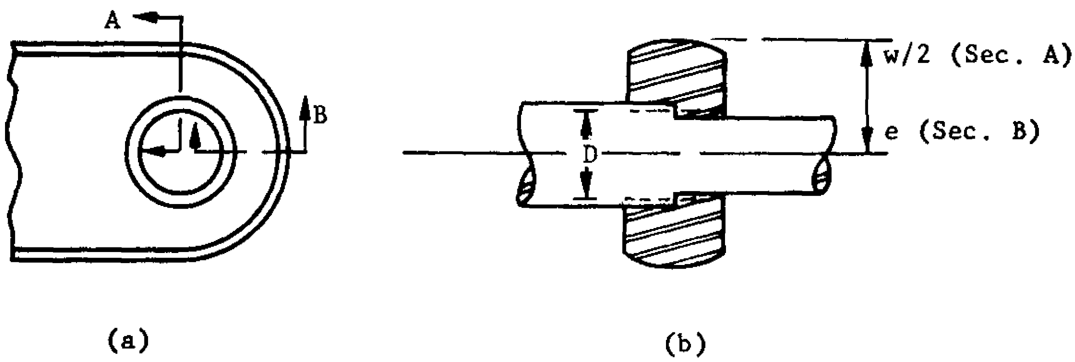

Fig. B 2.1.0-7

Dashed lines show equivalent lug

2. Critical bearing stress

NASA Design Manual Section 3.0.0 lists the values of the ultimate and yield bearing stress of materials for e/D values of 2.0 and 1.5, these are valid for values of D/t to 5.5. The ultimate and yield bearing stress for geometrical conditions outside of the above range may be determined in the following manner:

(a) Ultimate bearing stress: For the particular D/t and e/D, obtain K_{br} from Fig. B 2.1.0-3 then

$$F_{bru} = K_{br} F_{tux}$$

where

F_{tux} = Ultimate strength of lug material in transverse direction.

B 2.1.0 Analysis of Lugs with Axial Loading (Cont'd)

(b) Yield bearing stress: With the particular e/D obtain K_{bry} from Fig. B 2.1.0-5. Then

$$F_{bry} = K_{bry} F_{tyx}$$

where

F_{tyx} = Tensile yield stress of lug material in transverse direction.

3. Eccentrically located hole

If the hole is located as in Fig. B 2.1.0-8 (e_1 less than e_2), the ultimate and yield lug loads are determined by obtaining P'_{bru}, P'_{tu} and P'_y for the equivalent lug shown and multiplying by the factor

$$\text{factor} = \frac{e_1 + e_2 + 2D}{2e_2 + 2D}$$

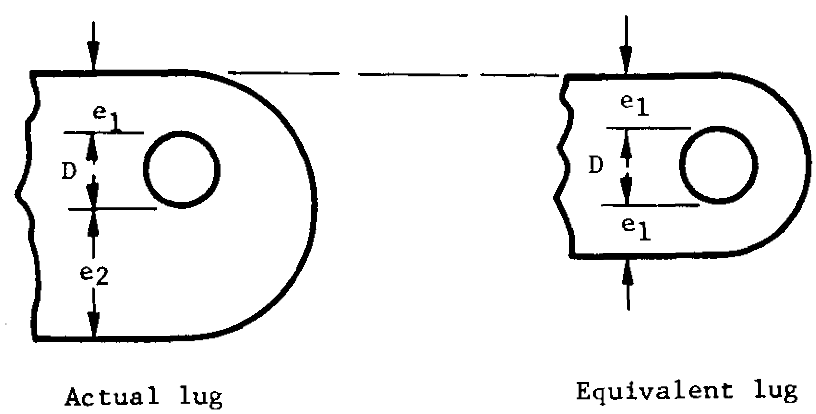

Fig. B 2.1.0-8

4. Multiple shear connections

Lug-pin combinations having the geometry shown in Fig. B 2.1.0-9 are analyzed according to the following criteria:

(a) The load carried by each lug is determined by distributing the total applied load "P" among the lugs as shown on Fig. B 2.1.0-9 and the value of "C" is obtained from Table B 2.1.0.1.

B 2.1.0 Analysis of Lugs with Axial Loading (Cont'd)

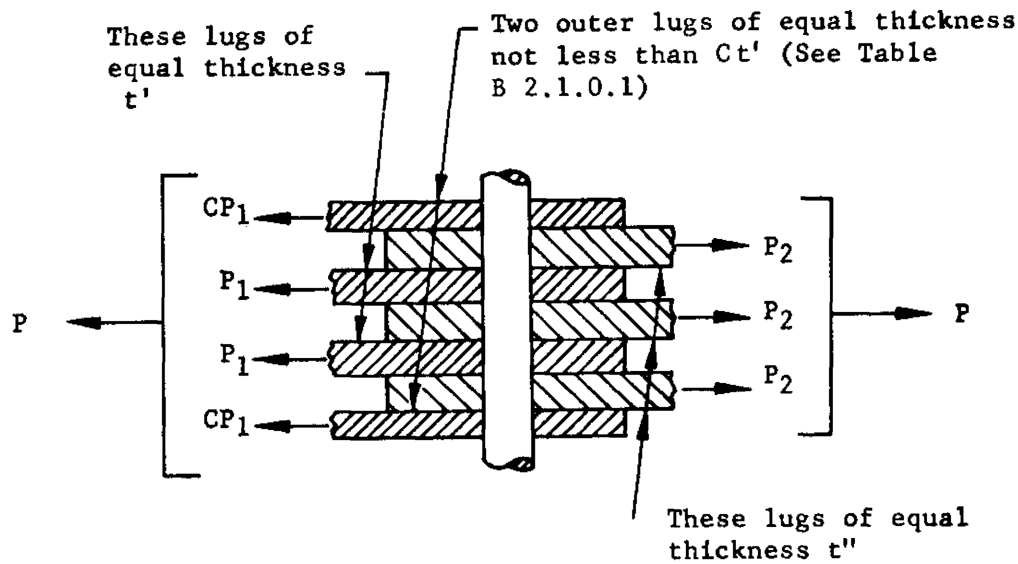

Fig. B 2.1.0-9

(b) The maximum shear load on the pin is given in Table B 2.1.0.1.

(c) The maximum bending moment in the pin is given by the formula, $M = \frac{P_1 b}{2}$ where "b" is given in Table B 2.1.0.1.

Table B 2.1.0.1

Total number of lugs including both sides	C	Pin Shear	b
5	.35	.50 P_1	.28 $\frac{t' + t''}{2}$
7	.40	.53 P_1	.33 $\frac{t' + t''}{2}$
9	.43	.54 P_1	.37 $\frac{t' + t''}{2}$
11	.44	.54 P_1	.39 $\frac{t' + t''}{2}$
∞	.50	.50 P_1	.50 $\frac{t' + t''}{2}$

B 2.2.0 Analysis of Lugs with Transverse Loading

Shape Parameter

In order to determine the ultimate and yield loads for lugs with transverse loading, the shape of the lug must be taken into account. This is accomplished by use of a shape parameter given by

$$\text{Shape parameter} = \frac{A_{av}}{A_{br}}$$

where

A_{br} is the bearing area = Dt

A_{av} is the weighted average area given by

$$A_{av} = \frac{6}{\left(\frac{3}{A_1}\right) + \left(\frac{1}{A_2}\right) + \left(\frac{1}{A_3}\right) + \left(\frac{1}{A_4}\right)}$$

A_1, A_2, A_3 and A_4 are areas of the lug sections indicated in Fig. B 2.2.0-1.

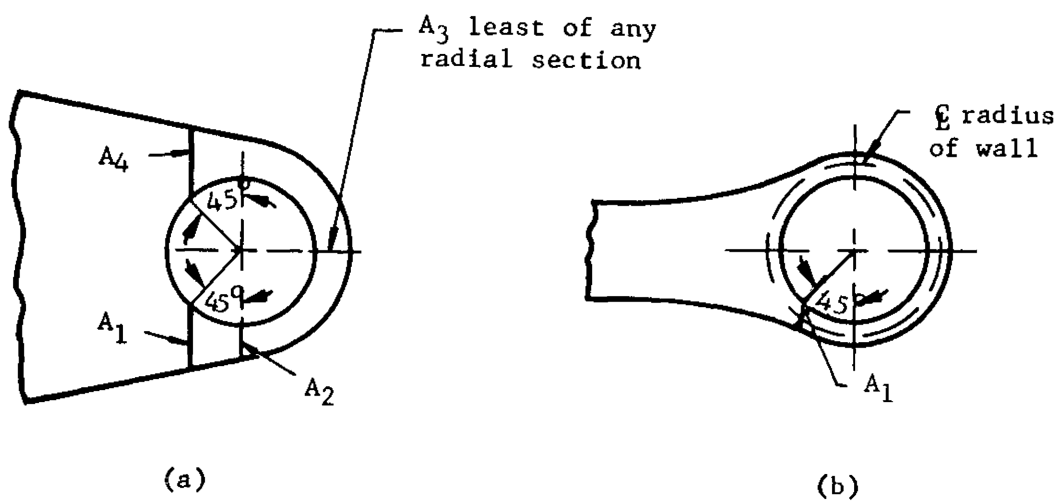

Fig. B 2.2.0-1

(1) Obtain the areas A_1, A_2, A_3, and A_4 as follows:

(1a) A_1, A_2, and A_4 are measured on the planes indicated in Fig. B 2.2.0-1a (perpendicular to the axial center line), except that in a necked lug, as shown in Fig. B 2.2.0-1b, A_1 and A_4 should be measured perpendicular to the local line.

B 2.2.0 Analysis of Lugs with Transverse Loading (Cont'd)

(1b) A_3 is the least area on any radial section around the hole.

(1c) Thought should always be given to assure that the areas A_1, A_2, A_3, and A_4 adequately reflect the strength of the lug. For lugs of unusual shape (e.g. with sudden changes of cross section), an equivalent lug should be sketched as shown in Fig. B 2.2.0-2 and used in the analysis.

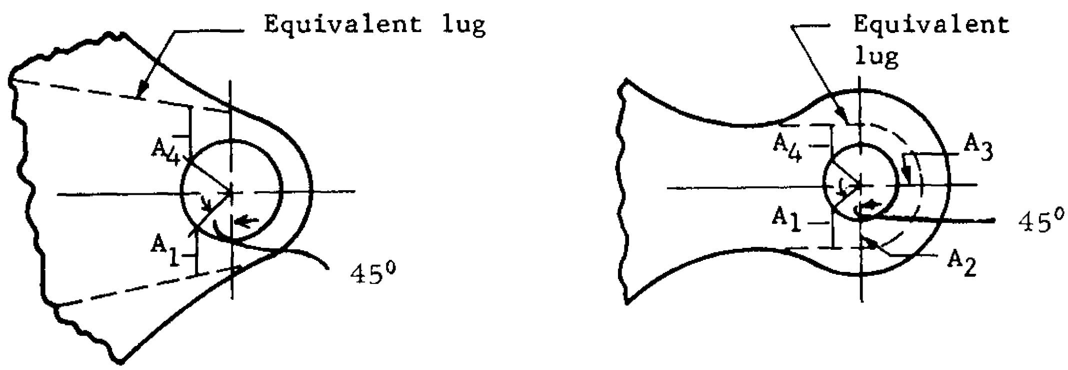

Fig. B 2.2.0-2

(2) Obtain the weighted average

$$A_{av} = \frac{6}{(3/A_1) + (1/A_2) + (1/A_3) + (1/A_4)}$$

(3) Compute $A_{br} = Dt$ and A_{av}/A_{br}

(4) Ultimate load P'_{tru} for lug failure:

(a) Obtain K_{tru} from Fig. B 2.2.0-4

(b) $P'_{tru} = K_{tru} A_{br} F_{tu_x}$

(5) Yield load P'_y of the lug:

(a) Obtain K_{try} from Fig. B 2.2.0-4

(b) $P'_y = K_{try} A_{br} F_{ty_x}$

(6) Check bushing yield and pin shear as outlined previously.

B 2.2.0 Analysis of Lugs with Transverse Loading (Cont'd)

(7) Investigate pin bending as for axial load with following modifications: Take $(P'_u)min = P'_{tru}$. In the equation $r = [e - (D/2)] /t$ use for the $[e - (D/2)]$ term the edge distance at $\alpha = 90^o$.

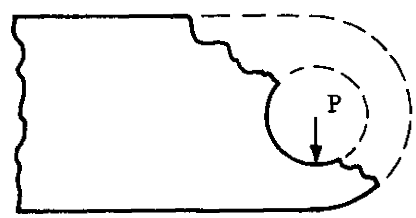

Fig. B 2.2.0-3

B 2.2.0 Analysis of Lugs with Transverse Loading (Cont'd)

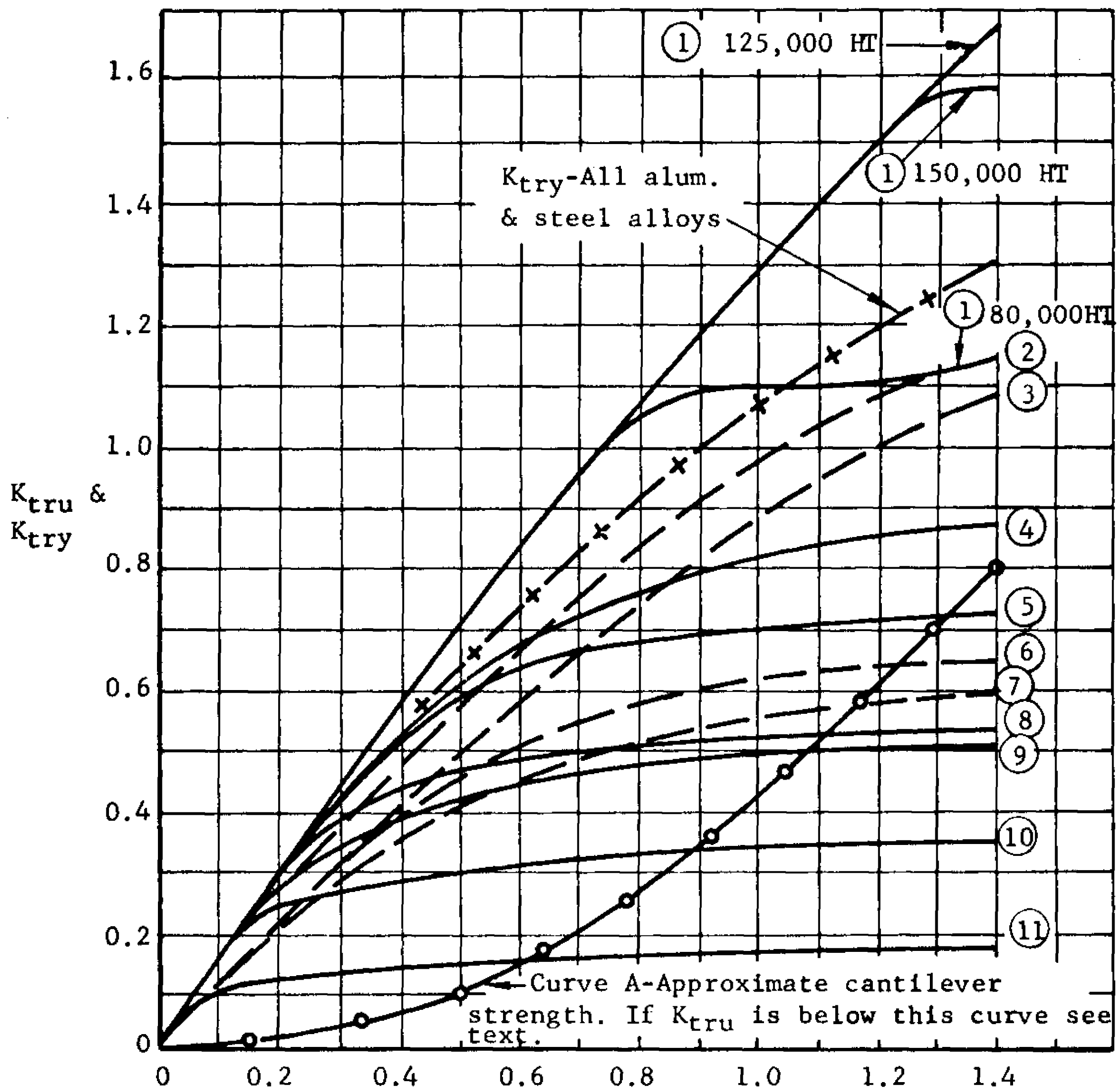

Fig. B 2.2.0-4

Legend on following pages

B 2.2.0 Analysis of Lugs with Transverse Loading (Cont'd)

Legend - Fig. B 2.2.0-4

Curve 1:

4130, 4140, 4340, and 8630 steels, heat treatment as noted.

Curve 2:

2024-T4 and 2024-T3 plate ≤ 0.5 in.

Curve 3:

220-T4 aluminum alloy casting

Curve 4:

17-7 PH (THD)

Curve 5:

2014-T6 and 7075-T6 plate ≤ 0.5 in.

Curve 6:

2024-T3 and 2024-T4 plate > 0.5 in., 2024-T4 bar

Curve 7:

195-T6 and 356-T6 aluminum alloy casting

Curve 8:

2014-T6 and 7075-T6 plate > 0.5 in., ≤ 1 in.
7075-T6 extrusion
2014-T6 hand forged billet ≤ 36 sq. in.
2014-T6 and 7075-T6 die forgings

Curve 9:

2024-T6 plate
2024-T4 and 2024-T42 extrusion

Curve 10:

2014-T6 and 7075-T6 plate > 1 in.
7075-T6 hand forged billet ≤ 16 sq. in.

B 2.2.0 Analysis of Lugs with Transverse Loading (Cont'd)

Legend - Fig. B 2.2.0-4 Cont'd

Curve 11:

7075-T6 hand forged billet > 16 sq. in.
2014-T6 hand forged billet > 36 sq. in.

All curves are for K_{tru} except the one noted as K_{try}
Note: The curve for 125,000 HT steel in Fig. B 2.2.0-4 agrees closely with test data. Curves for all other materials have been obtained by the best available means of correcting for material properties and may possibly be very conservative to some places.

In no case should the ultimate transverse load be taken as less than that which could be carried by cantilever beam action of the portion of the lug under the load (Fig. B 2.2.0-3). The load that can be carried by cantilever beam action is indicated very approximately by curve (A) in Fig. B 2.2.0-4, should K_{tru} be below curve (A), separate calculation as a cantilever beam is warranted.

B 2.3.0 Analysis of Lugs with Oblique Loading

Interaction Relation

In analyzing lugs subject to oblique loading it is convenient to resolve the loading into axial and transverse components (denoted by subscripts "a" and "tr" respectively), analyze the two cases separately and utilize the results by means of an interaction equation. The interaction equation $R_a^{1.6} + R_{tr}^{1.6} = 1$, where R_a and R_{tr} are ratios of applied to critical loads in the indicated directions, is to be used for both ultimate and yield loads for both aluminum and steel alloys.

where, for ultimate loads

R_a = (Axial component of applied load) divided by (smaller of P'_{bru} and P'_{tu} from Eq. 1 and Eq. 2.)

R_{tr} = (Transverse component of applied load) divided by (P'_{tru} from analysis procedure for α = 90 deg.)

and for yield load:

R_a = (Axial component of applied load) divided by (P'_y from Eq. 3.)

R_{tr} = (Transverse component of applied load) divided by (P'_{try} from Analysis Procedure for α = 90 deg.)

Analysis Procedure

(1) Resolve the applied load into axial and transverse components and obtain the lug ultimate and yield Factor of Safety from the interaction equation:

$$F.S. = \frac{1}{\left[R_a^{1.6} + R_{tr}^{1.6}\right]^{0.625}}$$

(2) Check pin shear and bushing yield as in Section B 2.1.0.

(3) Investigate pin bending using the procedure for axial load modified as follows:

$$\text{Take } (P'_u)_{min} = \frac{P}{\left(R_a^{1.6} + R_{tr}^{1.6}\right)^{0.625}}$$

In the equation $r = [e - (D/2)] / t$ use for the $[e-(D/2)]$ term the edge distance at the value of "α" corresponding to the direction of load on the lug.

B 2.3.0 Analysis of Lugs with Oblique Loading (Cont'd)

Reference

Melcone, M. A. and F. M. Hoblit, Developments in the Analysis of Method for Determining the Strength of Lugs Loaded Obliquely or Transversely, Product Engineering, June, 1953.