CHAPTER 4 STEEL

4.0

GENERAL PROPERTIES

- 4.00 The general strength properties and the related characteristics of various steels are listed in the tables at the end of this chapter. Particular attention should be paid to the detailed notes at the bottom of each table and to the general explanatory notes in Chapter 3. These tables will be revised and amplified from time to time as found necessary and to include new materials of construction.
- 4.1

COLUMNS

- 4.10 Column Formulas
- 4.100 Primary Failure. The general formulas for primary instability are given in Sec. 1.27. For convenience, these formulas are repeated in Table 4-1 in simplified form applicable to round steel tubes. These formulas also can be used for columns having cross sections other than those of round tubes when local instability is not critical.
- 4.101 Local Failure. Table 4-1 also contains notes concerning the local instability of round tubes. The local failure stresses for columns having cross sections of other shapes are given in the allowable stress curves at the end of this chapter.
- 4.102 Effects of Welding. The primary failure stress of a column having welded ends can be determined from the formulas of Table 4-1 without regard for the effects of welding. These stresses, however, should not exceed a "cut-off" stress which accounts for the effects of welding on the local failure of the column. In the case of X-4130 tubing having tensile yield stresses of 75,000 and 85,000 psi, the welding cut-offs are at stresses of 67,500 and 76,600 psi, respectively. See Sec. 4.510 for the effects of welding in other cases.
- 4.11 Column Stress Curves. Curves of the allowable column stresses for various types of steel tubing are given in Figs. 4-1 to 4-5. The allowable stress is plotted against the effective slenderness ratio which is defined by the formula:
 - L'/pvc ---- (4:1)
- 4.12 Column Load Curves. Figures 4-6 to 4-19 give the allowable loads of X-4130 round tube columns against length. It should be noted that these curves can be used for any condition of end restrain if the effective length of the column, L/\sqrt{c} , is used with the scale for c = 1.
- 4.2

BEAMS

4.20 General. See Sec. 1.21, Eq. 1:3, and Sec. 1.414 for general information on beams.

COLUMN FORMULAS FOR ROUND STEEL TUBES TABLE 4-1

F _{ty} -ps1 F _{co} -ps1 Short Columns Crittical (a) L'/ρ L'/ρ L'/ρ 56,000 36,000 36,000-1.172(L'/ρ)² 1:24 124 276x10 ⁶ /(L'/ρ)² 75,000 79,500 79,500-51.9(L'/ρ)³ 1:25 91.5 286x10 ⁶ /(L'/ρ)² 85,000 90,100 90,100-64.4(L'/ρ)³ 1:25 86.0 286x10 ⁶ /(L'/ρ)² 100,000 100,000-8.74(L'/ρ)² 1:24 75.6 286x10 ⁶ /(L'/ρ)² 155,000 155,000-15.92(L'/ρ)² 1:24 65.0 286x10 ⁶ /(L'/ρ)² 165,000 165,000-22.78(L'/ρ)² 1:24 58.9 286x10 ⁶ /(L'/ρ)²								
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	Material	F _{ty} -psi			e contraction of the contraction	Critical (b)	Long Columns (a)	Local
$\begin{array}{cccccccccccccccccccccccccccccccccccc$					Basic Eq.	Γ'/ρ	l	Failure
75,000 $79,500$ $79,500-51.9(1./\rho)^{1.5}$ $1;25$ 91.5 $286x10^6/(1./\rho)^2$ $85,000$ $90,100$ $90,100-64.4(1./\rho)^{1.5}$ $1;25$ 86.0 $286x10^6/(1./\rho)^2$ $100,000$ $100,000$ $100,000$ $100,000$ $100,000 100,000 15,000-8.74(1./\rho)^2 1;24 65.0 286x10^6/(1./\rho)^2 155,000 155,000 155,000-15.92(1./\rho)^2 1;24 58.9 286x10^6/(1./\rho)^2 1 155,000 165,000-25.78(1./\rho)^2 1;24 58.9 286x10^6/(1./\rho)^2 1 155,000 165,000-25.78(1./\rho)^2 1 1 1 1 1 1 1 1 1 $	1025	26,000	26,000	56,000-1,172(L'/p)2	1:24		276x10 ⁶ /(1,1/0)2	Mote (c)
85,000 90,100 $90,100-62,4(L'/\rho)^{1.5}$ 1:25 86.0 $286 \times 10^6/(L'/\rho)^2$ $100,000 100,000 100,000 -8.74(L'/\rho)^2$ 1:24 75.6 $286 \times 10^6/(L'/\rho)^2$ $155,000 135,000 135,000-15.92(L'/\rho)^2$ 1:24 65.0 $286 \times 10^6/(L'/\rho)^2$ 1:54 65.0 $286 \times 10^6/(L'/\rho)^2$ 1:54 65.0 $286 \times 10^6/(L'/\rho)^2$ 1:54 65.0 $165,000 - 25.78(L'/\rho)^2$ 1:24 68.9 $286 \times 10^6/(L'/\rho)^2$ 1	X-4130	75,000	79,500	79,500-51.9(1,/p)1.5	1,25		286x10 ⁶ /(1.1/2) ²	(a) each
100,000 100,000 100,000-8.74(L'/\rho) ² 1:24 75.6 286x10 ⁶ /(L'/\rho) ² 155,000 155,000 155,000 155,000 165,000 165,000 165,000-22.78(L'/\rho) ² 1:24 65.0 286x10 ⁶ /(L'/\rho) ² 1:24 58.9 286x10 ⁶ /(L'/\rho) ²	X-4130		90,100	(e) 90,100-64,4(L'/p)1.5	1:25		286×10 ⁶ /(1// ₂) 2	(a) Back
135,000 135,000 155,000-15.92(L'/p) ² 1:24 65.0 286x10 ⁶ /(L'/p) ² 165,000 165,000 165,000-22.78(L'/p) ² 1:24 58.9 286x10 ⁶ /(L'/p) ²	Heat-treated Alloy Steel		100,000	100,000-8,74(L'/o)2	1.24		(d/ T) / company	(၁) ဓာဂ္ဂလ
165,000 165,000-22.78(L'/p) ² 1:24 65.0 286x10 ⁶ /(L'/p) ²	Heat_treated Alloy Steel	155,000	135,000	2 / 1 1 000 3 K	2		zgeztu~/(L'/p)~	Note (c)
165,000 165,000-28.78(L'/p) ² 1:24 58.9 286x10 ⁶ /(L'/p) ²	Heat_treated (d)		200	_(d/,T)%8*CT-000*CGT	1:24		286x10 ⁶ /(L'/p) ²	Note (c)
	Alloy Steel		165,000	165,000-28.78(L'/p)a	1,24		286x10 ⁶ /(L'/p) ²	Note (c)

Note (a). L'/p = L/pv/6; L'/o shall not exceed 150 without specific authority from the procuring or

<u>ء</u>

licensing agency. Critical L/ρ is that above which columns are "long" and below which they are "short". Not necessary to investigate for local instability when D/t < 50. See Mechanical Properties Tables at end of Chapter. (e) ਦ ਦ Note Note Note Note

FOR USE ON CIVIL AIRPLANES ONLY. This formula applies only to tubing "as received". Is annealed and reheat-treated, the column formula based on Fty = 75,000 psi must be used.

STEEL

- Simple Beams. Beams of solid, tubular, or similar cross-sections can be assumed to fail through exceeding an allowable modulus of rupture in bending (F_b) . For solid sections, it usually can be assumed that F_b equals the ultimate tensile stress. This assumption is conservative and higher values may be used if substantiated by test data.
- 4.210 Round Tubes. For round tubes, the value of F_b will depend on the D/t ratio, as well as the ultimate tensile stress. Figure 4-20 gives the bending modulus of rupture for chrome molybdenum steel tubing.
- 4.211 Thin-walled Cylinders. Information on the failure of thin-walled cylinders in bending is given in Secs. 1.631 and 1.641.
- 4.212 <u>Unconventional Cross-sections</u>. Sections other than solid or tubular should be tested to determine the allowable bending stress.
- 4.22 Built-up Beams. Built-up beams usually will fail due to local failures of the component parts. In welded steel tube beams, the allowable tensile stresses should be reduced properly for the effects of welding.
- 4.23 Thin-web Beams. The allowable stresses for thin web beams will depend on the nature of the failure and are determined from the allowable stresses of the web in tension and of the flanges and stiffeners in compression. See Ref. 15 for general stress analysis methods.
- 4.3 TORSION
- 4.30 General. The torsion failure of steel tubes may be due to plastic failure of the metal, elastic instability of the walls, or to an intermediate condition. Pure shear failure usually will not occur within the range of wall thicknesses commonly used for aircraft tubing.
- 4.31 Allowable Torsional Shear Stresses. In the range of low values of D/t, no theoretical formula is applicable directly. The results of tests have been used to determine the empirical curves of Figs. 4-21 and 4-22.

For high values of D/t, the equations given in Sec. 1.632 can be used, provided that the allowable stress so determined does not exceed the proportional limit in shear.

- 4.4 COMBINED LOADINGS
- Round Tubes in Bending and Compression. The general theory of failure under combined loadings is given in Sec. 1.424. In the case of combined bending and compression it is necessary to consider the effects of secondary bending; that is, bending produced by the axial load acting in conjuncation with the lateral deflection of the column. In general, Eq. 1:37 Sec. 1.424 can be used in the following form for safe values:
 - $\frac{f_b!}{F_b!} + \frac{f_c}{F_c} = 1.0 - - - - - - (4:2)$

where fb' = maximum bending stress including effects of secondary bending.

Fb = bending modulus of rupture

 f_c = axial compressive stress

 $F_{\rm C}$ = allowable column stress

4.41 Tubes in Bending and Torsion. Equation 1:37, Sec. 1.424 can be used in the following forms for safe values:

Round tubes: $R_b^2 + R_s^2 = 1.0 - - - - - - (4:3)$

Streamline tubes: $R_b + R_S = 1.0 - - - - - - - (4:4)$

Higher values can be used if substantiated by adequate test data.

4.42 Tubes in Bending, Compression and Torsion. The bending stresses should include the effects of secondary bending due to compression. The following empirical equation will serve as a working basis, pending a more thorough investigation of the subject:

$$R_c + R_b! + R_s^2 = 1.0 - - - - - - - - - - - - - - - - (4:5)$$

In addition to using the above equation, the maximum normal compressive stress should also be determined. The latter should not exceed the yield stress of the material.

4.5

JOINTS, FITTINGS AND PARTS

- 4.50 Bolted and Riveted Joints.
- 4.500 Allowable Shear Stresses. The allowable shear stress for rivets, bolts and pins is given in Table 4-11.
- Allowable Bearing Stresses. The basic values of the allowable bearing 4.501 stresses for various steels will be found in the tables at the end of this REVISED chapter. These stresses are applicable only when the D/t ratio (diameter OCT '40 of rivet over thickness of sheet) is less than 5.5. When this ratio is equal to or greater than 5.5, the allowable bearing strengths must be substantiated by tests covering both yield and ultimate of the joint. The allowable bearing strength of steel sheets on rivets, bolts, and pins is given in Table 4-12. These values are to be used only for the design of the connecting elements of rigid joints when there is no possibility of relative movement between the parts joined without deformation of these parts. For other types of joints, the allowable bearing stresses are to be reduced by dividing by the factors of safety specified in Table 4-2 (designated as "bearing factors"), or are to be used in accordance with Table 4-3, whichever is applicable.

For antifriction bearings the critical <u>limit</u> load should not exceed the manufacturer's non-Brinell rating.

TABLE 4-2

MATERIALS FACTORS FOR PLAIN BEARINGS HAVING SMALL RELATIVE MOVEMENT

(The requirements of this table are mandatory on Army and Navy airplanes and are recommended on civil airplanes. Note also the requirements in CAR 04.271 to 04.277 inclusive which apply to civil airplanes.)

Type of Bearing	Shock or		T
	Vibration	Lubrication	Factor
Rigid connection, rivets, drive fit bolts, or taper pins, no relative movement.	None	None	1.0
Rigid connection, rivets, drive fit bolts, or taper pins, no relative movement.			
	Yes	None	1.5
Free fits, no relative rotation	None	None	1.5
Free fits, infrequent relative rotation.	None	None	2.0
Free fits, no relative movement.	Yes	Immaterial	2.0
Free fits, infrequent relative movement.	Yes	Immaterial	2.5

TABLE 4-3

ULTIMATE BEARING STRESS FOR PLAIN LUBRICATED BEARINGS HAVING FREQUENT RELATIVE MOVEMENT

(The requirements of this table are mandatory on Army and Navy airplanes and are recommended on civil airplanes. Note also the requirements in CAR 04.271 to 04.277 inclusive which apply to civil airplanes.)

Type of Bearing	Shock or	-	
Production of the control of the con	Vibration	Lubrication	lb./sq.in
Free fits, frequent relative movement, approximately 100 revolutions per hour (or equivalent) per flight.	None	Grease	15,000
Free fits, subject to very frequent relative movement with three or more bearings in line, sealed or protected.	None	Grease	12,000
Free fits, subject to very frequent relative movement with three or more bearings in line, unprotected from dirt.	None	Light Grease	8,000
Free fits, subject to very frequent relative movement with three or more bearings in line, unprotected from			,
dirt.	Yes	011	1,500

Hollow-end Rivets. If hollow-end rivets with solid cross-sections for a portion of the length (AN 450) are used, the strength of these rivets may be taken equal to the strength of solid rivets of the same material, provided that the bottom of the cavity is at least 25 percent of the rivet diameter from the plane of shear, as measured toward the hollow end, and further provided that they are used in locations where they will not be subjected to appreciable tensile stresses.

4.51 Welded Joints.

- 4.510 Effects of Welding on Base Metal. The allowable stresses in the base metal near the weld for steels that have been welded after heat treatment are given in the tables at the end of this chapter. When heat treated after welding, the allowable stresses should be reduced to 80 percent of the standard heat treated values.
- 4.511 Allowable Loads for Welded Seams. The allowable load on the weld metal in welded seams can be computed from the following formulas:

(Low carbon steel)

P = 32,000Lt - - - (4:6)

(Chrome-molybdenum steel)

P = .48 Lts. - - - (4:7)

where P = allowable load, lbs.

- L = Length of welded seams, ins.
- t = thickness of thinnest material joined by the weld in the case of lap welds between two steel plates or between plates and tubes, ins.
- t = average thickness in inches of the weld metal in the case of tube assemblies. (Cannot be assumed greater than 1.25 times the thickness of the welded stock).
- s = 90,000 psi for material not heat-treated after welding.
- s = ultimate tensile stress of material heat-treated after welding, but not to exceed 150,000 psi.
- Welded Cluster. In welded structures where 7 or more members converge, the allowable stress shall be determined by dividing the normal allowable stress by a materials factor of 1.5, unless the joint is reinforced in a manner for which specific authority has been obtained from the licensing or procuring agency. A tube that is continuous through a joint should be assumed as 2 members.
- 4.52 Brazed Joints. The term "brazing" is defined as a method of joining steel parts by means of a copper-zinc mixture which is applied by melting with an air-gas flame or dioping into the molten mixture. The strength of brazed joints depends upon the area and the clearances between the parts to be joined. A brazing mixture may have a shearing

strength as high as 40,000 pounds per square inch, but this strength is influenced by several factors, and, therefore, should not be used in design. In general a value of 10,000 pounds per square inch can be assumed as the allowable ultimate shear stress. Procedures and restrictions in the use of brazing will be found in the detailed requirements of the procuring or licensing agencies and should be observed carefully.

4.53 Tie Rods, Lugs and Cables. The rated strength of AN standard tie rods is given in Table 4-13. Tension lugs conforming with the dimensions in Table 4-13 show minimum margins of safety with respect to the strengths listed in column 2b of that table approximately as follows:

Bearing of pin in hole	15%
Shear in lug	25%
Tension across lateral section through hole	77 00'
Tension in necked down section aft of hole	1004

For lugs not conforming to the dimensions of Table 4-13, the strengths may be computed by the following methods:

$P_{t} = WtF_{t}$	whichever is	(4:8)
$P_t = (2R-D)tF_t$	smaller	(4:9)
$P_b = DtF_{br}$		(4:10)
P _S = (2R-D)tF _S		(4:11)

where:

Pt = Allowable tensile strength in the shank or eye in pounds.

 P_{br} = Allowable bearing strength on the pin in pounds.

Ps = Allowable shearing strength in the eye in pounds.

D = Diameter of pin in inches.

t = Thickness of lug in inches.

R = Outside radius of eye and radius at base of eye in inches.

W = Minimum width of shank in inches.

 $.F_{t}$ = Allowable ultimate tensile stress.

F_{br} = Allowable bearing stress.

 F_s = Allowable shearing stress.

The strength of steel cable is given in Table 4-14.

STEEL

4.530 REVISED OCT '40	Cable Terminal Efficiency. In calculating the strength of aircraft cables and wires the following efficiencies shall be used:
	Flexible and extra flexible cable
	(7 x 7 flexible and 7 x 19 extra flexible cable with Army (Navy) full five tuck splice) 75%
	Hard wire (loop terminal equipped with shakle and ferrule) 85%
	19 strand wire (with wrapped and soldered splice)

	•		M ECHA NI ÇA	TABLE 4 _ 4			10253	STEEL
			CONDITION		1 BEFORE WELDING	AFTER WELDING ³ (PROPERTIES IN AFFECTED ZONE)	3	4
				ARMY	TUBE 57-180-1	TUBE 57-180-1		
		SPECT	FICATION \	NAVY	TUBE 49-T-1	TUBE. 49-T-1		
		SPECT	ricalion	FEDERAL	SHEET QQ-S-651 BAR QQ-S-646	SHEET QQ-S-651 BAR QQ-S-646		
			<u></u>	SAE				
	1	Ftu	Ultimate Stress,	psi	55 000	45 000		
NO.	2	F _{ty}	Yield Stress,	psi	36 000			
TENSION	3	F _{tp}	Proportional Limit	, psi	25 000			
[□	4	E	Modulus of Elastic	ity, · psi	28 000 000			
	5		Elongation in 2 in	. , %				
	6	Fou	Ultimate (block) St	tress, psi	65 000			
COMPRESSION	7	Fcy	Yield Stress,	ps1	36 000			
PRES	8	Fop	Proportional Limit	, psi	25 000			
ŝ	9	F _{eo.}	Column Yield Stress	, psi	36 000			
	10	Eo	Modulus of Elastic	ty, pai	28 000 000 `	<u>.</u>		
5	11	F _{su}	Witimate Stress,	psi	35 000			
	162	F _{st}	Torsional Modulus of Rupture,	of psi	50 000	·		
SHEAR	13	13 F _{sp} Proportional Limit (torsion),		psi	20 000			
	14	G	Modulus of Rigidity (torsion),	psi	10 000 000			
ပ္ခ	15	Fbr	Ultimate Stress,	psi	90 000			
BEARING	16		Rockwell Number					
<u> </u>	17		Brinell Mumber					
FATIGUE	18	Fbe	Bending Endurance 1 (300,000,000 cycles completely reverse	s of	25 000			
FAT	19	F _{se}	Torsional Endurance (20,000,000 cycles completely reverse	of				·
	20	₩	Specific Weight,	0.2833	lb/cu in.	490 lb/cu ft.		
	21		Nominal Chemical Composition	on 0.25% (., .65 Mm, .045% P(max.), .050% S (max.)	
	22	REMAR	1. See notes in 2. Where joints line, or fish allowable ter 3. In welded str stress shall materials fac which specifi	with tapered we e-mouth welds for usile stress near vetures where a be determined to the of 1.5, unless a suthority has	ormed by cuts of 60 or the welding can seven or more membe by dividing the nor less the joint is results of the contract of th	O degrees or less to degrees or less are be assumed to be 50, rs converge, the all med allowable stress eenforced in a manne m the licensing or p oint should be assum	oused, the COO psi. Lowable s by a or for procuring	

			MECHA NI CA	TABLE 4 - 5	(REVISED OCT 40)		ALLOY S	STEELS
			CONDITION		1) ANNEALED PLATE AND EAR (OVER 1 1/2" THICK)	ANNEALED PLATE, TUBE, AND BAR(1 1 THICK AND UNDER)	(3) NEAR WELDING, 3 WHEN WELDED AFTER HEAT TREATMENT	(4) NEAR WELDING, 3 WHEN WELDED AFTER HEAT TREATMENT (X-4130)
				ARMY				
				NAVY				
		SPECIF	ICATION	FEDERAL				
				SAE				
1	1	Ftu	Ultimate Stress,	psi	55 000	65 000		80 00L 4
-	2	F _{ty}	Yield Stress,	psi	36 000	45 000	SEE COLUMNS	
rension	3	F _{tp}	Proportional Limit	, psi	25 000	30 000	(1) and (2)	
NEL .	4	Е	Modulus of Elastic	ity, psi	29 000 000	29 000 000	FOR PHYSICAL	29 000 000
	5	· ·	Elongation in 2 in	., %			PROPERTIES	
-	6	Fou	Ultimate (block) S	tress, psi	55 000	65 000		67 500
TON I	7	Foy	Yield Stress,	psi				
COMPRESSION	8	Fep	Proportional Limit		25 000	30 000		
OMP	9	Foo	Column Yield Stres		36 000	36 000		
)	10	Ea	Modulus of Elastic	ity, psi	29 000 000	29 000 000		29 000 000
	11	Fau	Ultimate Stress,	psi	35 000	40 000		50 000
SHEAR	12	Fst	Torsional Modulus Rupture,	of psi	50 000	55 000		70 000
	13	F _{sp}	Proportional Limit (torsion),	psi	20 000	25 000		35 000
	14	G	Modulus of Rigidit (torsion),	psi	11 000 000	11 000 000		11 000 000
	15	Fbr	Ultimate Stress,	psi	90 000	110 000		125 000
BEARING	16		Rockwell Number				<u> </u>	
E	17		Brinell Number	· · · · · · · · · · · · · · · · · · ·				
FATIGUE	18	Fbs	Bending Endurance (300,000,000 cycl completely revers	es of	25 000	30 000		16 000
FAT	19	Fse	Torsional Enduran (20,000,000 cycle completely revers	s of ed stress)				
	20	π	Specific Weight,	÷ • 0,28	3 lb/cu in.	490 lb/ou ft.		
	21		Nominal Chemical Composit	ion				
	22	REMA	1. See notes: 2. Except as: alloy stee; display the stress. 3. In welded stress she materials which spee agency. A two member 4. Where join line, or i allowable 5. Butt, fist	acted, the values containing I approperties gistructures when the determination of 1.5, ific authority tube that is the with tapere is hemouth wold	ess than 1/2 perceven in the column reserven or more med by dividing the unless the joint has been obtained continuous through dwelds at angles a formed by outs of	able apply to any of nt carbon. Any of the corresponding to its embers converge, the normal allowable at its reenforced in a mit from the licensing of a joint should be as of 30 degrees or less of 60 degrees or less can be assumed to be doning tubing. Flash	allowable ellowable ess by a mner for or procuring ssumed as a to the centor are used, the 90,000 psi.	

	_							
			M ECHA NI CA	TABLE 4 - 6	(REVISED OCT 40)		ALLOY	STEELS
			CONDITION		(1) NORMALIZED PLATE TUBE AND BAR OVER .189* THICK (X-4130)	NORMALIZED PLATE TUBE AND BAR188" THICK AND UNDER (X-4130)	NEAR WELDING (2) WHEN WELDED AFTER HEAT TREATMENT (X-4130) SPECIAL	MORMALIZED (2) TUBES188" THICK AND UNDER (X-4130) SPECIAL
				ARMY		_	l	
		n n n a x n	CATION	navy	BAR RD.TUBING 44T18 STR.TUBING 44T17	RD. TUBING 44T18 STR. TUBING 44T17		
		PLECIE	ICATION	FEDERAL				
			·	SAE	X-4130	X-4130	X-4130	X-4130
	1	Ftu	Ultimate Stress,	psi	90 000	95 000	84 100 (4)	100 000
_	2	Fty	Yiold Stress,	psi	70 000	75 000		85 000
TENSION	3	F _{tp}	Proportional Limit	, psi	50 000	-	_	
TE.	4	E	Modulus of Elastic	ity, psi	29 000 000	29 000 000	29 000 000	29 000 000
ŀ	5		Elongation in 2 in	. , %				12
-					90 000	95 000	76 600	100 000
NG.	6	Fcu	Ultimate (block) S				1.0 027	85 000
COMPRESSION	7	Foy	Yield Stress,	psi.	70 000	75 000		00 000
MCPR	8	Fep	Proportional Limit		50 000			00,100
8	9	Fee	Column Yield Stres		74 100	79 500		90 100
	10	Eo	Modulus of Elastic	ity, psi	29 000 000	, 29 000 000	29 000 000	29 000 000
AR	11	F _{su}	Ultimate Stress,	psi	55 000	55 000	52 500	58 000
	12	Fst	Torsional Modulus Rupture,	of psi	80 000	80 000	73 500	84 000
SHEAR	13	F _{sp}	Proportional Limit (torsion),	psi	40 000	40 000		·
	14	Modulus of Rigidity (torsion).		y psi	21 000 000	11 000 000	11 000 000	11 000 000
<u>e</u>	15	Fbr	Ultimate Stress,	psi/	140 000	140 000	130 000	147 000
BEARING	16		Rockwell Number					<u> </u>
H	17		Brinell Number					
CUE	18	Fbe	Bending Endurance (300,000,000 cycle completely reverse	s of .	45 000	45 000		
PATIGUE	19	F ₅₀	Torsional Endurance (20,000,000 cycles completely reverse	r of				
	20	Ħ	Specific Weight,		lb/cu in.	490 lb/cu ft.		
	21		Nominal Chemical Composit	lon				
	22	REMAR	RKS					
			Their use is guaranteed to tubing "as a 4 of Table of Table of Table of 1.5, unlines been obtinuous thrules the form to the form to the form to the table of the form to the table of	ics in this lin s permissible p my the manufact received. If i - 5 and column tructures where termined by div ses the joint i tained from the bugh a joint sh s with tapered sh mouth welds	royided that the turer of the tubing annealed and rehee n ? of this Table seven or more men iding the normal as reenforced in a licensing or procuid be assumed as welds at angles of formed by cuts of	thers converge, the dilowable stress by a manner for which spanning agency. A til	apply only to sprties in column sellowable stress a materials factor soific authority se that is couto to the center are used, the	

1 F _t 2 F _t 3 F _t 4 E 5 F _c 7 F _c	ty Y	CONDITION CATION Itimate Stress, ield Stress, roportional Limit odulus of Elastic	ARMY NAVY FEDERAL SAE psi psi	HEAT TREATED TO Ftu = 100 000 psi	(2) HEAT TREATED TO Ftu = 125 000 psi	(3) HEAT TREATED TO Fu = 150 000 psi	HEAT TREATED TO Ftu= 180 000 psi
1 F _t 2 F _t 3 F _t 4 E 5 F _c 7 F _c	tu U. ty Y: tp P:	ltimate Stress, ield Stress, roportional Limit	NAVY FEDERAL SAE psi psi	100 000			
1 F _t 2 F _t 3 F _t 4 E 5 F _c 7 F _c	tu U. ty Y: tp P:	ltimate Stress, ield Stress, roportional Limit	FEDERAL SAE psi psi	100 000			
1 F _t 2 F _t 3 F _t 4 E 5 F _c 7 F _c	tu U. ty Y: tp P:	ltimate Stress, ield Stress, roportional Limit	SAE psi psi	100 000			
2 F _t 3 F _t 4 E 5 F _c 7 F _c	ty Y	ield Stress,	psi psi	100 000			
2 F _t 3 F _t 4 E 5 F _c 7 F _c	ty Y	ield Stress,	psi	100 000		1	
3 F _t 4 B 5 F _c 7 F _c	tp P	roportional Limit		· · · · · · · · · · · · · · · · · · ·	125 000	150 000	180 000
3 F _t 4 B 5 F _c 7 F _c	tp P		, psi	80 000	100 000	135 000	165 000
4 B 5 F _C 7 F _C	. <u>M</u>	odulus of Elastic		70 000	90 000	115 000	140 000
6 F _c	E		ity, psi	29 000 000	29 000 000	29 000 000	29 000 000
7 F _c		longation in 2 in.	. , %				
7 F _c	_ U	ltimate (block) St	ress, psi	100 000	125 000	150 000	180 000
	-	ield Stress,	pai		100 000	135 000	165 000
8 F.		roportional Limit,	psi	70 000	90 000	115 000	140 000
	-	olumn Yield Stress		80 000	100 000	135 000	165 000
O E		odulus of Elastic	ity, psi	29 000 000	29 000 000	29 000 000	29 000 000
1 F,	su U	ltimate Stress,	psi	65 000	75 000	90 000	105 000
2 F ₅		orsional Modulus o upture,	of psi	90 000	110 000	125 000	145 000
3 F _s	sp P	roportional Limit (torsion),	psi	55 000	65 000	80 000	95 000
4 G	M	odulus of Rigidit (torsion),	y psi	11 000 000	11 000 000	11 000 000	11 000 000
.5 Իլ	br U	Itimate Stress,	psi	140 000	175 000	190 000	200 000
.6	R	ockwell Number			<u> </u>		
.7	В	Finell Number					
	(ending Endurance 300,000,000 cycle completely reverse	s of d stress)	50 000	65 000	78 000	85 000
19 F	30 17	Corsional Enduranc 20,000,000 cycles completely reverse	of				
30 W	r s	pecific Weight,	0.2833	lb/cu in.	490 lb/cu ft.		
21		Nominal Chemical Compositi	on				
22 R	REMARKS	1 See notes i 2 Except as m alloy steel display the stress. Th tubes, shee correspond actual cast	oted, the values containing le properties gives values apput, castings, for those obtaining and the te	ess than 1/2 percent ven in the column of ly to the materials orgings, etc. In to ned from test bars, at bars, these values	t carben. Any of the orresponding to its in various forms, the case of castings. Due to the differences should be reduced	ultimate tensile such as bars, rods, the above values ences between the	
			Chemical Compositi REMARKS 1 See notes i 2 Except as n alloy steel display the stress. Th tubes, shee correspond actual cast	Chemical Composition REMARKS 1 See notes in Chapter 3. 2 Except as noted, the valuabley steels containing library the properties gistress. These values apputibes, sheet, castings, for correspond to those obtains actual casting and the te	Chemical Composition REMARKS 1 See notes in Chapter 3. 2 Except as noted, the values given in this ta alloy steels containing less than 1/2 percentisplay the properties given in the column of stress. These values apply to the materials tubes, sheet, castings, forgings, etc. In the correspond to those obtained from test bars, actual casting and the test bars, these values.	Chemical Composition REMARKS 1 See notes in Chapter 3. 2 Except as noted, the values given in this table apply to any of alloy steels containing less than 1/2 percent carbon. Any of the display the properties given in the column corresponding to its stress. These values apply to the materials in various forms, tubes, sheet, castings, forgings, etc. In the case of castings correspond to those obtained from test bars. Due to the differ	Chemical Composition REMARKS 1 See notes in Chapter 3. 2 Except as noted, the values given in this table apply to any of the structural alloy steels containing less than 1/2 percent carbon. Any of these steels will display the properties given in the column corresponding to its ultimate tensile stress. These values apply to the materials in various forms, such as bars, rods, tubes, sheet, castings, forgings, etc. In the case of castings the above values correspond to those obtained from test bars. Due to the differences between the actual casting and the test bars, these values should be reduced by 50 percent

		CONDITION	CONDITION								
				HEAT TREATED TO	(2	3	(4)			
			ARMY					·			
			NAVY								
	SPECIF	ICATION	FEDERAL								
			SAE								
1	Ftu	Ultimate Stress,	psi	200 000							
2	Fty	Yield Stress,	psi	165 000							
3	-	Proportional Limit	, psi	150 000							
4	E	Modulus of Elastic	ity, psi	29 000 000							
Б		Elongation in 2 in	., %								
6	R	Mitimata (block) S	tress. psi	200 000							
		· · · · · · · · · · · · · · · · · · ·		165 000				'			
			·	150,000							
				· · · · · · · · · · · · · · · · · · ·	-						
10				193 000			/				
11	F _{su}	Ultimate Stress,	psi	115 000							
12	F _{st}	Torsional Modulus Rupture,	of psi	155 000							
13	F _{sp}	Proportional Limit (torsion),	psi	105 000							
14	G	Modulus of Rigidity (torsion), psi		11 000 000							
15	Fbr	Ultimate Stress,	psi			·					
16		Rockwell Number									
17		Brinell Number			<u> </u>						
18	Fbe	1(300.000.000 cycl	es or .	94 000							
19	F ₅₀	(20,000,000 avcle	s of								
20	₩	Specific Weight,	0.2833	lb/cu in.	490	lb/cu ft	•				
21		Nominal Chemical Composit	ion								
22	REMA	1. See notes 2. Except as alloy stee display th stress. I rods, tube values cor between th by 50 perc. 3. The use of	noted, the values containing lace properties githese values apples, sheet, castifies outual castifies actual castifies when used if higher heat-ti	ess then 1/2 percent of the column of the co	t carbon orrespon in vari In the t bars. , these wable st	ding to it ous forms, case of control to the values showed the control to the con	these steels will a ultimate tens such as bars, astings the abo e differences uld be reduced the 180,000 psi	ve			
	3 4 5 6 7 8 8 9 9 10 11 12 13 14 15 16 17 18 19 20 21	3	Ftp Proportional Limit K Modulus of Elastic Elongation in 2 in Fou Ultimate (block) S Fcy Yield Stress, Fcp Proportional Limit Fco Column Yield Stress, Le Foo Column Yield Stress, Le Fst Torsional Modulus Rupture, Fsp Proportional Limit (torsion), Fsp Proportional Modulus of Rigidit (torsion), Fsp Proportional Limit (torsion), Fsp Proportional Limit (torsion), Fsp Proportional Modulus of Rigidit (torsion), Fsp Proportional Limit (torsion), Fsp Proportional Modulus of Rigidit (torsion), Received to torsional Modulus of Rigidit (torsion), Receiv	Functional Limit, psi Kendulus of Elasticity, psi Elongation in 2 in., % Elongation in 2 in., % Four Ultimate (block) Stress, psi Four Yield Stress, psi Four Column Yield Stress, psi Elongation Limit, psi Four Column Yield Stress, psi Ultimate Stress, psi Functional Modulus of Elasticity, psi Functional Modulus of Elasticity, psi Functional Limit (torsion), psi Functional Limit (torsion), psi Kenture, psi Modulus of Rigidity (torsion), psi Functional Endurance Limit, psi Rockwell Number Functional Endurance Limit, psi (300,000,000 cycles of completely reversed stress) Functional Endurance Limit, psi (20,000,000 oyoles of completely reversed stress) Remarks 1. See notes in Chapter 3. 2. Except as noted, the valual alloy steels containing I display the properties gistress. These values approach to the between the actual casting the server of the serv	1 Ftp Proportional Limit, psi 150 000 Kelongation in 2 in., % Fou Ultimate (block) Stress, psi 200 000 Fou Viteld Stress, psi 165 000 Fop Proportional Limit, psi 150 000 Fop Modulus of Elasticity, psi 155 000 Ultimate Stress, psi 155 000 Fop Modulus of Elasticity, psi 155 000 For Modulus of Elasticity, psi 155 000 Let For Torsional Modulus of Rupture, psi 155 000 For Modulus of Rigidity (torsion), psi 105 000 Let For Ultimate Stress, psi 1100 000 For Modulus of Rigidity (torsion), psi 100 000 For Modulus of Rigidity	3 Ptp Proportional Limit, psi 150 000 4 N Modulus of Elasticity, psi 29 000 000 5 Elongation in 2 in., % 6 Fou Ultimate (block) Stress, psi 200 000 7 Fcy Yield Stress, psi 165 000 8 Fop Proportional Limit, psi 150 000 9 Foo Column Yield Stress, psi 165 000 10 Eo Modulus of Elasticity, psi 165 000 11 Fsu Ultimate Stress, psi 155 000 12 Fst Torsional Modulus of Rupture, psi 155 000 13 Fsp Proportional Limit psi 105 000 14 G Modulus of Rigidity psi 1000 000 15 Fbr Ultimate Stress, psi 1100 000 16 Rockwell Number psi 1000 000 17 Brinell Number 991 18 Fbe Bending Endurance Limit, psi (300,000,000 cycles of completely reversed stress) 20 W Specific Weight, 0.2833 1b/cu in. 490 Nominal Chemical Composition 22 REMARKS 1. See notes in Chapter 3. 2. Except as noted, the values given in this table apple along the stress. These values apply to the materials in variance, these values apply to the materials in variance and the column correspond to those obtained from test bars. These values apply to the materials in variance and the column correspond to those obtained from test bars. The use of higher heat-treatment than that correspond to those obtained from test bars. The use of higher heat-treatment than that correspond to those obtained from test bars.	3 Ptp Proportional Limit, psi 150 000 4 E Modulus of Elasticity, psi 29 000 000 5 Elongation in 2 in., % 6 Pou Ultimate (block) Stress, psi 200 000 7 Pcy Yield Stress, psi 165 000 8 Pop Proportional Limit, psi 150 000 9 Pco Column Yield Stress, psi 165 000 10 Eo Modulus of Elasticity, psi 155 000 11 Psu Ultimate Stress, psi 156 000 12 Fst Torsional Modulus of Rupture, psi 156 000 13 Fsp Proportional Limit (torsion), psi 155 000 14 G Modulus of Rigidity (torsion), psi 105 000 15 Fbr Ultimate Stress, psi 110 000 000 16 Rookwell Number 17 Brinell Number 18 Proportional Endurance Limit, psi 200 000 000 000 000 000 000 000 000 00	3			

			MECHANICA	TABLE 4	g (revised oct '40) OF MATERIALS	· · · · · · · · · · · · · · · · · · ·		CORROSION (· · · · · · · · · · · · · · · · · · ·
			CONDITION		ANNEALED SHEET BAR AND TUBING	COLD	2) WORKED AND BAR	(3) NEAR WELDING WHEN ARC WELDED OR ACETYLENE WELDED	4
••				ARMY	SHEET 11068 BAR 10079 TUBING 51-180-3	SHEET BAR	11068 10079		
				NAVY	SHEET 47519	Sheet Bar	47S21 46S18		
÷		SPECI	FICATION	FEDERAL					
				SAE			* 1 - 1,1,1		
	1	F _{tu}	.Ultimate Stress,	psi	80 000		000 =	SEE COLUMN	
×	2	F _{ty}	Yield Stress,	psi	35 000 30 000 (tubing only	75) 140	000	(1)	
TENSION	3	F _{tp}	Proportional Limit	, psi	20 000	35	000 <u>-</u>	FOR PHYSICAL	
T.	4	E	Modulus of Elastic	lty, psi	26 000 000	26 000	000	PROPERTIES	
	5		Elongation in 2 in	., %					
	6	Fcu	Ultimate (block) S	ress, psi	80 000		000 –		
SION	7	Fcy	Yield Stress,	psi					
COMPRESSION	8	Fop	Proportional Limit	, psi	15 000		000 =	<u> </u>	
COPIE	9	Foo	Column Yield Stress	s, psi	30 000	60	000 – 000		•
	10	10 Bo Modulus of Elasticity		ity, psi	· · · · · · · · · · · · · · · · · · ·	,			
æar	11	F _{su}	Ultimate Stress,	psi	70 000		000 - 000		
	12	Fst	Torsional Modulus (Rupture,	of psi					
	13	F _{sp}	Proportional Limit (torsion),	psi					
	14	G	Modulus of Rigidity (torsion),	r psi					
NG	15	Fbr	Ultimate Stress,	psi					
BEARING	16		Rockwell Number						
proj	17		Brinell Number	····					
FATIGUE	18	Fbe	Bending Endurance (300,000,000 cycle completely reverse	Limit, psi s of l stress)		75	00rs		
FAI	19	F _{se}	Torsional Endurance (20,000,000 cycles completely reverse		30 000	55	000		
	20	W	Specific Weight,	•	lb/cu in.		lb/cu ft.		
	21		Nominal Chemical Compositi	on					
	22	REMAF	1. See notes 1	n Chapter 3 1 having an u	Ltimate tensile stres	s of 185,	000 psi.		

TABLE 4-10-APPROXIMATE RELATIONS BETWEEN HARDNESS AND TENSILE STRENGTH OF S. A. E. STEELS

Brinell		Vickers (Firth-	Rockwell		Shore	Tenáile	Brinell		Vickers (Firth-	Rockwell		gh	Tensile
Diam, in Mm.		Diamond) Hardness Number	C Scale, 150 Kg., Load 120 Deg. Diamond Cone	B Scale, 100 Kg., Load, 1/4 In. Diam, Ball	Shore	Strength	Diam. in Mm. 3000 Kg., Load, 10 Mm. Ball	Hardness Number	Diamond)	C Scale, 150 Kg.,	B Scale, 100 Kg.,	Shore	Strength
3000 Kg., Load, 10 Mm. Ball	Number				Sclero- scope Number	1000 Lb. Per Sq. In.			Hardness Number	Load 120 Deg. Diamond Cone	Load, 1/6 In. Diam. Ball	Sclero- scope Number	1000 Lb. Per Sq. In.
2.20 2.25 2.35 2.45 2.50 2.55 2.50 2.75 2.80 2.75 2.80 2.95 3.00 3.15 3.25 3.30 3.35 3.40 3.40 3.55 3.65 3.70 3.80 3.80 3.80	780 745 712 682 682 653 627 601 578 555 534 495 447 461 444 429 415 401 388 375 361 311 321 321 321 321 321 321 321 321 32	1,150 1,050 1,050 885 820 717 675 633 598 567 540 472 454 473 420 4389 375 363 350 327 316 287 279 270 270 276 288 248 241	708 664 206 55 553 20 94 7 65 44 42 1 408 37 65 34 33 3 33 3 32 28 6 25 4 23	100	106 100 95 91 87 81 78 81 78 65 67 65 63 61 55 57 55 54 48 48 44 42 40 38 37 38 37 38	384 368 362 337 324 311 298 287 276 266 247 238 229 220 212 204 196 182 170 165 160 155 160 142 134 142 134 131 128	4.05 4.10 4.15 4.20 4.30 4.35 4.45 4.45 4.55 4.80 4.85 4.70 4.85 4.90 5.10 5.10 5.10 5.10 5.10 5.10 5.10 5.1	223 217 212 207 202 197 192 183 179 174 170 166 163 159 158 148 143 140 143 128 128 126 121 118 116 1112 109 107	223 217 212 207 202 197 192 187 183 179 174 170 166 163 159 156 153 149 148 143 140 137 134 121 128 128 126 121 118 116 1114 112 109 107 105 103 1001	20	97 96 96 97 98 99 99 99 99 89 88 87 86 85 84 83 87 78 77 69 69 68 67 68 67 68 67	32 31 31 30 30 28 28 28 27 27 26 26 25 24 23 23 23 22 22 21 21 20 20	110 107 104 101 99 97 95 93 93 89 87 85 83 82 80 78 75 74 72 71 68 65 64 63 62 61 62 61 65 65 65 65 65 65 65 65 65 65 65 65 65
3.95 4.00	235 229	235 229	22 21	99 98	34 33	116 113	5.90 5.95 6.00	99 97 95	97 95	• • • •	57 56	***	50 49

*Note: Emphasis is laid on the fact that this table gives an approximate relationship of Brinell, Rockwell and Soleroscope values. It is impossible to give more than an approximate relationship due to the inevitable influence of size, mass, composition and method of heat treatment. Where more precise factors are required they should be especially developed for each steel composition, heat treatment and part. (This table was reproduced by permission of the Society of Automotive Engineers).