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.

REVISED OCT '40

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:

$$L'/\rho\sqrt{c} \quad \text{- - - - - - - - - - - - - - - - -} \quad (4:1)$$

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.

TABLE 4-1 COLUMN FORMULAS FOR ROUND STEEL TUBES

(REVISED OCT '40)

Material	F_{ty}-psi	F_{co}-psi	Short Columns		Critical (b) L'/ρ	Long Columns (a)	Local Failure
			Column Formula (a)	Basic Eq.			
1025	36,000	36,000	$36{,}000-1.172(L'/\rho)^2$	1:24	124	$276\times10^6/(L'/\rho)^2$	Note (c)
X-4130	75,000	79,500	$79{,}500-51.9(L'/\rho)^{1.5}$	1:25	91.5	$286\times10^6/(L'/\rho)^2$	Note (c)
X-4130	85,000	90,100	(e) $90{,}100-64.4(L'/\rho)^{1.5}$	1:25	86.0	$286\times10^6/(L'/\rho)^2$	Note (c)
Heat-treated (d) Alloy Steel	100,000	100,000	$100{,}000-8.74(L'/\rho)^2$	1:24	75.6	$286\times10^6/(L'/\rho)^2$	Note (c)
Heat-treated (d) Alloy Steel	135,000	135,000	$135{,}000-15.92(L'/\rho)^2$	1:24	65.0	$286\times10^6/(L'/\rho)^2$	Note (c)
Heat-treated (d) Alloy Steel	165,000	165,000	$165{,}000-23.78(L'/\rho)^2$	1:24	58.9	$286\times10^6/(L'/\rho)^2$	Note (c)

Note (a). $L'/\rho = L/\rho\sqrt{c}$; L'/ρ shall not exceed 150 without specific authority from the procuring or licensing agency.

Note (b). Critical L/ρ is that above which columns are "long" and below which they are "short".

Note (c). Not necessary to investigate for local instability when $D/t < 50$.

Note (d). See Mechanical Properties Tables at end of Chapter.

Note (e). FOR USE ON CIVIL AIRPLANES ONLY. This formula applies only to tubing "as received". If annealed and reheat-treated, the column formula based on $F_{ty} = 75{,}000$ psi must be used.

4.21 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.

REVISED OCT '40

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 Unconventional Cross-sections. 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

4.40 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:

$$\frac{f_b'}{F_b} + \frac{f_c}{F_c} = 1.0 \qquad (4{:}2)$$

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

F_b = bending modulus of rupture

f_c = axial compressive stress

F_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.

4.501 REVISED OCT '40 Allowable Bearing Stresses. The basic values of the allowable bearing stresses for various steels will be found in the tables at the end of this chapter. These stresses are applicable only when the D/t ratio (diameter 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 limit load should not exceed the manufacturer's non-Brinell rating.

TABLE 4-2

(ADDED OCT '40)

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 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

(ADDED OCT '40)

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 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	Oil	1,500

4.502 ADDED OCT '40 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.

4.512 REVISED OCT '40 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 dipping 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 - - - -	110%
Tension in necked down section aft of hole - - - -	100%

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 - - - - - - - - (4:8)

$P_t = (2R-D)tF_t$ — is smaller - - - - - - - - - (4:9)

$P_b = DtF_{br}$ - (4:10)

$P_s = (2R-D)tF_s$ - - - - - - - - - - - - - - - - - - (4:11)

where:

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

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

P_s = 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.

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)	100%

TABLE 4 - 4 (REVISED OCT '40)
MECHANICAL PROPERTIES OF MATERIALS

1025 STEEL

			CONDITION		① BEFORE WELDING	② AFTER WELDING[3] (PROPERTIES IN AFFECTED ZONE)	③	④
SPECIFICATION				ARMY	TUBE 57-180-1	TUBE 57-180-1		
				NAVY	TUBE 49-T-1	TUBE 49-T-1		
				FEDERAL	SHEET QQ-S-651 BAR QQ-S-646	SHEET QQ-S-651 BAR QQ-S-646		
				SAE				
TENSION	1	F_{tu}	Ultimate Stress,	psi	55 000	45 000[2]		
	2	F_{ty}	Yield Stress,	psi	36 000			
	3	F_{tp}	Proportional Limit,	psi	25 000			
	4	E	Modulus of Elasticity,	psi	28 000 000			
	5		Elongation in 2 in., %					
COMPRESSION	6	F_{cu}	Ultimate (block) Stress,	psi	55 000			
	7	F_{cy}	Yield Stress,	psi	36 000			
	8	F_{cp}	Proportional Limit,	psi	25 000			
	9	F_{co}	Column Yield Stress,	psi	36 000			
	10	E_c	Modulus of Elasticity,	psi	28 000 000			
SHEAR	11	F_{su}	Ultimate Stress,	psi	35 000			
	12	F_{st}	Torsional Modulus of Rupture,	psi	50 000			
	13	F_{sp}	Proportional Limit (torsion),	psi	20 000			
	14	G	Modulus of Rigidity (torsion),	psi	10 000 000			
BEARING	15	F_{br}	Ultimate Stress,	psi	90 000			
	16		Rockwell Number					
	17		Brinell Number					
FATIGUE	18	F_{be}	Bending Endurance Limit, (300,000,000 cycles of completely reversed stress)	psi	25 000			
	19	F_{se}	Torsional Endurance Limit, (20,000,000 cycles of completely reversed stress)	psi				
	20	w	Specific Weight,		0.2833 lb/cu in.	490 lb/cu ft.		
	21		Nominal Chemical Composition		0.25% C, .65 Mn, .045% P(max.), .050% S (max.)			

22 REMARKS

1. See notes in Chapter 3.
2. Where joints with tapered welds at angles of 30 degrees or less to the center line, or fish-mouth welds formed by cuts of 60 degrees or less are used, the allowable tensile stress near the welding can be assumed to be 50,000 psi.
3. In welded structures where seven 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 reenforced 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 two members.

TABLE 4 – 5 (REVISED OCT '40)

MECHANICAL PROPERTIES OF MATERIALS

ALLOY STEELS[2]

					(1) ANNEALED PLATE AND BAR (OVER 1 1/2" THICK)	(2) ANNEALED PLATE, TUBE, AND BAR (1 1/2" THICK AND UNDER)	(3) NEAR WELDING,[3] WHEN WELDED AFTER HEAT TREATMENT	(4) NEAR WELDING,[3] WHEN WELDED AFTER HEAT TREATMENT (X-4130)
CONDITION								
SPECIFICATION			ARMY					
			NAVY					
			FEDERAL					
			SAE					
TENSION	1	F_{tu}	Ultimate Stress,	psi	55 000	65 000		80 000[4]
	2	F_{ty}	Yield Stress,	psi	36 000	45 000	SEE COLUMNS	
	3	F_{tp}	Proportional Limit,	psi	25 000	30 000	(1) and (2)	
	4	E	Modulus of Elasticity,	psi	29 000 000	29 000 000	FOR PHYSICAL	29 000 000
	5		Elongation in 2 in., %				PROPERTIES	
COMPRESSION	6	F_{cu}	Ultimate (block) Stress,	psi	55 000	65 000		67 500
	7	F_{cy}	Yield Stress,	psi				
	8	F_{cp}	Proportional Limit,	psi	25 000	30 000		
	9	F_{co}	Column Yield Stress,	psi	36 000	36 000		
	10	E_c	Modulus of Elasticity,	psi	29 000 000	29 000 000		29 000 000
SHEAR	11	F_{su}	Ultimate Stress,	psi	35 000	40 000		50 000
	12	F_{st}	Torsional Modulus of Rupture,	psi	50 000	55 000		70 000
	13	F_{sp}	Proportional Limit (torsion),	psi	20 000	25 000		35 000
	14	G	Modulus of Rigidity (torsion),	psi	11 000 000	11 000 000		11 000 000
BEARING	15	F_{br}	Ultimate Stress,	psi	90 000	110 000		125 000
	16		Rockwell Number					
	17		Brinell Number					
FATIGUE	18	F_{be}	Bending Endurance Limit, (300,000,000 cycles of completely reversed stress)	psi	25 000	30 000		16 000[5]
	19	F_{se}	Torsional Endurance Limit, (20,000,000 cycles of completely reversed stress)	psi				
	20	w	Specific Weight,		0.283 lb/cu in.	490 lb/cu ft.		
	21		Nominal Chemical Composition					

22 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.
3. In welded structures where seven 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 reenforced 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 two members.
4. Where joints with tapered welds at angles of 30 degrees or less to the center line, or fish-mouth welds formed by cuts of 60 degrees or less are used, the allowable tensile stress near the welding can be assumed to be 90,000 psi.
5. Butt, fish-mouth, or tapered telescope welds in tubing. Flash resistance welds test 50% higher.

TABLE 4 - 6 (REVISED OCT '40)

MECHANICAL PROPERTIES OF MATERIALS

ALLOY STEELS

CONDITION				① NORMALIZED PLATE TUBE AND BAR OVER .188" THICK (X-4130)	② NORMALIZED PLATE TUBE AND BAR - .188" THICK AND UNDER (X-4130)	③ NEAR WELDING(2) WHEN WELDED AFTER HEAT TREATMENT (X-4130) SPECIAL	④ NORMALIZED (2) TUBES - .188" THICK AND UNDER (X-4130) SPECIAL
SPECIFICATION			ARMY				
			NAVY	BAR 46S23 RD.TUBING 44T18 STR.TUBING 44T17	RD. TUBING 44T18 STR. TUBING 44T17		
			FEDERAL				
			SAE	X-4130	X-4130	X-4130	X-4130
TENSION	1	F_{tu}	Ultimate Stress, psi	90 000	95 000	84 100(4)	100 000
	2	F_{ty}	Yield Stress, psi	70 000	75 000		85 000
	3	F_{tp}	Proportional Limit, psi	50 000			
	4	E	Modulus of Elasticity, psi	29 000 000	29 000 000	29 000 000	29 000 000
	5		Elongation in 2 in., %				12
COMPRESSION	6	F_{cu}	Ultimate (block) Stress, psi	90 000	95 000	76 600	100 000
	7	F_{cy}	Yield Stress, psi	70 000	75 000		85 000
	8	F_{cp}	Proportional Limit, psi	50 000			
	9	F_{co}	Column Yield Stress, psi	74 100	79 500		90 100
	10	E_c	Modulus of Elasticity, psi	29 000 000	29 000 000	29 000 000	29 000 000
SHEAR	11	F_{su}	Ultimate Stress, psi	55 000	55 000	52 500	58 000
	12	F_{st}	Torsional Modulus of Rupture, psi	80 000	80 000	73 500	84 000
	13	F_{sp}	Proportional Limit (torsion), psi	40 000	40 000		
	14	G	Modulus of Rigidity (torsion), psi	11 000 000	11 000 000	11 000 000	11 000 000
BEARING	15	F_{br}	Ultimate Stress, psi	140 000	140 000	130 000	147 000
	16		Rockwell Number				
	17		Brinell Number				
FATIGUE	18	F_{be}	Bending Endurance Limit, psi (300,000,000 cycles of completely reversed stress)	45 000	45 000		
	19	F_{se}	Torsional Endurance Limit, psi (20,000,000 cycles of completely reversed stress)				
	20	w	Specific Weight, 0.2833 lb/cu in. 490 lb/cu ft.				
	21		Nominal Chemical Composition				
	22		REMARKS				

REMARKS

1. See notes in Chapter 3.
2. The properties in this line are for use in connection with civil aircraft only. Their use is permissible provided that the tensile properties stated are guaranteed by the manufacturer of the tubing. These properties apply only to tubing "as received". If annealed and reheat-treated, the properties in column 4 of Table 4 - 5 and column 2 of this Table must be used.
3. In welded structures where seven 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 reenforced 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 two members.
4. Where joints with tapered welds at angles of 30 degrees or less to the center line, or fish mouth welds formed by cuts of 60 degrees or less are used, the allowable tensile stress near the welding can be assumed to be 94,500 psi.

TABLE 4 - 7 (REVISED OCT '40)

MECHANICAL PROPERTIES OF MATERIALS

ALLOY STEELS[2]

				①	②	③	④
CONDITION				HEAT TREATED TO F_{tu} = 100 000 psi	HEAT TREATED TO F_{tu} = 125 000 psi	HEAT TREATED TO F_{tu} = 150 000 psi	HEAT TREATED TO F_{tu} = 180 000 psi
SPECIFICATION			ARMY				
			NAVY				
			FEDERAL				
			SAE				
TENSION	1	F_{tu}	Ultimate Stress, psi	100 000	125 000	150 000	180 000
	2	F_{ty}	Yield Stress, psi	80 000	100 000	135 000	165 000
	3	F_{tp}	Proportional Limit, psi	70 000	90 000	115 000	140 000
	4	E	Modulus of Elasticity, psi	29 000 000	29 000 000	29 000 000	29 000 000
	5		Elongation in 2 in., %				
COMPRESSION	6	F_{cu}	Ultimate (block) Stress, psi	100 000	125 000	150 000	180 000
	7	F_{cy}	Yield Stress, psi		100 000	135 000	165 000
	8	F_{cp}	Proportional Limit, psi	70 000	90 000	115 000	140 000
	9	F_{co}	Column Yield Stress, psi	80 000	100 000	135 000	165 000
	10	E_c	Modulus of Elasticity, psi	29 000 000	29 000 000	29 000 000	29 000 000
SHEAR	11	F_{su}	Ultimate Stress, psi	65 000	75 000	90 000	105 000
	12	F_{st}	Torsional Modulus of Rupture, psi	90 000	110 000	125 000	145 000
	13	F_{sp}	Proportional Limit (torsion), psi	55 000	65 000	80 000	95 000
	14	G	Modulus of Rigidity (torsion), psi	11 000 000	11 000 000	11 000 000	11 000 000
BEARING	15	F_{br}	Ultimate Stress, psi	140 000	175 000	190 000	200 000
	16		Rockwell Number				
	17		Brinell Number				
FATIGUE	18	F_{be}	Bending Endurance Limit, psi (300,000,000 cycles of completely reversed stress)	50 000	65 000	78 000	85 000
	19	F_{se}	Torsional Endurance Limit, psi (20,000,000 cycles of completely reversed stress)				
	20	w	Specific Weight, 0.2833 lb/cu in.	490 lb/cu ft.			
	21		Nominal Chemical Composition				
	22		REMARKS				

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 when used for determining allowable stresses.

270850 O—40——6

TABLE 4 - 8 (REVISED OCT '40)

MECHANICAL PROPERTIES OF MATERIALS

ALLOY STEELS[2]

					①	②	③	④
CONDITION					HEAT TREATED[3] TO F_{tu}=200 000 psi			
SPECIFICATION			ARMY					
			NAVY					
			FEDERAL					
			SAE					
TENSION	1	F_{tu}	Ultimate Stress,	psi	200 000			
	2	F_{ty}	Yield Stress,	psi	165 000			
	3	F_{tp}	Proportional Limit,	psi	150 000			
	4	E	Modulus of Elasticity,	psi	29 000 000			
	5		Elongation in 2 in., %					
COMPRESSION	6	F_{cu}	Ultimate (block) Stress,	psi	200 000			
	7	F_{cy}	Yield Stress,	psi	165 000			
	8	F_{cp}	Proportional Limit,	psi	150 000			
	9	F_{co}	Column Yield Stress,	psi	165 000			
	10	E_c	Modulus of Elasticity,	psi				
SHEAR	11	F_{su}	Ultimate Stress,	psi	115 000			
	12	F_{st}	Torsional Modulus of Rupture,	psi	155 000			
	13	F_{sp}	Proportional Limit (torsion),	psi	105 000			
	14	G	Modulus of Rigidity (torsion),	psi	11 000 000			
BEARING	15	F_{br}	Ultimate Stress,	psi				
	16		Rockwell Number					
	17		Brinell Number					
FATIGUE	18	F_{be}	Bending Endurance Limit, (300,000,000 cycles of completely reversed stress)	psi	94 000			
	19	F_{se}	Torsional Endurance Limit, (20,000,000 cycles of completely reversed stress)	psi				
	20	w	Specific Weight,	0.2833 lb/cu in.	490 lb/cu ft.			
	21		Nominal Chemical Composition					

22 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 when used for determining allowable stresses.
3. The use of higher heat-treatments than that corresponding to F_{tu}= 180,000 psi shall be based on rulings of the procuring or licensing agencies.

TABLE 4 - 9 (REVISED OCT '40)
MECHANICAL PROPERTIES OF MATERIALS

CORROSION RESISTANT (STAINLESS) STEEL

					(1)	(2)	(3)	(4)
CONDITION					ANNEALED SHEET BAR AND TUBING	COLD WORKED SHEET AND BAR	NEAR WELDING WHEN ARC WELDED OR ACETYLENE WELDED	
SPECIFICATION				ARMY	SHEET 11068 BAR 10079 TUBING 51-180-3	SHEET 11068 BAR 10079		
				NAVY	SHEET 47S19	SHEET 47S21 BAR 46S18		
				FEDERAL				
				SAE				
TENSION	1	F_{tu}	Ultimate Stress,	psi	80 000	125 000 - 185 000	SEE COLUMN	
	2	F_{ty}	Yield Stress,	psi	35 000 30 000 (tubing only)	75 000 - 140 000	(1)	
	3	F_{tp}	Proportional Limit,	psi	20 000	35 000 - 80 000	FOR PHYSICAL	
	4	E	Modulus of Elasticity,	psi	26 000 000	26 000 000	PROPERTIES	
	5		Elongation in 2 in., %					
COMPRESSION	6	F_{cu}	Ultimate (block) Stress,	psi	80 000	125 000 - 185 000		
	7	F_{cy}	Yield Stress,	psi				
	8	F_{cp}	Proportional Limit,	psi	15 000	35 000 - 50 000		
	9	F_{co}	Column Yield Stress,	psi	30 000	80 000 - 110 000		
	10	E_c	Modulus of Elasticity,	psi				
SHEAR	11	F_{su}	Ultimate Stress,	psi	70 000	90 000 - 125 000		
	12	F_{st}	Torsional Modulus of Rupture,	psi				
	13	F_{sp}	Proportional Limit (torsion),	psi				
	14	G	Modulus of Rigidity (torsion),	psi				
BEARING	15	F_{br}	Ultimate Stress,	psi				
	16		Rockwell Number					
	17		Brinell Number					
FATIGUE	18	F_{be}	Bending Endurance Limit, (300,000,000 cycles of completely reversed stress)	psi		75 000 [2]		
	19	F_{se}	Torsional Endurance Limit, (20,000,000 cycles of completely reversed stress)	psi	30 000	55 000		
	20	w	Specific Weight,		lb/cu in.	lb/cu ft.		
	21		Nominal Chemical Composition					

22 REMARKS
1. See notes in Chapter 3
2. For material having an ultimate tensile stress of 185,000 psi.

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

Brinell		Vickers (Firth-Diamond)	Rockwell		Shore	Tensile Strength
Diam. in Mm. 3000 Kg., Load, 10 Mm. Ball	Hardness Number	Hardness Number	C Scale, 150 Kg., Load 120 Deg. Diamond Cone	B Scale, 100 Kg., Load, 1/16 In. Diam. Ball	Scleroscope Number	1000 Lb. Per Sq. In.
2.20	780	1,150	70	...	106	384
2.25	745	1,050	68	...	100	368
2.30	712	960	66	...	95	352
2.35	682	885	64	...	91	337
2.40	653	820	62	...	87	324
2.45	627	765	60	...	84	311
2.50	601	717	58	...	81	298
2.55	578	675	57	...	78	287
2.60	555	633	55	...	75	276
2.65	534	598	53	...	72	266
2.70	514	567	52	...	70	256
2.75	495	540	50	...	67	247
2.80	477	515	49	...	65	238
2.85	461	494	47	...	63	229
2.90	444	472	46	...	61	220
2.95	429	454	45	...	59	212
3.00	415	437	44	...	57	204
3.05	401	420	42	...	55	196
3.10	388	404	41	...	54	189
3.15	375	389	40	...	52	182
3.20	363	375	38	...	51	176
3.25	352	363	37	...	49	170
3.30	341	350	36	...	48	165
3.35	331	339	35	...	46	160
3.40	321	327	34	...	45	155
3.45	311	316	33	...	44	150
3.50	302	305	32	...	43	146
3.55	293	296	31	...	42	142
3.60	285	287	30	...	40	138
3.65	277	279	29	...	39	134
3.70	269	270	28	...	38	131
3.75	262	263	26	...	37	128
3.80	255	256	25	...	37	125
3.85	248	248	24	...	36	122
3.90	241	241	23	100	35	119
3.95	235	235	22	99	34	116
4.00	229	229	21	98	33	113

Brinell		Vickers (Firth-Diamond)	Rockwell		Shore	Tensile Strength
Diam. in Mm. 3000 Kg., Load, 10 Mm. Ball	Hardness Number	Hardness Number	C Scale, 150 Kg., Load 120 Deg. Diamond Cone	B Scale, 100 Kg., Load, 1/16 In. Diam. Ball	Scleroscope Number	1000 Lb. Per Sq. In.
4.05	223	223	20	97	32	110
4.10	217	217	...	96	31	107
4.15	212	212	...	96	31	104
4.20	207	207	...	95	30	101
4.25	202	202	...	94	30	99
4.30	197	197	...	93	29	97
4.35	192	192	...	92	28	95
4.40	187	187	..	91	28	93
4.45	183	183	...	90	27	91
4.50	179	179	...	89	27	89
4.55	174	174	...	88	26	87
4.60	170	170	...	87	26	85
4.65	166	166	...	86	25	83
4.70	163	163	...	85	25	82
4.75	159	159	...	84	24	80
4.80	156	156	...	83	24	78
4.85	153	153	...	82	23	76
4.90	149	149	...	81	23	75
4.95	146	146	...	80	22	74
5.00	143	143	...	79	22	72
5.05	140	140	...	78	21	71
5.10	137	137	...	77	21	70
5.15	134	134	...	76	21	68
5.20	131	131	...	74	20	66
5.25	128	128	...	73	20	65
5.30	126	126	...	72	...	64
5.35	124	124	...	71	...	63
5.40	121	121	...	70	...	62
5.45	118	118	...	69	...	61
5.50	116	116	...	68	...	60
5.55	114	114	...	67	...	59
5.60	112	112	...	66	...	58
5.65	109	109	...	65	...	56
5.70	107	107	...	64	...	55
5.75	105	105	...	62	...	54
5.80	103	103	...	61	...	53
5.85	101	101	...	60	...	52
5.90	99	99	...	59	...	51
5.95	97	97	...	57	...	50
6.00	95	95	...	56	...	49

*Note: Emphasis is laid on the fact that this table gives an approximate relationship of Brinell, Rockwell and Scleroscope 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).