# Bulletin on Formulas and Calculations for Casing, Tubing, Drill Pipe, and Line Pipe Properties

API BULLETIN 5C3
SIXTH EDITION, OCTOBER 1, 1994

**Contains ISO 10400:1993**

**Petroleum and natural gas industries—Formulae and calculations for casing, tubing, drill pipe, and line pipe properties**

**American Petroleum Institute**
1220 L Street, Northwest
Washington, D.C. 20005

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**Exploration and Production Department**

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# CONTENTS


FOREWORD ..... vii

1 SCOPE ..... 1

2 COLLAPSE PRESSURE ..... 1
- 2.1 Collapse Pressure Formulas ..... 1
- 2.2 Derivation of Collapse Pressure Formulas ..... 6
- 2.3 Collapse Testing Procedure ..... 11
- 2.4 Application of Collapse Pressure Formulas to Line Pipe ..... 13

3 PIPE BODY YIELD STRENGTH ..... 14
- 3.1 Pipe Body Yield Strength ..... 14
- 3.2 Application of Pipe Body Yield Strength Formula to Line Pipe ..... 14

4 INTERNAL PRESSURE RESISTANCE ..... 14
- 4.1 Internal Yield Pressure ..... 14
- 4.2 Internal Pressure Leak Resistance at $E_1$ or $E_7$ Plane ..... 15
- 4.3 Application of Internal Pressure Resistance Formulas to Line Pipe ..... 16

5 JOINT STRENGTH ..... 16
- 5.1 Round Thread Casing Joint Strength ..... 16
- 5.2 Buttress Thread Casing Joint Strength ..... 17
- 5.3 Extreme-Line Casing Joint Strength ..... 18
- 5.4 Tubing Joint Strength ..... 19
- 5.5 Joint Strength of Round Thread Casing With Combined Bending and Internal Pressure ..... 20
- 5.6 Line Pipe Joint Strength ..... 21

6 WEIGHTS ..... 21
- 6.1 Nominal Weight ..... 21
- 6.2 Calculated Plain-End Weight ..... 22
- 6.3 Calculated Threaded and Coupled Weight ..... 22
- 6.4 Calculated Upset and Threaded Weight for Integral Joint Tubing and Extreme-Line Casing ..... 23
- 6.5 Calculated Upset Weight ..... 23
- 6.6 Weight Gain Due to End Finishing ..... 24
- 6.7 Calculated Coupling Weight ..... 24
- 6.8 Calculated Weight Removed in Threading ..... 27
- 6.9 Calculated Weight of External Upsets ..... 30
- 6.10 Calculated Weight of Internal Upsets ..... 31
- 6.11 Calculated Weight of External-Internal Upsets ..... 31
- 6.12 Calculated Weight of Extreme-Line Upsets ..... 31

7 ELONGATION ..... 33

8 FLATTENING TESTS ..... 33
- 8.1 Flattening Tests for Casing and Tubing ..... 33
- 8.2 Flattening Tests for Line Pipe ..... 33

9 HYDROSTATIC TEST PRESSURES ..... 33
- 9.1 Hydrostatic Test Pressures for Plain-End Pipe, Extreme-Line Casing, and Integral-Joint Tubing ..... 33
- 9.2 Hydrostatic Test Pressure for Threaded and Coupled Pipe ..... 34

10 MAKEUP TORQUE FOR ROUND THREAD CASING AND TUBING ..... 36

11 GUIDED BEND TESTS FOR SUBMERGED ARC WELDED LINE PIPE ...... 37

12 DETERMINATION OF MINIMUM IMPACT SPECIMEN SIZE FOR API COUPLINGS AND PIPE ...... 38
12.1 Critical Thickness ...... 38
12.2 Calculated Coupling Blank Thickness ...... 38
12.3 Calculated Wall Thickness for Transverse Specimens ...... 38
12.4 Calculated Wall Thickness for Longitudinal Specimens ...... 39
12.5 Minimum Specimen Size for API Couplings ...... 39
12.6 Impact Specimen Size for Pipe ...... 40
12.7 Larger Size Specimens ...... 40
12.8 Reference Information ...... 40

13 METRICATION ...... 44
13.1 Metric Conversions and Calculations ...... 44
13.2 Rounding of Metric Units ...... 44

14 CALCULATION ACCURACY AND ROUNDING ...... 45
14.1 Accuracy ...... 45
14.2 Intermediate Rounding ...... 45
14.3 Final Rounding ...... 45

Figures

1—Grade N-80 Transition Collapse Formula Derivation ...... 10
2—Ovality Gauge ...... 13
3—Coupled Pipe ...... 22
4—Upset Pipe ...... 23
5—Upset Pipe–Both Ends ...... 23
6—Pipe Coupling ...... 25
7—Pipe Coupling With Special Bevel ...... 26
8—Weight Calculations for Buttress Thread Couplings ...... 27
9—Round Threads and Line Pipe Threads ...... 27
10—Buttress Threads ...... 28
11—Extreme-Line Thread ...... 28
12—Integral Joint Tubing ...... 29
13—Extreme-Line Casing ...... 30
14—External Upset ...... 30
15—Internal Upset ...... 31
16—Pin Upset ...... 32
17—Box Upset ...... 32
18—Guided Bend Test Jig ...... 37

Tables

1—Yield Collapse Pressure Formula Range ...... 2
2—Formula Factors and *D/t* Range for Plastic Collapse ...... 3
3—Formula Factors and *D/t* Range for Transition Collapse ...... 4
4—*D/t* Range for Elastic Collapse ...... 5
5—Average Plastic Collapse Pressure Regression Formulas ...... 7
6—Tolerance Limit *C* to Be Subtracted From Average Collapse Formulas to Convert to a Minimum Base ...... 9
7—Flattening Tests—Distance Between Plates ...... 34
8—Factors for Test Pressure Formulas ...... 35
9—Critical Thickness of Various API Couplings ...... 39
10—Calculated Coupling Blank Thickness for API Couplings ...... 40
11—Transverse Impact Specimen Size Required for API Couplings ...... 41
12—Longitudinal Impact Specimen Size Required for API Couplings ...... 42

13—Minimum Size Transverse Charpy Impact Test Specimens for Various API Couplings ........ 43
14—Minimum Size Longitudinal Charpy Impact Test Specimens for API Couplings for All Pipe Less Than $3^1/_2$-Inch Outside Diameter and for Larger Sizes Where Transverse Test Specimens One-Half Size or Larger Are Not Possible ........ 43
15—Number of Decimals to Be Shown in Metric Units ........ 44

## FOREWORD

Note: This section is not part of ISO 10400:1993.

API Bulletin 5C3 serves as the basis for ISO 10400:1993. The complete text of both the API and ISO standards is contained in this document. Some differences exist between the API version and the ISO version of this standard; for example:

- The Special Notes and Foreword are not part of ISO 10400:1993.
- Section 12 is not part of ISO 10400:1993.

Language that is unique to the ISO version is shown in ***bold oblique type*** in the text or, where extensive, is identified by a note under the title of the section. Language that is unique to the API version is identified by a note under the title of the section or is shaded. The bar notations identify parts of this publication that have been changed from the previous API edition.

This standard is under the jurisdiction of the Committee on Standardization of Tubular Goods.

*This standard shall become effective on the date printed on the cover but may be used voluntarily from the date of distribution.*

# Bulletin on Formulas and Calculations for Casing, Tubing, Drill Pipe, and Line Pipe Properties

## 1 Scope

The purpose of this bulletin is to show the formulas used in the calculation of the various pipe properties given in API standards, including background information regarding their development and use. This bulletin is under the jurisdiction of the Committee on Standardization of Tubular Goods.

## 2 Collapse Pressure

### 2.1 COLLAPSE PRESSURE FORMULAS

The minimum collapse pressures given in API Bulletin 5C2 are calculated by means of Formulas 1, 3, 5, and 7, adopted at the 1968 Standardization Conference and reported in API Circular PS-1360 dated September 1968.

Formulas 2, 4, and 6 for the intersections between the four collapse pressure formulas have been determined algebraically and used for calculating the applicable *D/t* range for each collapse pressure formula. Factors A, B, C, F, and G have been calculated using Formulas 21, 22, 23, 26, and 27. When determining the appropriate formula to be used for calculating collapse resistance for a particular *D/t* ratio and minimum yield strength, the *D/t* ranges determined by Formulas 2, 4, and 6 govern, rather than the collapse formula that gives the lowest collapse pressure. The *D/t* ranges are given in Tables 1, 2, 3, and 4.

The collapse pressures for API Bulletin 5C2 are calculated using the specified values for $D$ and $t$, rounding *D/t* to two decimals carrying eight digits in all intermediate calculations and rounding the collapse pressure to the nearest 10 pounds per square inch.

Theoretical studies of the effect of ovality on tubular collapse resistance consistently indicate that an ovality of 1 to 2 percent can effect a reduction in collapse resistance on the order of 25 percent. However, experimental/empirical investigations indicate a much smaller effect. Test data indicate that ovality is only one of many pipe parameters that influence collapse (including residual stress, isotropy, shape of stress-strain curve/microstructure, and yield strength). Thorough review of industry collapse data indicates that the influence of ovality does not warrant singling out the ovality as a dominant parameter. A work group on collapse resistance concluded the effect of ovality on tubular collapse has been handled during the adjustment of average collapse predictions to minimum performance values and that ovality should not be awarded the status of an independent variable in an API formula for collapse performance.

#### 2.1.1 Yield Strength Collapse Pressure Formula

The yield strength collapse pressure is not a true collapse pressure, but rather the external pressure, $P_{Y_p}$, that generates minimum yield stress, $Y_p$, on the inside wall of a tube as calculated by Formula 1.

$$P_{Y_p} = 2Y_p\left[\frac{(D/t)-1}{(D/t)^2}\right] \quad (1)$$

Formula 1 for yield strength collapse pressure is applicable for *D/t* values up to the value of *D/t* corresponding to the intersection with the plastic collapse Formula 3. This intersection is calculated by Formula 2 as follows:

$$(D/t)_{yp} = \frac{\sqrt{(A-2)^2 + 8(B + C/Y_p)} + (A-2)}{2(B + C/Y_p)} \quad (2)$$

The applicable $D/t$ ratios for yield strength collapse are shown in Table 1.

### 2.1.2 Plastic Collapse Pressure Formula

The minimum collapse pressure for the plastic range of collapse is calculated by Formula 3:

$$P_p = Y_p\left[\frac{A}{D/t} - B\right] - C \quad (3)$$

The formula for minimum plastic collapse pressure is applicable for $D/t$ values ranging from $(D/t)_{PT}$, Formula 2 for yield point collapse pressure, to the intersection with the Formula 5 for transition collapse pressure $(D/t)_{PT}$. Values for $(D/t)_{PT}$ are calculated by means of Formula 4:

$$(D/t)_{PT} = \frac{Y_p(A-F)}{C + Y_p(B-G)} \quad (4)$$

The factors and applicable $D/t$ range for the plastic collapse formula are shown in Table 2.

### 2.1.3 Transition Collapse Pressure Formula

The minimum collapse pressure for the plastic to elastic transition zone $P_T$ is calculated by Formula 5:

$$P_T = Y_p\left[\frac{F}{D/t} - G\right] \quad (5)$$

Table 1—Yield Collapse Pressure Formula Range

| (1) Grade[a] | (2) $D/t$ Range[b] |
|---|---|
| H-40 | 16.40 and less |
| -50 | 15.24 and less |
| J-K-55 | 14.81 and less |
| -60 | 14.44 and less |
| -70 | 13.85 and less |
| C-E-75 | 13.60 and less |
| L-N-80 | 13.38 and less |
| C-90 | 13.01 and less |
| C-T-X-95 | 12.85 and less |
| -100 | 12.70 and less |
| P-G-105 | 12.57 and less |
| P-110 | 12.44 and less |
| -120 | 12.21 and less |
| Q-125 | 12.11 and less |
| -130 | 12.02 and less |
| S-135 | 11.92 and less |
| -140 | 11.84 and less |
| -150 | 11.67 and less |
| -155 | 11.59 and less |
| -160 | 11.52 and less |
| -170 | 11.37 and less |
| -180 | 11.23 and less |

[a]Grades indicated without letter designation are not API grades but are grades in use or grades being considered for use and are shown for information purposes.
[b]The $D/t$ range values were calculated from Formulas 2, 21, 22, and 23 to eight or more digits.

Table 2—Formula Factors and *D/t* Range for Plastic Collapse

| (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|
| | Formula Factor[b] | | | |
| Grade[a] | A | B | C | *D/t* Range[b] |
| H-40 | 2.950 | 0.0465 | 754 | 16.40 to 27.01 |
| -50 | 2.976 | 0.0515 | 1056 | 15.24 to 25.63 |
| J-K-55 | 2.991 | 0.0541 | 1206 | 14.81 to 25.01 |
| -60 | 3.005 | 0.0566 | 1356 | 14.44 to 24.42 |
| -70 | 3.037 | 0.0617 | 1656 | 13.85 to 23.38 |
| C-E-75 | 3.054 | 0.0642 | 1806 | 13.60 to 22.91 |
| L-N-80 | 3.071 | 0.0667 | 1955 | 13.38 to 22.47 |
| C-90 | 3.106 | 0.0718 | 2254 | 13.01 to 21.69 |
| C-T-X-95 | 3.124 | 0.0743 | 2404 | 12.85 to 21.33 |
| -100 | 3.143 | 0.0768 | 2553 | 12.70 to 21.00 |
| P-G-105 | 3.162 | 0.0794 | 2702 | 12.57 to 20.70 |
| P-110 | 3.181 | 0.0819 | 2852 | 12.44 to 20.41 |
| -120 | 3.219 | 0.0870 | 3151 | 12.21 to 19.88 |
| Q-125 | 3.239 | 0.0895 | 3301 | 12.11 to 19.63 |
| -130 | 3.258 | 0.0920 | 3451 | 12.02 to 19.40 |
| S-135 | 3.278 | 0.0946 | 3601 | 11.92 to 19.18 |
| -140 | 3.297 | 0.0971 | 3751 | 11.84 to 18.97 |
| -150 | 3.336 | 0.1021 | 4053 | 11.67 to 18.57 |
| -155 | 3.356 | 0.1047 | 4204 | 11.59 to 18.37 |
| -160 | 3.375 | 0.1072 | 4356 | 11.52 to 18.19 |
| -170 | 3.412 | 0.1123 | 4660 | 11.37 to 17.82 |
| -180 | 3.449 | 0.1173 | 4966 | 11.23 to 17.47 |

[a]Grades indicated without letter designation are not API grades but are grades in use or grades being considered for use and are shown for information purposes.
[b]The *D/t* range values and formula factors were calculated from Formulas 2, 4, 21, 22, 23, 26, and 27 to eight or more digits.

The formula for $P_T$ is applicable for $D/t$ values from $(D/t)_{PT}$, Formula 4 for plastic collapse pressure, to the intersection $(D/t)_{TE}$ with Formula 7 for elastic collapse. Values for $(D/t)_{TE}$ are calculated by Formula 6:

$$(D/t)_{TE} = \frac{2 + B/A}{3B/A} \tag{6}$$

The factors and applicable $D/t$ range for the transition collapse pressure formula are shown in Table 3.

### 2.1.4 Elastic Collapse Pressure Formula

The minimum collapse pressure for the elastic range of collapse is calculated by Formula 7:

$$P_E = \frac{46.95 \times 10^6}{(D/t)\,((D/t) - 1)^2} \tag{7}$$

The applicable $D/t$ range for elastic collapse is shown in Table 4.

### 2.1.5 Collapse Pressure Under Axial Tension Stress

The collapse resistance of casing in the presence of an axial stress is calculated by modifying the yield stress to an axial stress equivalent grade according to Formula 8:

$$Y_{pa} = \left[\sqrt{1 - 0.75\,(S_a/Y_p)^2} - 0.5\,S_a/Y_p\right]Y_p \tag{8}$$

*Where:*

$S_a$ = axial stress, pounds per square inch (tension is positive).
$Y_p$ = minimum yield strength of the pipe, pounds per square inch.
$Y_{pa}$ = yield strength of axial stress equivalent grade, pounds per square inch.

Collapse resistance formula factors and *D/t* ranges for the axial stress equivalent grade are then calculated by means of Formulas 2, 4, 6, 21, 22, 23, 26, and 27. Using formula factors for the axial stress equivalent grade, collapse resistance under axial stress is calculated by means of Formulas 1, 3, 5, and 7.

The reduced collapse pressures are calculated using *D/t* rounded to two decimals and carrying eight digits in all intermediate calculations and rounding the reduced collapse pressure to the nearest 10 pounds per square inch.

API collapse resistance formulas are not valid for the yield strength of axial stress equivalent grade ($Y_{pa}$) less than 24,000 pounds per square inch.

Formula 8 is based on the Hencky-von Mises maximum strain energy of distortion theory of yielding.

Example:

Calculate collapse pressure of size 7, weight 26, grade P-110, with axial stress of 11,000 pounds per square inch. Wall thickness is 0.362 inches.

$S_a$ = 11,000 pounds per square inch
$Y_p$ = 110,000 pounds per square inch

Table 3—Formula Factors and *D/t* Range for Transition Collapse

| (1) | (2) | (3) | (4) |
|---|---|---|---|
| | Formula Factors[b] | | |
| Grade[a] | F | G | *D/t* Range[b] |
| H-40 | 2.063 | 0.0325 | 27.01 to 42.64 |
| -50 | 2.003 | 0.0347 | 25.63 to 38.83 |
| J-K-55 | 1.989 | 0.0360 | 25.01 to 37.21 |
| -60 | 1.983 | 0.0373 | 24.42 to 35.73 |
| -70 | 1.984 | 0.0403 | 23.38 to 33.17 |
| C-E-75 | 1.990 | 0.0418 | 22.91 to 32.05 |
| L-N-80 | 1.998 | 0.0434 | 22.47 to 31.02 |
| C-90 | 2.017 | 0.0466 | 21.69 to 29.18 |
| C-T-X-95 | 2.029 | 0.0482 | 21.33 to 28.36 |
| -100 | 2.040 | 0.0499 | 21.00 to 27.60 |
| P-G-105 | 2.053 | 0.0515 | 20.70 to 26.89 |
| P-110 | 2.066 | 0.0532 | 20.41 to 26.22 |
| -120 | 2.092 | 0.0565 | 19.88 to 25.01 |
| Q-125 | 2.106 | 0.0582 | 19.63 to 24.46 |
| -130 | 2.119 | 0.0599 | 19.40 to 23.94 |
| S-135 | 2.133 | 0.0615 | 19.18 to 23.44 |
| -140 | 2.146 | 0.0632 | 18.97 to 22.98 |
| -150 | 2.174 | 0.0666 | 18.57 to 22.11 |
| -155 | 2.188 | 0.0683 | 18.37 to 21.70 |
| -160 | 2.202 | 0.0700 | 18.19 to 21.32 |
| -170 | 2.231 | 0.0734 | 17.82 to 20.60 |
| -180 | 2.261 | 0.0769 | 17.47 to 19.93 |

[a]Grades indicated without letter designation are not API grades but are grades in use or grades being considered for use and are shown for information purposes.
[b]The *D/t* range values and formula factors were calculated from Formulas 4, 6, 21, 22, 23, 26, and 27 to eight or more digits.

Table 4—*D/t* Range for Elastic Collapse

| (1) Grade[a] | (2) *D/t* Range[b] |
|---|---|
| H-40 | 42.64 and greater |
| -50 | 38.83 and greater |
| J-K-55 | 37.21 and greater |
| -60 | 35.73 and greater |
| -70 | 33.17 and greater |
| C-E-75 | 32.05 and greater |
| L-N-80 | 31.02 and greater |
| C-90 | 29.18 and greater |
| C-T-X-95 | 28.36 and greater |
| -100 | 27.60 and greater |
| P-G-105 | 26.89 and greater |
| P-110 | 26.22 and greater |
| -120 | 25.01 and greater |
| Q-125 | 24.46 and greater |
| -130 | 23.94 and greater |
| S-135 | 23.44 and greater |
| -140 | 22.98 and greater |
| -155 | 22.11 and greater |
| -155 | 21.70 and greater |
| -160 | 21.32 and greater |
| -170 | 20.60 and greater |
| -180 | 19.93 and greater |

[a]Grades indicated without letter designation are not API grades but are grades in use or grades being considered for use and are shown for information purposes.
[b]The *D/t* range values were calculated from Formulas 6, 21, and 22 to eight or more digits.

Substituting in Formula 8:

$Y_{pa}$ = 104,087 pounds per square inch

Substituting $Y_{pa}$ for $Y$ in Formulas 2, 4, 6, 21, 22, 23, 26, and 27:

$A = 3.158, B = 0.0789, C = 2675, F = 2.051, G = 0.0512$

$(D/t)_{YP} = 12.59, (D/t)_{PT} = 20.75, (D/t)_{TE} = 27.02$

*D/t* range for yield collapse = 12.59 and less

*D/t* range for plastic collapse = 12.59 to 20.75

*D/t* range for transition collapse = 20.75 to 27.02

*D/t* range for elastic collapse = 27.02 and greater

$D/t = 7/0.362 = 19.34$, which indicates that collapse is in the plastic range. Substituting $A = 3.158$, $B = 0.0789$, and $C = 2675$ into Formula 3 for plastic collapse:

$P = Y_{pa}\,[A/(D/t) - B] - C = 104{,}087\,(3.158/19.34 - 0.0789) - 2675$

$P$ = 6110 pounds per square inch

### 2.1.6 Effect of Internal Pressure on Collapse

The external pressure equivalent of external pressure and internal pressure is determined by means of Formula 9. The formula is based on the internal pressure acting on the inside diameter and the external pressure acting on the outside diameter.

$$P_e = P_o - (1 - 2/(D/t))P_i \tag{9}$$

Formula 9 was taken from a dissertation entitled "Collapse Resistance of Pipe," presented to Century University, Los Angeles, California, by W. O. Clinedinst in 1985.

### 2.1.7 Collapse Pressure Formula Symbols

$D$ = nominal outside diameter, inches.
$t$ = nominal wall thickness, inches.
$Y_P$ = minimum yield strength of the pipe, pounds per square inch.
$P_Y$ = minimum yield strength collapse pressure, pounds per square inch.
$P_P$ = minimum plastic collapse pressure, pounds per square inch.
$P_T$ = minimum plastic/elastic transition collapse pressure, pounds per square inch.
$P_E$ = minimum elastic collapse pressure, pounds per square inch.
$P_e$ = equivalent external pressure, pounds per square inch.
$P_i$ = internal pressure, pounds per square inch.
$P_o$ = external pressure, pounds per square inch.
$(D/t)_{YP}$ = $D/t$ intersection between yield strength collapse and plastic collapse.
$(D/t)_{PT}$ = $D/t$ intersection between plastic collapse and transition collapse.
$(D/t)_{TE}$ = $D/t$ intersection between transition collapse and elastic collapse.

## 2.2 DERIVATION OF COLLAPSE PRESSURE FORMULAS

Of the four formulas used for collapse pressure, those for yield strength collapse and elastic collapse were derived on a theoretical basis, the plastic formula was derived empirically from 2488 collapse tests for grades K-55, N-80, and P-110, while the plastic/elastic transition collapse pressure formula was determined on an arbitrary basis. The plastic and transition collapse formulas and the modification of the elastic collapse formula constant were developed by Glen Hebard and reported in Appendix 2-k-4, API Circular PS-1360, Report of the 1968 Pipe Committee meeting.

### 2.2.1 Yield Strength Collapse Pressure Formula Derivation

For heavy wall pipe, the use of plastic collapse Formula 3 for $P_P$ could result in compression stresses equaling or exceeding the yield strength. While there was experimental evidence that the collapse pressure could exceed the external pressure causing yielding, it was thought unsafe to use a collapse pressure value causing yielding. Therefore, the yield strength collapse is based on the pressure that generates minimum yield stress on the inside wall of the tube calculated by means of the Lamé equation. The derivation of the Lamé equation can be found in books covering theoretical elastic stress analysis.

### 2.2.2 Plastic Collapse Pressure Formula Derivation

Formula 3 for plastic collapse pressure, $P_P$, and factors $A$, $B$, and $C$ were derived by statistical regression analysis from 402 collapse tests on K-55, 1440 collapse tests on N-80, and 646 collapse tests on P-110 seamless casing. The data used were reported in *Development of Collapse Pressure Formulas* by W. O. Clinedinst (December 1963), which is available upon request from the API Dallas office. The data were gathered to represent the $D/t$ ranges typically involved in plastic collapse for the particular grades. The regression analysis resulted in the formulas of the Stewart type shown in Table 5 originally developed by Professor Reid Stewart of Western University, Allegheny, Pennsylvania, (predecessor of the present University of Pittsburgh) and published as an American Society of Mechanical Engineers (ASME) paper in May 1906. These regression formulas (10, 11, and 12) for average collapse pressure are substantially the same as those on which the collapse values given in the eleventh edition (1969) of API Bulletin 5C2 were based. The difference in the new formulas from the old arises from the method of determining minimum values from the average values. The new minimum values were determined by subtracting a constant pressure determined for the particular grade from the average, while the old minimum values were determined by reducing the average values by 25 percent.

Table 5 — Average Plastic Collapse Pressure Regression Formulas

| (1) Grade | (2) Average Plastic Collapse Regression Formula | (3) Coef. of Det. $R^2$ | (4) Standard Error, $Sp$ | (5) Formula No. |
|---|---|---|---|---|
| K-55 | $P = \dfrac{164{,}450}{D/t} - 2976$ | 0.6478 | 435 | 10 |
| N-80 | $P = \dfrac{245{,}600}{D/t} - 5336$ | 0.8627 | 719 | 11 |
| P-110 | $P = \dfrac{349{,}800}{D/t} - 9020$ | 0.7720 | 1048 | 12 |

Statistical minimum values for the regression formulas are based on one-sided tolerance limits developed following methods that can be found in *Statistical Theory With Engineering Applications* by A. Hald, published by John Wiley & Sons, Inc., New York, 1952. Formulas 13, 14, 15, and 16 for one-sided tolerance limits are developed by such methods. These tolerance limits are subtracted from the average collapse pressure formulas to obtain minimum collapse pressure formulas.

$$C = t_P(\theta) \times Z \times S_P \tag{13}$$

$$t_P(\theta) \cong \frac{u_{1-\theta} + u_P\sqrt{(1 - u_P^2/2f)/N + u_{1-\theta}^2/2f}}{1 - u_P^2/2f} \tag{14}$$

$$t_{0.95}\ (0.005) = \frac{2.570 + 1.645\sqrt{(1-1.3530/(N-1))/N + 3.30245/(N-1)}}{1 - 1.3530/(N-1)} \tag{15}$$

$$Z = \sqrt{1 + \frac{1}{N} + \frac{(t/D - \overline{t/D})^2}{Ns^2_{t/D}}} \tag{16}$$

Formula 14 was taken directly from Hald's book, *Statistical Theory With Engineering Applications*. Formula 16 provides a correction for variation from average $t/D$ used in the regression and is based on information taken from George W. Snedecor's *Statistical Methods* published by the Iowa State College Press in 1956.

The following is a glossary of symbols used in Formulas 13 through 16:

$C$ = tolerance limit to be subtracted from average collapse pressure formula to obtain the minimum collapse pressure formula, pounds per square inch
$t_p(\theta)$ = tolerance interval corresponding to a confidence level of $P$ that the proportion of the population not included does not exceed $\theta$
$Z$ = correction factor for variation in $t/D$ from average
$S_P$ = standard error of estimate of the regression formula
$\theta$ = the proportion of the population not included
$1 - \theta$ = the proportion of the population included
$u_{1-\theta}$ = fractile, the deviation from the mean of a standardized normal cumulative distribution that includes the fraction $1 - \theta$ of the population
$p$ = confidence level
$u_p$ = fractile corresponding to confidence level, $p$
$N$ = number of tests
$f$ = degrees of freedom = $N - 1$
$\overline{(t/D)}$ = average value of the $t/D$ ratios used in the regression
$s_{t/D}$ = standard deviation of $t/D$ ratios used in the regression
$(t/D) - \overline{(t/D)}$ = the maximum absolute value of this quantity occurring in the test data is to be used in Formula 16 for calculating $Z$

Formula 15 was obtained from Formula 14 by taking $P = 0.95$ and $\theta = 0.005$ and substituting the corresponding values of $u_p = u_{0.95} = 1.645$ and $u_{1-\theta} = u_{0.995} = 2.574$ obtained from a table of probability integrals.

Values for the tolerance limit $C$ were calculated using Formulas 13 through 16 and are shown in Table 6.

Subtracting the tolerance limit $C$ values from the average collapse pressure Formulas 10, 11, and 12, the following Formulas 17, 18, and 19 for minimum collapse pressures are obtained:

| Grade | Minimum Plastic Collapse Pressure Formula | |
|---|---|---|
| K-55 | $P_P = \dfrac{164450}{D/t} - 4181$ | (17) |
| N-80 | $P_P = \dfrac{245600}{D/t} - 7291$ | (18) |
| P-110 | $P_P = \dfrac{349800}{D/t} - 11875$ | (19) |

These formulas for minimum plastic collapse pressure are based on the conception that there is a 95 percent probability or confidence level that the collapse pressure will exceed the minimum stated with no more than 0.5 percent failures.

While Formulas 17, 18, and 19 could be used in the form shown, they have been converted to the following standard form primarily to facilitate extrapolation and interpolation to obtain collapse formulas for other grades for which adequate collapse test data are not available from which to obtain formulas direct:

$$P_p = Y_p\left[\frac{A}{D/t} - B\right] - C \tag{20}$$

The following factors $A$, $B$, and $C$ for grades K-55, N-80, and P-110 were curve fit to provide formulas for determining these factors for other grades by extrapolation and interpolation:

| Grade | Factor A | Factor B | Factor C |
|---|---|---|---|
| K-55 | 2.990 | 0.0541 | 1205 |
| N-80 | 3.070 | 0.0667 | 1955 |
| P-110 | 3.180 | 0.082 | 2855 |

$$A = 2.8762 + 0.10679 \times 10^{-5} \times Yp + 0.21301 \times 10^{-10} \times Yp^2 - 0.53132 \times 10^{-16} \times Yp^3 \tag{21}$$
$$B = 0.026233 + 0.50609 \times 10^{-6} \times Yp \tag{22}$$
$$C = -465.93 + 0.030867 \times Yp - 0.10483 \times 10^{-7} \times Yp^2 + 0.36989 \times 10^{-13} \times Yp^3 \tag{23}$$

Factors for grades K-55, N-80, and P-110 calculated using Formulas 21, 22, and 23 are as follows:

| Grade | Factor A | Factor B | Factor C |
|---|---|---|---|
| K-55 | 2.991 | 0.0541 | 1206 |
| N-80 | 3.071 | 0.0667 | 1955 |
| P-110 | 3.181 | 0.0819 | 2852 |

The maximum deviation of the factors determined by the formulas from those determined by regression analysis is 0.122 percent.

As additional data become available, these formulas can be verified or modified where necessary. Analysis of collapse test data should conform to the principles followed in developing the present formulas.

Table 6 — Tolerance Limit $C$ to Be Subtracted From Average Collapse Formulas to Convert to a Minimum Base

| (1) Grade | (2) $C$ |
|---|---|
| K-55 | 1205 |
| N-80 | 1955 |
| P-110 | 2855 |

### 2.2.3 Transition Collapse Pressure Formula Derivation

When the curves of the formulas for average plastic collapse pressures are extended to higher $D/t$ values, they intersect the average elastic collapse pressure curve. However, as the curves for minimum plastic collapse pressures are extended to higher $D/t$ values, they fall below the minimum elastic collapse pressure curve without intersecting it. In order to overcome this anomaly, a plastic/elastic transition collapse pressure formula has been developed that intersects the $D/t$ value where the average plastic collapse pressure formula gives a collapse pressure of zero and is tangent to the minimum elastic collapse pressure Formula 7. This formula is used to determine minimum collapse pressures between its tangency to the elastic collapse pressure curve and its intersection with the plastic collapse pressure curve. This is shown in Figure 1 for grade N-80 casing.

The formula for plastic/elastic transition collapse pressure is of the Stewart form as follows:

$$P_T = Y_P\left[\frac{F}{D/t} - G\right] \tag{24}$$

*Where:*

$P_T$ = minimum transition collapse pressure.

The two conditions mentioned, (a) intersection with the average collapse pressure curve $P_P$ (average) $= Y_P\,[A/(D/t)] - B$, where $P_P$ (average) $= 0$, and (b) tangent to the elastic curve,

$$P_E = \frac{46.95 \times 10^6}{(D/t)[(D/t) - 1]^2} \tag{25}$$

permit evaluation of $A$ and $B$ according to Formulas 26 and 27 as follows:

$$F = \frac{46.95 \times 10^6\left[\dfrac{3B/A}{2 + B/A}\right]^3}{Y_p\left[\dfrac{3B/A}{2 + (B/A)} - (B/A)\right]\left[1 - \dfrac{3B/A}{2 + (B/A)}\right]^2} \tag{26}$$

$$G = FB/A \tag{27}$$

### 2.2.4 Elastic Collapse Pressure Formula Derivation

The minimum elastic collapse pressure formula was derived from the theoretical elastic collapse pressure formula developed by W. O. Clinedinst in a paper entitled "A Rational Expression for the Critical Collapsing Pressure of Pipe Under External Pressure" presented at API's annual meeting in Chicago in 1939.

$$P = \frac{2E}{1 - \nu^2} \times \frac{1}{(D/t)[(D/t) - 1]^2} \tag{28}$$

*Where:*

$E$ = elastic modulus, pounds per square inch.
$\nu$ = Poisson's ratio.

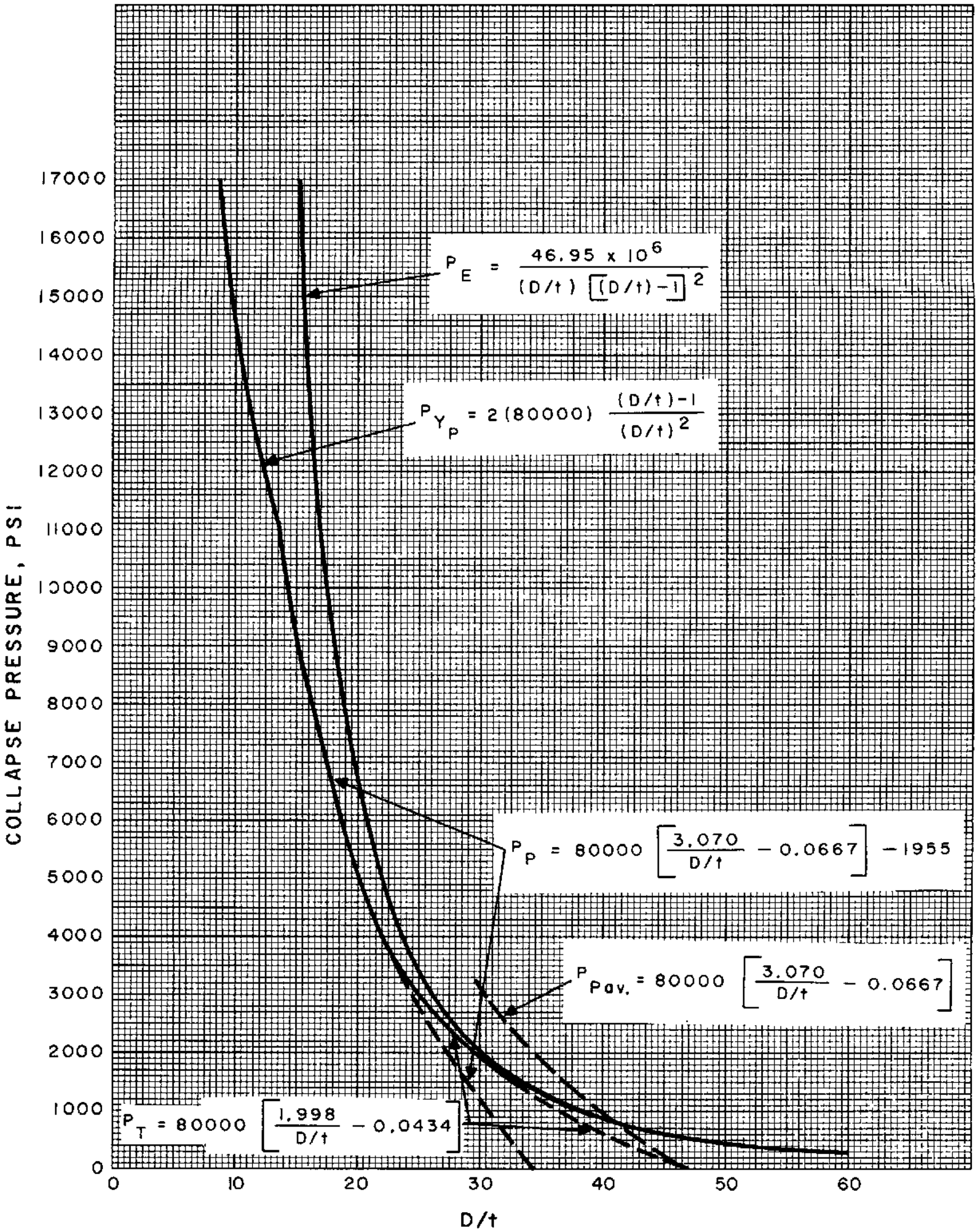



Figure 1—Grade N-80 Transition Collapse Formula Derivation

The curve plotted from the formula for theoretical elastic collapse, assuming $E$ is equal to $30 \times 10^6$ and $\nu$ is equal to 0.3, was found to be an adequate upper boundary for collapse pressures as determined by test.

The average collapse resistance formula adopted by API in 1939 was taken as 95 percent of the theoretical formula for elastic collapse resistance rounded to two decimals. The minimum elastic collapse resistance formula adopted in 1968 was taken as 75 percent of the average elastic collapse resistance formula rounded to three decimals.

$$P_E = \frac{46.95 \times 10^6}{(D/t)[(D/t)-1]^2} \tag{29}$$

## 2.3 COLLAPSE TESTING PROCEDURE

To be acceptable for API use, collapse testing shall be according to 2.3.1 through 2.3.4.

### 2.3.1 Test Specimen

The test specimen shall have a length at least twice the outside diameter.

### 2.3.2 Test Apparatus

The test apparatus shall be such as to expose the full specimen length to the test pressure. It shall not impose radial or axial restraint or axial load on the specimen, either mechanically or hydraulically, and shall not apply pressure to the inside surface of the specimen. To ensure that the specimen is not axially restrained during testing, the initial clearance between the end of the specimen and the end of the test chamber must be at least 0.06 inch for a test specimen 28 inches or less in length and proportionately greater for a longer test specimen.

The test chamber shall be equipped with a maximum reading pressure measuring device that is open to the test chamber during the test. The device shall have a minimum of 750 divisions between zero and its maximum working pressure and shall be certified by the manufacturer to be accurate within one-fourth of 1 percent of the full scale reading.

The pressure measuring device shall be equipped with a dampening system to bleed pressure slowly from the device at the time of specimen collapse.

The pressure measuring device shall be calibrated at intervals of six months by means of a dead weight tester or more frequently if there is reason to doubt its accuracy. The percentage of error within the working range of the pressure measuring device shall not exceed 1.0 percent.

Note: The 1.0 percent level of accuracy corresponds to the accuracy required of tension-testing machines (ASTM E4).

### 2.3.3 Test Procedure

The exterior surface of the specimen shall be hydraulically loaded at a sufficiently slow rate to permit reading of the collapsing pressure within the specified accuracy.

### 2.3.4 Data Reporting

The following data shall be reported:

a. The API designation of the test specimen pipe, such as nominal diameter, nominal weight per foot, and grade.
b. The average outside diameter and the difference between maximum and minimum outside diameters of the specimen (ovality). A pi-tape may be used to obtain the average outside diameter. The difference between the maximum and minimum outside diameters (ovality) may be obtained by using an ovality gauge as shown in Figure 2.
c. The average wall thickness and the difference between maximum and minimum wall thickness based on eight readings of the specimen.
d. Process of manufacture:

1. Seamless S
2. Welded W

e. Type of heat treatment:
1. Normalized NR
2. Normalized and tempered NT
3. Quenched and tempered QT
4. None AR

f. Type of straightening:
1. Rotary R
2. Hot rotary H
3. Press P
4. None N

g. The clearance between the end of the test specimen and the test chamber.

h. The test specimen length.

i. The physical properties representing the collapse test specimen, including yield strength, tensile strength, and percent elongation in accordance with API Specifications 5CT ***[ISO 11960, in process]*** and 5D, from a tensile test specimen taken from the same length of pipe as the collapse test specimen and adjacent to it.

j. The test specimen collapse pressure, defined as the maximum external pressure required to collapse the specimen. If the specimen did not collapse, the maximum pressure attained shall be reported along with the statement that it did not collapse.

k. To facilitate data processing, it is desirable that the data be submitted as individual 80 character records according to the following format:

| Character Columns, CC | Data Description | Symbol |
|---|---|---|
| 1–6 | OD size, dp (decimal point) in CC3 | |
| 7–12 | Nominal weight per foot dp in CC10 | |
| 13–16 | Grade, left justified | H40 |
| | | N80 |
| | | P110 |
| | | etc. |
| 17–22 | Average OD, dp in CC19 | |
| 23–26 | Max. OD-min. OD, dp in CC23 | |
| 27–30 | Average wall, dp in CC27 | |
| 31–34 | Max. wall-min. wall, dp in CC31 | |
| 35 | Process of manufacture | |
| | a. Seamless | S |
| | b. Welded | W |
| 36–37 | Type of heat treatment | |
| | a. Normalized | NR |
| | b. Normalized and tempered | NT |
| | c. Quenched and tempered | QT |
| | d. None (as rolled) | AR |
| 38 | Type of straightening | |
| | a. Rotary | R |
| | b. Hot rotary | H |
| | c. Press | P |
| | d. None | N |
| 39–42 | Test chamber end clearance, dp in CC39 | |
| 43–47 | Test specimen length, dp in CC46 | |

*(continued on page 13)*

| Character Columns, CC | Data Description | Symbol |
|---|---|---|
| 48–52 | Yield strength, ksi, dp in CC51 | |
| 53–57 | Tensile strength, ksi, dp in CC56 | |
| 58–59 | Elongation in percent, whole number, right justified | |
| 60–64 | Collapse or maximum pressure, whole number, right justified | |
| 65 | Specimen collapsed, blank | |
| | Specimen did not collapse | |
| 66–69 | Test number, right justified | |
| 70–72 | Manufacturer designation | |
| 73 | Residual stress sign, compression at inside diameter is negative | |
| 74–75 | Residual stress ksi, right justified | |
| 76 | Axial stress sign, tension is positive | |
| 77–79 | Axial stress, right justified | |

## 2.4 APPLICATION OF COLLAPSE PRESSURE FORMULAS TO LINE PIPE

The collapse pressure formulas presented in 2.1 and 2.2 are empirical relations derived from tests on pipe representative of the casing and tubing inventories listed in API Specification 5CT. Application of these relations outside the range of yield strengths and *D/t* ratios contained in API Specification 5CT is not recommended. These formulas do not apply to cold expanded pipe because Bauschinger effects significantly reduce collapse resistance.

Some line pipe grades listed in API Specification 5L have a rough casing equivalent in API Specification 5CT. However, the API Specification 5L inventory of line pipe contains *D/t* ratios that often exceed casing *D/t* ratios significantly.

For line pipe having a yield strength and *D/t* falling within the limits of the sizes and thicknesses listed in API Specification 5CT, application of the formulas in 2.2 should yield reasonable estimates of minimum collapse pressure. Nevertheless, as with the application of any of the formulas in this document, sound engineering judgment should prevail.

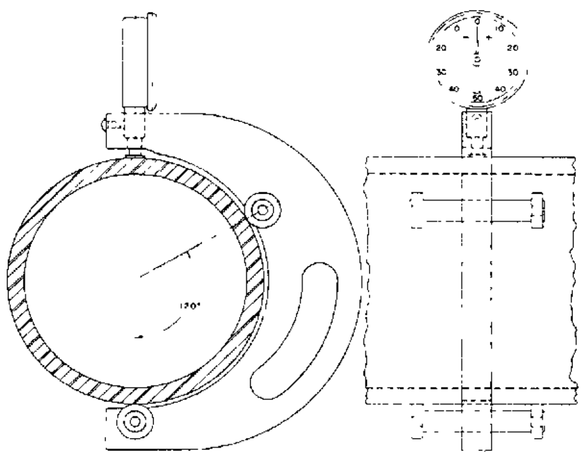


Figure 2—Ovality Gauge

# 3 Pipe Body Yield Strength

## 3.1 PIPE BODY YIELD STRENGTH

Pipe body yield strength is the axial load required to yield the pipe. It is taken as the product of the cross-sectional area and the specified minimum yield strength for the particular grade of pipe.

Values for pipe body yield strength were calculated by means of Formula 30:

$$P_y = 0.7854(D^2 - d^2)Y_p \tag{30}$$

*Where:*

$P_y$ = pipe body yield strength in pounds rounded to the nearest 1000.
$Y_p$ = specified minimum yield strength for pipe, pounds per square inch.
$D$ = specified outside diameter, inches.
$d$ = specified inside diameter, inches.

## 3.2 APPLICATION OF PIPE BODY YIELD STRENGTH FORMULA TO LINE PIPE

The pipe body yield strength of line pipe under tensile axial load may be calculated by means of Formula 30. The pipe body yield strength of line pipe under compressive axial load may also be calculated by means of Formula 30. However, when loaded in compression, pipe with a high *D/t* ratio or pipe with a high slenderness ratio, such as line pipe, may undergo compressive axial buckling prior to reaching pipe body yield. Due to the sensitivity of compressive axial buckling of pipe to anomalies, this type of critical load is normally determined empirically and is not covered in this document.

# 4 Internal Pressure Resistance

## 4.1 INTERNAL YIELD PRESSURE

The internal yield pressure for plain end pipe is determined by Formula 31. The internal yield pressure for threaded and coupled pipe is the lowest of the internal yield pressure for pipe or the internal yield pressure of the coupling, using Formulas 31 and 32.

### 4.1.1 Internal Yield Pressure for Pipe

Internal yield pressure for pipe is calculated from Formula 31. The factor 0.875 appearing in Formula 31 allows for minimum wall.

$$P = 0.875\left[\frac{2\,Y_p\,t}{D}\right] \tag{31}$$

*Where:*

$P$ = minimum internal yield pressure in pounds per square inch, rounded to the nearest 10 pounds per square inch.
$Y_p$ = specified minimum yield strength in pounds per square inch, as given in API Specification 5CT ***[ISO 11960, in process]***.
$t$ = nominal wall thickness, inches.
$D$ = nominal outside diameter, inches.

Internal yield pressures were calculated by using the tabulated values of diameter and thickness to obtain a $t/D$ ratio value rounded to the nearest 0.000001, which is then used in Formula 31.

### 4.1.2 Internal Yield Pressure for Couplings

Internal yield pressure for threaded and coupled pipe is the same as for plain end pipe, except where a lower pressure is required to avoid leakage due to insufficient coupling strength. The lower pressure is based on Formula 32 and is rounded to the nearest 10 pounds per square inch.

$$P = Y_c\left(\frac{W - d_1}{W}\right) \tag{32}$$

*Where*:

$P$ = minimum internal yield pressure in pounds per square inch, rounded to the nearest 10 pounds per square inch.
$Y_c$ = minimum yield strength of coupling, pounds per square inch.
$W$ = nominal outside diameter of coupling rounded to the nearest 0.001 inches.
$d_1$ = diameter at the root of the coupling thread at the end of the pipe in the power-tight position rounded to the nearest 0.001 inches.

For round thread casing and tubing,

$$d_1 = E_1 - (L_1 + A)\,T + H - 2S_{rn} \tag{33}$$

*Where*:

$E_1$ = pitch diameter at hand-tight plane, inches (API Specification 5B ***[ISO 10422]***).
$L_1$ = length, from end of pipe to hand-tight plane, inches (API Specification 5B ***[ISO 10422]***).
$A$ = hand-tight standoff, inches (caution: "A" in API Specification 5B ***[ISO 10422]*** is given in "turns.")
$T$ = taper
= 0.0625 in./in.
$H$ = thread height, inches
= 0.08660 for 10 TPI
= 0.10825 for 8 TPI.
$S_{rn}$ = 0.014 inches for 10 TPI
= 0.017 inches for 8 TPI.

For buttress thread casing,

$$d_1 = E_7 - (L_7 + I)\,T + .062 \tag{34}$$

*Where*:

$E_7$ = pitch diameter, inches (API Specification 5B ***[ISO 10422]***).
$L_7$ = length of perfect threads, inches (API Specification 5B ***[ISO 10422]***).

| | Size, inches | | |
|---|---|---|---|
| | $4\frac{1}{2}$ | $5$–$13\frac{3}{8}$ | Over $13\frac{3}{8}$ |
| $I$ = | 0.400 | 0.500 | 0.375 |
| $T$ = | 0.0625 | 0.0625 | 0.0833 |

## 4.2 INTERNAL PRESSURE LEAK RESISTANCE AT $E_1$ OR $E_7$ PLANE

The internal pressure leak resistance at the $E_1$ or $E_7$ plane is calculated from Formula 35 and rounded to the nearest 10 pounds per square inch. Formula 35 is based on the seal being at the $E_1$ plane for round threads and the $E_7$ plane for buttress threads where the coupling is the weakest and the internal pressure leak resistance the lowest. Also Formula 35 is based on the internal leak resistance pressure being equal to the interface pressure between the pipe and coupling threads resulting from makeup and the internal pressure itself, with stresses in the elastic range.

$$P = E\,T\,N\,p\,(W^2 - E_s^2)/2E_s W^2 \tag{35}$$

*Where*:

$P$ = internal pressure leak resistance, in pounds per square inch, rounded to nearest 10 pounds per square inch.
$E$ = $30 \times 10^6$ (modulus of elasticity).

$T$ = thread taper, in./in.
= 0.0625 for round thread casing
= 0.0625 for buttress thread casing 13$^3/_8$ and smaller
= 0.0833 for buttress thread casing 16 and larger.
$N$ = number of thread turns makeup
= A for round thread casing (API Specification 5B ***[ISO 10422]***)
= A + 1$^1/_2$ for buttress thread casing 13$^3/_8$ and smaller
= A + 1 for buttress thread casing 16 and larger.
$p$ = thread pitch, inches
= 0.125 for round thread casing
= 0.200 for buttress thread casing.
$d$ = inside diameters, inches.
$W$ = coupling outside diameter, inches.
$E_s$ = pitch diameter at plane of seal, inches,
= $E_1$ for round thread, inches,
= $E_7$ for buttress thread casing, inches.

The interface pressure between the pin and box as a result of makeup is as follows:

$$P_1 = E\,T\,N\,p\,(W^2 - E_s^2)\,(E_s^2 - d^2)/2E_s^3\,(W^2 - d^2) \qquad (36)$$

Subsequent to makeup, internal pressure $P_i$ causes a change in the interface pressure by an amount $P_2$,

$$P_2 = P_i\,d^2\,(W^2 - E_s^2)/E_s^2\,(W^2 - d^2) \qquad (37)$$

Since the external box diameter is always greater than the contact diameter, which in turn is always greater than the internal pipe diameter, $P_2$ will always be less than $P_1$. Therefore, when the total interface pressure $P_1 + P_2$ equals the internal pressure $P_i$, the connection has reached the leak resistance limit $P$. In other words, if $P_i$ were greater than $P_1 + P_2$ leakage would occur.

$$P_1 + P_2 = P_i = P \qquad (38)$$

Substituting the appropriate values for $P_1$ and $P_2$ into Formula 38 and simplifying produces Formula 35.

### 4.3 APPLICATION OF INTERNAL PRESSURE RESISTANCE FORMULAS TO LINE PIPE

The pipe internal yield pressure of line pipe may be calculated using Formula 31.

## 5 Joint Strength

### 5.1 ROUND THREAD CASING JOINT STRENGTH

Round thread casing joint strength is calculated from Formulas 39 and 40. The lesser of the values obtained from the two formulas governs.

Formulas 39 and 40 apply to both short and long threads and couplings. Formula 39 is for minimum strength of a joint failing by fracture, and Formula 40 is for minimum strength of a joint failing by thread jumpout or pullout.

Fracture strength:

$$P_j = 0.95 A_{jp}\,U_p \qquad (39)$$

Pullout strength:

$$P_j = 0.95 A_{jp}\,L\left[\frac{0.74 D^{-0.59} U_p}{0.5L + 0.14D} + \frac{Y_p}{L + 0.14D}\right] \qquad (40)$$

*Where:*

$P_j$ = minimum joint strength, pounds.
$A_{jp}$ = cross-sectional area of the pipe wall under the last perfect thread, square inches
= $0.7854\ [(D - 0.1425)^2 - d^2]$ for eight round threads.
$D$ = nominal outside diameter of pipe, inches.
$d$ = nominal inside diameter of pipe, inches.
$L$ = engaged thread length, inches
= $L_4 - M$ for nominal makeup, API Specification 5B ***[ISO 10422]***.
$Y_p$ = minimum yield strength of pipe, pounds per square inch.
$U_p$ = minimum ultimate strength of pipe, pounds per square inch.

Joint strengths of round thread casing given in API Bulletin 5C2 were calculated using tabulated values of diameter and thickness and API-listed values of $L_4$ and $M$. Pipe area was calculated to three decimals, $D^{-0.59}$ was calculated to five digits using a seven-place logarithm table, and remaining calculations used six digits. Listed values were rounded to 1000 pounds.

Formulas 39 and 40 were adopted at the June 1963 Standardization Conference as reported in API Circular PS-1255. Derivation of the equations is covered in a paper, "Strength of Threaded Joints for Steel Pipe," presented by W. O. Clinedinst at the meeting of the petroleum section of ASME in October 1964. They are based on the results of an API-sponsored test program consisting of tension tests of 162 joints of round thread casing in grades K-55, N-80, and P-110 covering a range of wall thicknesses in 4$^1/_2$-inch, 5-inch, 5$^1/_2$-inch, 6$^5/_8$-inch, 7-inch, 9$^5/_8$-inch, and 10$^3/_4$-inch diameters using both short and long threads where called for by the size and grade tested. Fourteen tests failed by fracture of the pipe and 148 tests failed by pullout. Formula 39 agrees satisfactorily with the 14 test fractures. Formula 40 is based on analytical considerations and was adjusted to fit the data by statistical methods. The analytical procedure comprehended coupling properties, but it was found by analysis of the current group of tests that the coupling was noncritical for standard coupling dimensions. Subsequent testing established that these formulas are also applicable to J-55 casing.

The factor 0.95 in Formulas 39 and 40 originates in the statistical error of a multiple-regression equation with adjustment to permit the use of minimum properties in place of average properties.

Coupling fracture strength:

$$P_j = 0.95\ A_{jc} U_c \qquad (41)$$

*Where:*

$A_{jc}$ = cross-sectional area of the coupling, square inches,
= $0.7854\ (W^2 - d_1^2)$.
$W$ = outside diameter of the coupling, inches.
$d_1$ = diameter at the root of the coupling thread at the end of the pipe in the power-tight position rounded to the nearest 0.001 inches (see Formula 33), inches.
$U_c$ = minimum ultimate strength of the coupling, pounds per square inch.

## 5.2 BUTTRESS THREAD CASING JOINT STRENGTH

Buttress thread casing joint strength is calculated from Formulas 42 and 43. The lesser of the values obtained from the two formulas governs.

Pipe thread strength:

$$P_j = 0.95\ A_p U_p\ [1.008 - 0.0396(1.083 - Y_p/U_p)D] \qquad (42)$$

Coupling thread strength:

$$P_j = 0.95 A_c U_c \qquad (43)$$

*Where:*

$P_j$ = minimum joint strength, pounds.
$Y_p$ = minimum yield strength of pipe, pounds per square inch.
$U_p$ = minimum ultimate strength of pipe, pounds per square inch.
$U_c$ = minimum ultimate strength of coupling, pounds per square inch.
$A_p$ = cross-sectional area of plain-end pipe, square inches
= $0.7854\ (D^2 - d^2)$.
$A_c$ = cross-sectional area of coupling, square inches,
= $0.7854\ (W^2 - d_1^2)$.
$D$ = outside diameter of pipe, inches.
$W$ = outside diameter of coupling, inches.
$d$ = inside diameter of pipe, inches.
$d_1$ = diameter at the root of the coupling thread at the end of the pipe in the power-tight position rounded to the nearest 0.001 inches. See Formula 34.

Joint strengths were calculated to six-digit accuracy using cross-sectional areas of the pipe and the coupling rounded to three decimals. Final values were rounded to the nearest 1000 pounds for listing in API Bulletin 5C2.

The formulas were adopted at the June 1970 Standardization Conference as reported in API Circular PS-1398. They were based on a regression analysis of 151 tests of buttress thread casing ranging in size from 4 1/2 inches to 20 inches OD and in strength levels from 40,000 pounds per square inch to 150,000 pounds per square inch minimum yield. Derivation of the formals is covered in W. O. Clinedinst's report on "Buttress Thread Joint Strength" shown as Appendix 2-k-6, Circular PS-1398.

## 5.3 EXTREME-LINE CASING JOINT STRENGTH

Extreme-line casing joint strength is calculated from Formula 44 as follows:

$$P_j = A_{cr}\ U_p \tag{44}$$

*Where:*

$P_j$ = minimum joint strength, pounds.
$A_{cr}$ = critical section area of box, pin, or pipe, whichever is least, square inches,
= $0.7854\ (M^2 - d_b^2)$ if box is critical
= $0.7854\ (D_p^2 - d_j^2)$ if pin is critical
= $0.7854\ (D^2 - d^2)$ if pipe is critical.
$U_p$ = specified minimum ultimate strength, pounds per square inch.
$M$ = nominal joint OD, madeup, inches.
$d_b$ = box critical section ID, inches,
= $I + 2h - \Delta + \theta$.
$D_p$ = pin critical section OD, inches,
= $H + \delta - \phi$.
$d_j$ = nominal joint ID, madeup, inches.
$D$ = nominal OD of casing, inches.
$d$ = nominal ID of casing, inches.
$h$ = minimum box thread height, inches,
= 0.060 for 6 threads per inch
= 0.080 for 5 threads per inch.
$\Delta$ = taper drop in pin perfect thread length, inches,
= 0.253 for 6 threads per inch
= 0.228 for 5 threads per inch.
$\theta$ = 1/2 maximum thread interference, inches,
= $(H - I)/2$.
$H$ = maximum root diameter at last perfect pin thread, inches.
$I$ = minimum crest diameter of box thread at Plane $H$, inches.

$\delta$ = taper rise between Plane $H$ and Plane $J$, inches,
= 0.035 for 6 threads per inch
= 0.032 for 5 threads per inch.
$\phi$ = ½ maximum seal interference, inches,
= $(A - O)/2$.
$A$ = maximum diameter at pin seal tangent point, inches.
$O$ = minimum diameter at box seal tangent point, inches.

Using values listed in API standards, critical areas were calculated to three decimals and the joint strengths were rounded to 1000 pounds.

### *5.4 TUBING JOINT STRENGTH*

***Non-upset tubing joint strength is calculated using Formula 45, the product of the specified minimum yield strength and the area of the section under the last perfect thread of the pipe. Upset tubing joint strength is calculated using Formula 46, the product of the specified minimum yield strength and the area of the body of the pipe. The area of the section under the last perfect thread of API upset tubing is greater than the area of the body of the pipe. The areas of the critical sections of regular tubing couplings, special-clearance couplings, and the box of integral-joint tubing are, in all instances, greater than the governing critical areas of the pipe part of the joint and do not affect the strength of the joint.***

***For calculations based on the thread root area for non-upset tubing:***

$$P_j = Y_p \times 0.7854\,((D_4 - 2h_s)^2 - d^2) \qquad (45)$$

***For calculation based area of the body of the pipe for upset tubing:***

$$P_j = Y_p \times 0.7854\,(D^2 - d^2) \qquad (46)$$

### 5.4 TUBING JOINT STRENGTH

Nonupset tubing joint strength for sizes 4½ and smaller is calculated using Formula 45. Nonupset tubing joint strength for sizes larger than 4½ is calculated from Formulas 45 and 46, and the lesser of the values obtained from the two formulae governs. Formula 45 is the product of the specified minimum yield strength and the area of the section under the last perfect thread of the pipe and is applicable to all nonupset tubing in sizes 4½ and smaller and to those sizes and grades of casing used in tubing service that are expected to fail by fracture at the last engaged thread. Formula 46 is the product of the yield/tensile ratio and the pull-out strength calculated by Formula 40 and is applicable to those sizes and grades of casing used in tubing service that are expected to fail by pullout.

Load at yield:

$$P_j = Y_p \times 0.7854[(D_4 - 2h_s)^2 - d^2] \qquad (45)$$

Reduced effective load at yield:

$$P_j = \frac{Y_p}{U_p} 0.95 A_{jp} L \left[ \frac{0.74 D^{-0.59} U_p}{0.5L + 0.14D} + \frac{Y_p}{L + 0.14D} \right] \qquad (46)$$

Upset tubing joint strength is calculated using Formula 46-A and is the product of the specified minimum yield strength and the area of the body of the pipe. The area of the section under the last perfect thread of API upset tubing is greater than the area of the body of the pipe.

$$P_j = Y_p \times 0.7854(D^2 - d^2) \qquad (46\text{-A})$$

The areas of the critical sections of regular tubing couplings, special-clearance couplings, and the box of integral-joint tubing are in all instances greater than the governing critical areas of the pipe part of the joint and do not affect the strength of the joint.

*Where:*

$P_j$ = minimum joint strength, pounds.

$Y_p$ = specified minimum yield strength, pounds per square inch.
$D$ = tabulated outside diameter, inches.
$D_4$ = tabulated major diameter, inches.
$h_s$ = height of thread, inches,
= 0.05560 inches for 10 threads per inch
= 0.07125 inches for eight threads per inch.
$d$ = tabulated inside diameter, inches.

Joint strengths were calculated to an accuracy of at least six digits and rounded to 100 pounds.

## 5.5 JOINT STRENGTH OF ROUND THREAD CASING WITH COMBINED BENDING AND INTERNAL PRESSURE

Joint strength of round thread casing subjected to combined bending and internal pressure is calculated from Formulas 47 through 50 on a total load basis and is expressed in pounds.

Full fracture strength:

$$P_u = 0.95 A_{jp} U_P \tag{47}$$

Jumpout and reduced fracture strength:

$$P_j = 0.95 A_{jp} L \left[ \frac{0.74 D^{-0.59} U_p}{0.5L + 0.14D} + \frac{(1 + 0.5K) Y_p}{L + 0.14D} \right] \tag{48}$$

Bending load failure strength:

$$P_b = 0.95 A_{jp} \left[ U_p - \left( \frac{140.5\, BD}{(U_p - Y_p)^{0.8}} \right)^5 \right] \tag{49}$$

*Where:*

$P_b / A_{jp} \geq Y_p$

$$P_b = 0.95 A_{jp} \left[ \frac{U_p - Y_p}{0.644} + Y_p - 218.15\, BD \right] \tag{50}$$

*Where:*

$P_b / A_{jp} < Y_p$

Relationship between total and external load:

$$\text{Total load} = \text{external load} + \text{sealing head load} \tag{51}$$

*Where:*

$$\text{Sealing head load} = PA_H \tag{52}$$

Relationship between bending and radius of curvature:

$$B = 5730/R \tag{53}$$

*Nomenclature*:

$A_H$ = area corresponding to inside diameter, square inches
= $0.7854\,(D - 2t)^2$
$A_{jp}$ = cross-sectional area of the pipe wall under the last perfect thread, square inches
= $0.7854\,[(D - 0.1425)^2 - (D - 2t)^2]$
$B$ = bending, degrees per 100 feet
$D$ = nominal outside diameter of pipe, inches
$K$ = ratio of internal pressure stress to yield strength, or
= $\dfrac{PD}{2 Y_p t}$
$P$ = internal pressure, pounds per square inch
$Y_p$ = minimum yield strength of pipe, pounds per square inch

$L$ = engaged thread length, inches
$P_b$ = total tensile failure load with bending $B$, pounds
$P_j$ = total tensile load at jumpout or reduced fracture, pounds
$P_u$ = total tensile load at fracture, pounds
$R$ = bending radius of curvature, feet
$t$ = nominal wall thickness, inches
$U_p$ = minimum ultimate strength of pipe, pounds per square inch

Calculations were made to six or more digits accuracy without intermediate rounding of areas. The final joint strength values were rounded to the nearest 1000 pounds.

The formulas for joint strength on a total load basis are based on a paper entitled "The Effect of Internal Pressure and Bending on Tensile Strength of API Round Thread Casing" presented by W. O. Clinedinst at the symposium on mechanical properties of pipe during the API Midyear Standardization Conference in June 1967. The paper covered the development of combined loading joint strength formulas and the determination of material constants and formula coefficients based on the results of an API-sponsored research project where 26 tests were made on 5½-inch, 17 pound-per-foot, K-55, short round thread casing.

### 5.6 LINE PIPE JOINT STRENGTH

Formulas for the joint strength of threaded line pipe were developed and presented to the API Committee on Standardization of Tubular Goods by W. O. Clinedinst at the 1976 Standardization Conference. The data and formulas were reproduced in API Circular PS-1533 and are available on request from the API Dallas office.

Although the joint strengths calculated from the formulas are in good agreement with actual test results, the committee recommended that the data be presented for information only without specific endorsement of their applicability to any given size or grade of line pipe.

## 6 Weights

Note: The dimensional symbols and corresponding numerical values used in the formulas for calculation of weights in Section 6 are given in API Specification 5B ***[ISO 10422]*** and API Specifications 5CT ***[ISO 11960, in process]***, 5D, and 5L ***[See also ISO 3183-1]***.

The densities of martensitic chromium steels (L-80, Types 9Cr and 13Cr; C-75, Types 9CR and 13Cr) are different than carbon steels. A weight correction factor of 0.989 may be used for these types.

### 6.1 NOMINAL WEIGHT

Nominal weight, expressed in pounds per foot, is used in connection with pipe having end finish such as threads and couplings, upset and threaded ends, upset ends, etc., primarily for the purpose of identification in ordering. It is also used generally in the design of casing and tubing strings as the basis for determining joint safety factors in tension.

Nominal weight is approximately equal to the calculated theoretical weight per foot of a 20-foot length of threaded and coupled pipe based on the dimensions of the joint in use for the class of product when the particular diameter and wall thickness was introduced. Some nominal weights in the present API casing list are based on sharp thread joints that were in use before the first API specification was adopted in 1924. The same nominal weights are used for short thread joints, long thread joints, buttress thread joints, extreme-line joints, and the various proprietary joints offered to the oil industry. Nominal weights for upset drill pipe for weld-on tool joints are based on the calculated weight-per-foot values of the original threaded and coupled drill pipe.

In determining the nominal weights from calculated weights, it would appear that rounding has been variously to increments of 0.01, 0.05, 0.1, and 0.5 pound per foot, etc., with the order of percentage error being 0.5 percent and less. No definite procedure seems apparent. It would seem logical to use these rounding increments for adding isolated new nominal weights, selecting the increments most compatible with adjacent nominal weights.

## 6.2 CALCULATED PLAIN-END WEIGHT

Plain-end weight per foot expressed in pounds is calculated by Formula 54 for Specifications 5CT ***[ISO 11960, in process]***, 5D, and 5L ***[See also ISO 3183-1]***.

$$w_{pe} = 10.68(D - t)\, t \tag{54}$$

*Where:*

$w_{pe}$ = plain-end weight, calculated to four decimals and rounded to two decimals, pounds per foot.
$D$ = specified outside diameter, inches.
$t$ = specified wall thickness, inches.

## 6.3 CALCULATED THREADED AND COUPLED WEIGHT

Calculated threaded and coupled weight of pipe has not appeared as such in API standards since 1964. However, calculation of this value is necessary to provide a basis for establishing nominal weights when new wall thicknesses are added to the specifications. It is also used in the calculation of $e_w$, the weight gain due to end finishing of threaded and coupled pipe.

The calculated threaded and coupled weight is based on a 20-foot length measured from the outer face of the coupling to the end of the pipe as shown in Figure 3. It is calculated from Formula 55.

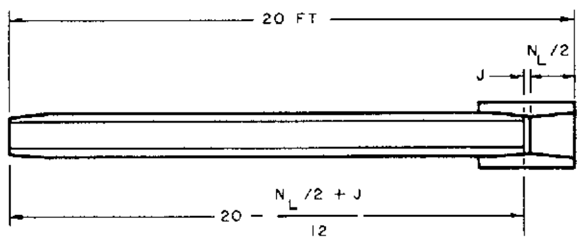



Figure 3—Coupled Pipe

$$w = \frac{\left[20 - \dfrac{N_L + 2J}{24}\right] w_{pe} + \begin{bmatrix}\text{weight of} \\ \text{coupling}\end{bmatrix} - \begin{bmatrix}\text{weight removed in} \\ \text{threading two pipe ends}\end{bmatrix}}{20} \tag{55}$$

*Where:*

$w$ = threaded and coupled weight calculated to four decimals and rounded to two decimals, pounds per foot.
$N_L$ = coupling length, inches.
$J$ = distance from end of pipe to center of coupling in power-tight position, inches.
$w_{pe}$ = plain-end weight calculated to four decimals, pounds per foot.
$\begin{bmatrix}\text{weight of} \\ \text{coupling}\end{bmatrix}$ = weight of coupling calculated to four decimals, pounds.
$\begin{bmatrix}\text{weight removed in} \\ \text{threading two pipe ends}\end{bmatrix}$ = weight of metal removed in threading both ends calculated to four decimals, pounds.

### 6.4 CALCULATED UPSET AND THREADED WEIGHT FOR INTEGRAL JOINT TUBING AND EXTREME-LINE CASING

Calculated upset and threaded weight of pipe has not appeared as such in API standards since 1964. However, this calculation is necessary for determination of $e_w$, the weight gain due to end finishing by upsetting and threading.

The formulas originally used by Armco Steel Corporation for calculating the upset and threaded weight values for extreme-line casing shown in the 1963 editions of API casing standards are no longer available due to destruction of some of their records. Calculations using the formulas shown here and in 6.8.1, 6.8.2, and 6.12 for extreme-line casing result in values substantially in agreement, but not always identical, with those shown in the 1963 API standards.

The calculated upset and threaded weight is based on a 20-foot length as shown in Figure 4 and is calculated from Formula 56.

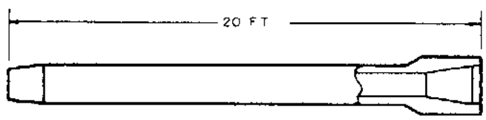



Figure 4—Upset Pipe

$$w = w_{pe} + \frac{\begin{bmatrix}\text{weight of}\\ \text{upsets}\end{bmatrix} - \begin{bmatrix}\text{weight removed in}\\ \text{threading two pipe ends}\end{bmatrix}}{20} \qquad (56)$$

*Where:*

$w$ = upset and threaded weight calculated to four decimals and rounded to two decimals, pounds per foot.

$w_{pe}$ = plain-end weight calculated to four decimals, pounds per foot.

$\begin{bmatrix}\text{weight of}\\ \text{upsets}\end{bmatrix}$ = weight of upsets calculated to four decimals, pounds.

$\begin{bmatrix}\text{weight removed in}\\ \text{threading two pipe ends}\end{bmatrix}$ = weight of metal removed in threading both ends calculated to four decimals, pounds.

### 6.5 CALCULATED UPSET WEIGHT

Calculated upset weight of upset drill pipe for weld on tool joints has not appeared as such in API standards since 1964. However, this calculation is necessary for determination of $e_w$, the weight gain due to end finishing by upsetting.

The calculated upset weight per foot is based on a 20-foot length measured end to end, including the upsets as shown in Figure 5, and is calculated from Formula 57.

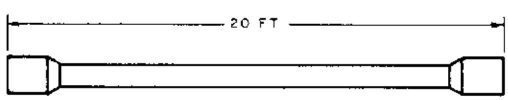



Figure 5—Upset Pipe–Both Ends

$$w = w_{pe} + \frac{\begin{bmatrix}\text{weight of} \\ \text{upsets}\end{bmatrix}}{20} \tag{57}$$

*Where:*

$w$ = upset weight calculated to four decimals and rounded to two decimals, pounds per foot.

$w_{pe}$ = plain-end weight calculated to four decimals, pounds per foot.

$\begin{bmatrix}\text{weight of} \\ \text{upsets}\end{bmatrix}$ = weight of upsets calculated to four decimals, pounds.

## 6.6 WEIGHT GAIN DUE TO END FINISHING

Since 1965, API standards list the calculated weight gain (or loss) due to end finishing, $e_w$, rather than calculated threaded and coupled weight, calculated upset and threaded weight, or calculated upset weight. Values of $e_w$ given in API standards are calculated from Formula 58. For plain-end pipe, $e_w = 0$.

$$e_w = 20(w - w_{pe}) \tag{58}$$

*Where:*

$e_w$ = weight gain (or loss) due to end finishing rounded to two decimals, pounds.

$w$ = calculated threaded and coupled weight, upset and threaded weight, or upset weight based on a 20-foot length, rounded to two decimals, pounds.

$w_{pe}$ = calculated plain-end weight rounded to two decimals, pounds per foot.

Values of $e_w$ may be calculated directly without the intermediate rounding of calculated weight with end finish and plain-end weight from Formulas 59, 60, and 61, but the values will not agree with those presently shown in API standards due to the difference in rounding procedures.

Direct calculation of $e_w$—threaded and coupled pipe:

$$e_w = \begin{bmatrix}\text{weight of} \\ \text{coupling}\end{bmatrix} - \left[\frac{N_L + 2J}{24}\right] w_{pe} - \begin{bmatrix}\text{weight removed in} \\ \text{threading two pipe ends}\end{bmatrix} \tag{59}$$

Direct calculation of $e_w$—upset and threaded pipe:

$$e_w = \begin{bmatrix}\text{weight of} \\ \text{upsets}\end{bmatrix} - \begin{bmatrix}\text{weight removed in} \\ \text{threading two pipe ends}\end{bmatrix} \tag{60}$$

Direct calculation of $e_w$—upset pipe:

$$e_w = \begin{bmatrix}\text{weight of} \\ \text{upsets}\end{bmatrix} \tag{61}$$

The value, $e_w$, is used to calculate the theoretical weight of a length of pipe by means of Formula 62:

$$W_L = w_{pe} L + e_w \tag{62}$$

*Where:*

$W_L$ = calculated weight of a piece of pipe of length $L$, pounds.

$w_{pe}$ = tabulated plain-end weight calculated to two decimals, pounds per foot.

$L$ = length of pipe including end finish, calculated to one decimal, feet.

$e_w$ = weight gain (or loss) due to end finishing, calculated to two decimals, pounds.

## 6.7 CALCULATED COUPLING WEIGHT

Coupling weights are calculated as shown in 6.7.1 for line pipe and round thread casing and tubing, and in 6.7.2 for buttress thread casing. Coupling weights are based on the lower value of hand-tight standoff in those sizes where more than one standoff value is given.

### 6.7.1 Calculated Coupling Weight for Line Pipe and Round Thread Casing and Tubing

Coupling weights for line pipe and round thread casing are calculated on the basis of hand-tight dimensions.

Coupling weights for line pipe are calculated on the basis of the dimensions shown in the 1942 edition of Specification 5L, which are identical with those shown in the 1971 edition ***[See also ISO 3183-1]***.

Coupling weights for round thread casing are calculated on the basis of the dimensions shown in the 1942 standards except for 18⅝-inch short and 20-inch-long round thread casing, which are based on hand-tight dimensions identical with the 1971 standard values.

Coupling weights shown for 18⅝-inch long round threads and for 16-inch round threads are based on the old sharp thread form and dimensions. The hand-tight standoff values in the 1971 standards were made one thread turn larger than those in the 1942 standards. Recalculation on the basis of the 1971 hand-tight dimensions would result in slightly different coupling weights.

Nonupset tubing coupling weights are based on 1942 coupling dimensions, except for the 1.050-, 1.315-, and 1.660-inch sizes, which were based on coupling dimensions added in 1962. The 1971 dimensions are identical with those from which the present coupling weights were calculated.

External upset tubing coupling weights are based on 1942 coupling dimensions except for the 1.050- and 1.315-inch sizes, which were based on coupling dimensions added in 1954. For regular diameter couplings, the dimensions used in calculating weights are identical with those in the 1971 standards. The special clearance coupling weights are based on the diameters introduced in the 1958 standards, which are identical to those in the 1971 standards. In calculating the weights of the special clearance couplings, an allowance is made for the weight removed by the special bevel. However, the weights were calculated several years before special clearance couplings were introduced into the standards in 1958 on the basis of a 12-degree bevel rather than the 20-degree bevel introduced in the 1962 standard. The weights were not recalculated for the change in bevel dimensions adopted for the special bevel in 1962. The special bevel is also available on regular diameter couplings, but separate listings of weights for these couplings are shown in the standards.

Weights for line pipe couplings and round thread casing and tubing couplings are calculated from Formulas 63 through 72, with reference to Figures 6 and 7.

#### 6.7.1.1 Couplings Without Special Bevel Weight Allowance, Based on Hand-Tight Dimensions

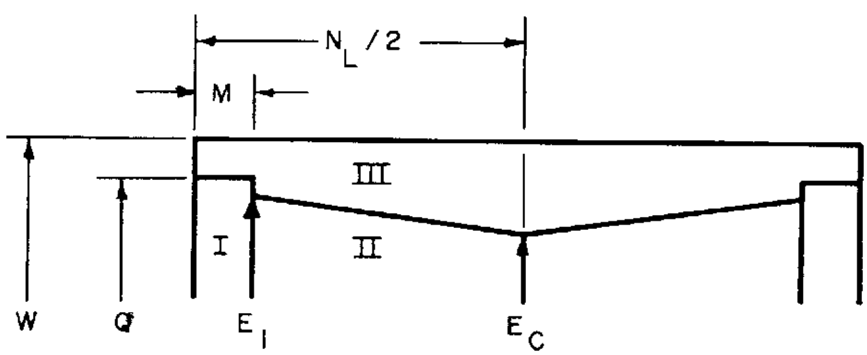



Figure 6— Pipe Coupling

$$E_c = E_1 - (N_L/2 - M)(\text{taper}) \quad (63)$$

$$\text{Vol. I} = 0.7854MQ^2 \quad (64)$$

$$\text{Vol. II} = 0.2618(N_L/2 - M)(E_1^2 + E_1 E_c + E_c^2) \quad (65)$$

$$\text{Vol. (I+II+III)} = 0.7854N_L W^2/2 \quad (66)$$

$$\text{Vol. III} = \text{Vol. (I+II+III)} - \text{Vol. I} - \text{Vol. II} \quad (67)$$

$$\begin{bmatrix} \text{calculated coupling} \\ \text{weight} \end{bmatrix} = 0.5666(\text{Vol. III}) \quad (68)$$

Note: Calculations for coupling weights are in pounds. The final calculated weight is rounded to two decimals with no intermediate rounding in the calculations.

#### 6.7.1.2 Coupling Weight Removed by Special Bevel

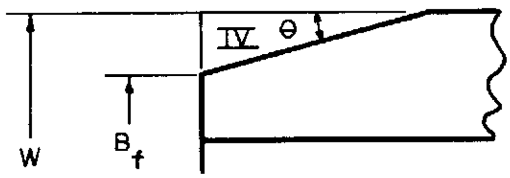



Figure 7—Pipe Coupling With Special Bevel

Formula 69, which is used to calculate the weight allowance for the special bevel on special clearance couplings for external upset tubing, is approximate. The exact formula for Vol. IV is shown as Formula 70.

$$\text{Vol. IV} = \frac{0.7854\,(W - B_f)\,(W^2 - B_f^2)}{2 \tan \theta} \quad (69)$$

$$\text{Vol. IV} = \frac{(W - B_f)}{\tan \theta}\,[0.785W^2 - 0.2618(B_f^2 + B_f W + W^2)] \quad (70)$$

$$\begin{bmatrix} \text{coupling weight} \\ \text{removed by} \\ \text{special bevel} \end{bmatrix} = 0.5666(\text{Vol. IV}) \quad (71)$$

#### 6.7.1.3 Coupling Weight With Special Bevel

The weight of a coupling with special bevel is calculated by subtracting the coupling weight removed by the special bevel, Formula 71 above, from the weight of the coupling without a special bevel, Formula 68, as indicated by Formula 72. Calculations for coupling weights are in pounds. The final calculated weight is rounded to two decimals with no intermediate rounding in the calculations.

$$\begin{bmatrix} \text{coupling weight} \\ \text{with special bevel} \end{bmatrix} = \begin{bmatrix} \text{coupling weight} \\ \text{without special bevel} \end{bmatrix} - \begin{bmatrix} \text{coupling weight} \\ \text{removed by special bevel} \end{bmatrix} \quad (72)$$

### 6.7.2 Calculated Coupling Weight for Buttress Thread Casing

Coupling weights for buttress thread casing are calculated on the basis of power-tight dimensions (instead of hand-tight dimensions as for line pipe and round thread casing and tubing) by Formulas 73 through 78, with reference to Figure 8.

$$E_c = E_7 - (L_7 + J)\,(\text{taper}) \quad (73)$$

$$E_E = E_7 + (g + X)\,(\text{taper}) \quad (74)$$

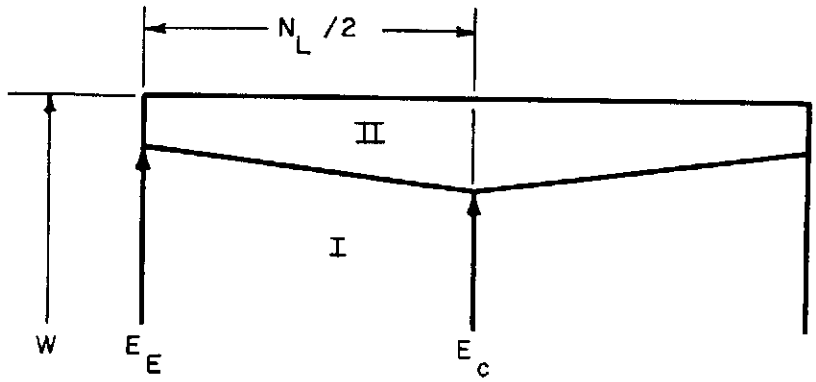



Figure 8—Weight Calculations for Buttress Thread Couplings

*Where*:

$X$ = 0.300 for sizes less than 16 inch
= 0.200 for sizes 16 inch and larger.
(taper) = 0.0625 for sizes less than 16 inch
= 0.0833 for sizes 16 inch and larger.

$$\text{Vol. I} = 0.2618\,(N_L/2)(E_E^2 + E_E E_c + E_c^2) \quad (75)$$

$$\text{Vol. (I+II)} = 0.7854(N_L/2)W^2 \quad (76)$$

$$\text{Vol. II} = \text{Vol. (I+II)} - \text{Vol. I} \quad (77)$$

$$\begin{bmatrix}\text{calculated} \\ \text{coupling weight}\end{bmatrix} = 0.5666(\text{Vol. II}) \quad (78)$$

Note. Calculations for coupling weights are in pounds. The final calculated weight is rounded to two decimals with no intermediate rounding in the calculations.

## 6.8 CALCULATED WEIGHT REMOVED IN THREADING

The weight removed in threading pipe or pin ends is calculated in accordance with 6.8.1. The weight removed in threading and recessing box ends is calculated in accordance with 6.8.2.

### 6.8.1 Calculated Weight Removed in Threading Pipe or Pin Ends

The weight removed by threading pipe or pin ends is calculated from Formulas 79 through 86 with reference to Figures 9, 10, and 11.

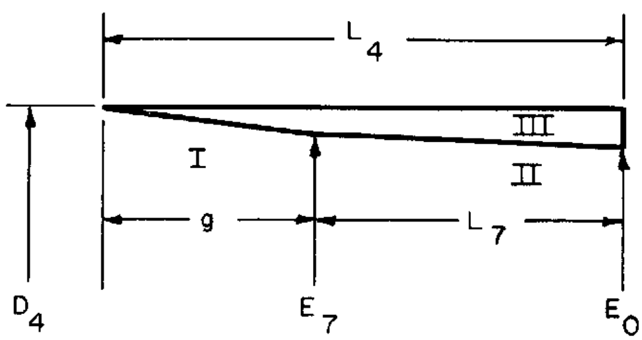



Figure 9—Round Threads and Line Pipe Threads

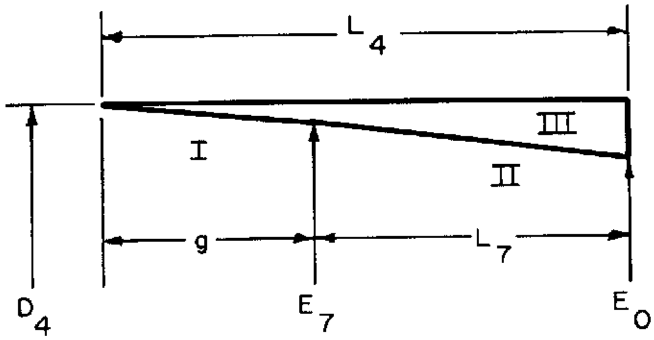



Figure 10—Buttress Threads

$$E_0 = E_7 - L_7\,(\text{taper}) \tag{79}$$

*Where:*

$D_4$ = upset outside diameter of upset pipe and pipe outside diameter of nonupset pipe and buttress thread casing.

(taper) = 0.0625 for all round threads and for buttress threads in size less than 16 inch.
= 0.0833 for buttress threads in sizes 16 inch and larger.

$$\text{Vol. I} = 0.2618g\,(D_4^2 + D_4E_7 + E_7^2) \tag{80}$$

$$\text{Vol. II} = 0.2618\,(L_4 - g)\,(E_7^2 + E_7E_0 + E_0^2) \tag{81}$$

$$\text{Vol. (I+II+III)} = 0.7854L_4D_4^2 \tag{82}$$

$$\text{Vol. III} = \text{Vol. (I+II+III)} - \text{Vol. I} - \text{Vol. II} \tag{83}$$

$$\begin{bmatrix}\text{calculated weight}\\ \text{removed in threading}\end{bmatrix} = 0.2833(\text{Vol. III}) \tag{84}$$

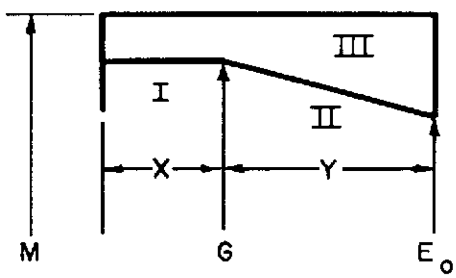



Figure 11—Extreme-Line Thread

*Where:*

$X$ = 0.360 for sizes 5 1/2 through 7 5/8 inches
= 0.404 for sizes 8 5/8 through 10 3/4.
$Y$ = 3.230 for sizes 5 1/2 through 7 5/8 inches
= 5.6585 for sizes 8 5/8 through 10 3/4 inches.
$E_0$ = G – 0.529 for sizes 5 1/2 through 7 5/8 inches
= G – 0.589 for sizes 8 5/8 through 10 3/4 inches.

$$\text{Vol. I} = 0.7854XG^2 \tag{85}$$

$$\text{Vol. II} = 0.2618Y(G^2 + GE_0 + E_0^2) \tag{86}$$

$$\text{Vol. (I+II+III)} = 0.7854\,(X + Y)M^2 \tag{87}$$

$$\text{Vol. III} = \text{Vol. (I+II+III)} - \text{Vol. I} - \text{Vol. II} \tag{88}$$

$$\begin{bmatrix}\text{calculated weight} \\ \text{removed in threading one pin}\end{bmatrix} = 0.2833(\text{Vol. III}) \tag{89}$$

### 6.8.2 Calculated Weight Removed in Threading Integral Joint Tubing and Extreme-Line Casing Box Ends

The weight removed by threading and recessing the box ends of integral joint tubing is calculated from Formulas 90 through 96, with reference to Figure 12.

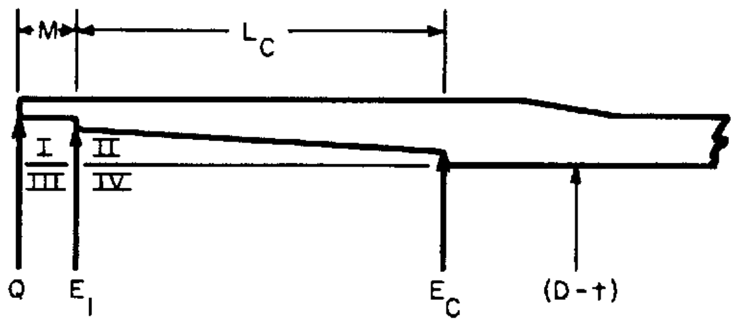



Figure 12—Integral Joint Tubing

$$L_c = L_1 + J + A \tag{90}$$

$$E_c = E_1 - L_c\ (\text{taper}) \tag{91}$$

*Where:*

$J$ = end of pipe to thread run-out in box power-tight.

$$\text{Vol. (I+III)} = 0.7854MQ^2 \tag{92}$$

$$\text{Vol. (II+IV)} = 0.2618L_c\,(E_1^2 + E_1E_c + E_1^2) \tag{93}$$

$$\text{Vol. (III+IV)} = 0.7854(M + L_c)(D - t)^2 \tag{94}$$

$$\text{Vol. (I+II)} = \text{Vol. (I+III)} + \text{Vol. (II+IV)} - \text{Vol. (III+IV)} \tag{95}$$

$$\begin{bmatrix}\text{weight removed in} \\ \text{threading and recessing}\end{bmatrix} = 0.2833\,[\text{Vol.(I+II)}] \tag{96}$$

The weight removed by threading and recessing the box ends of extreme-line casing is calculated from formulas 97 through 103, with reference to Figure 13.

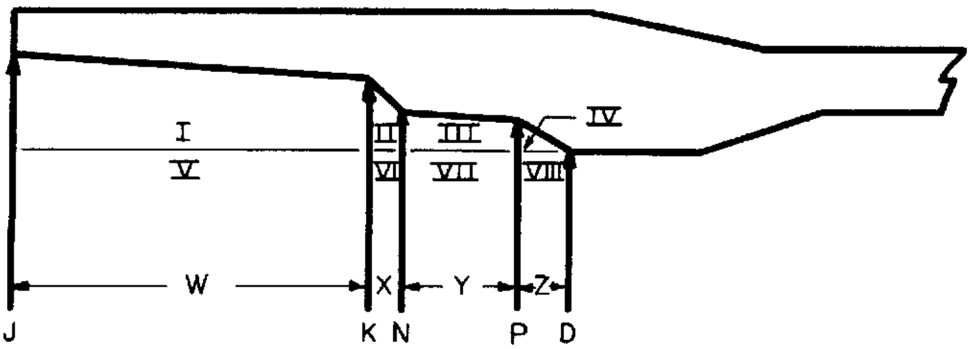



Figure 13—Extreme-Line Casing

*Where:*

$Z = 0.5(P - D)$

$$\text{Vol. (I+V)} = 0.2618W(J^2 + JK + K^2) \quad (97)$$

$$\text{Vol. (II+VI)} = 0.2618X(K^2 + KN + N^2) \quad (98)$$

$$\text{Vol. (III+VII)} = 0.2618Y(N^2 + NP + P^2) \quad (99)$$

$$\text{Vol. (IV+VIII)} = 0.2618Z(P^2 + PD + D^2) \quad (100)$$

$$\text{Vol. (V+VI+VII+VIII)} = 0.7854(W+X+Y+Z)D^2 \quad (101)$$

$$\text{Vol. (I+II+III+IV)} = \text{Vol. (I+V)} + \text{Vol. (II+VI)} + \text{Vol. (III+VII)} + \text{Vol. (IV+VIII)} - \text{Vol. (V+VI+VII+VIII)} \quad (102)$$

$$\begin{bmatrix} \text{calculated weight} \\ \text{removed in threading} \end{bmatrix} = 0.2833\,[\text{Vol. (I+II+III+IV)}] \quad (103)$$

Note: Calculations for weight removed in threading, or threading and recessing are in pounds and are carried to four decimals.

## 6.9 CALCULATED WEIGHT OF EXTERNAL UPSETS

The weight added by an external upset is calculated by Formulas 104 through 108, with reference to Figure 14.

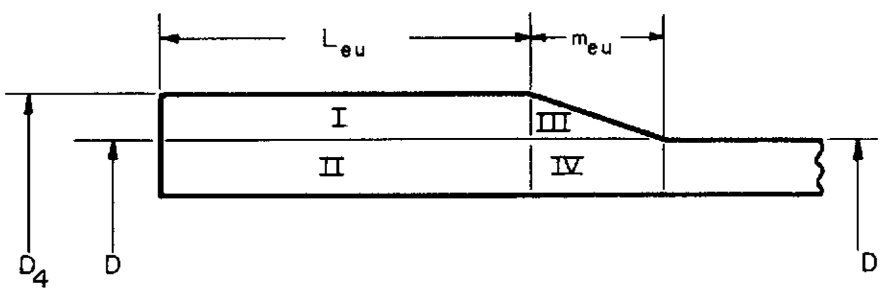



Figure 14—External Upset

$$\text{Vol.(I+II)} = 0.7854\, L_{eu}\, D_4^2 \tag{104}$$

$$\text{Vol.(III+IV)} = 0.2618 m_{eu}\,(D_4^2 + D_4 D + D^2) \tag{105}$$

$$\text{Vol.(II+IV)} = 0.7854\,(L_{eu} + m_{eu})D^2 \tag{106}$$

$$\text{Vol.(I+III)} = \text{Vol.(I+II)} + \text{Vol. (III+IV)} - \text{Vol.(II+IV)} \tag{107}$$

$$\begin{bmatrix}\text{calculated weight}\\ \text{of external upset}\end{bmatrix} = 0.2833[\text{Vol. (I+III)}] \tag{108}$$

Note: Calculations for the weight of an external upset are in pounds and carried to four decimals.

## 6.10 CALCULATED WEIGHT OF INTERNAL UPSETS

The weight added by an internal upset is calculated by Formulas 109 through 113, with reference to Figure 15.

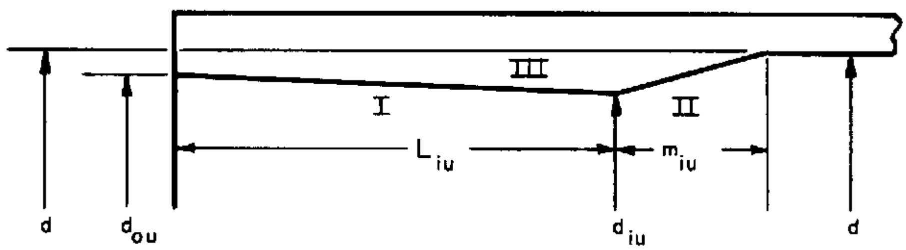



Figure 15—Internal Upset

$$\text{Vol. I} = 0.2618 L_{iu}\,(d_{ou}^2 + d_{ou}\, d_{iu} + d_{iu}^2) \tag{109}$$

$$\text{Vol. II} = 0.2618 m_{iu}\,(d^2 + d d_{iu} + d_{iu}^2) \tag{110}$$

$$\text{Vol. (I+II+III)} = 0.7854 d^2 (L_{iu} + m_{iu}) \tag{111}$$

$$\text{Vol. III} = \text{Vol. (I+II+III)} - \text{Vol. I} - \text{Vol. II} \tag{112}$$

$$\begin{bmatrix}\text{calculated weight}\\ \text{of internal upset}\end{bmatrix} = 0.2833\,(\text{Vol. III}) \tag{113}$$

Note: Calculations for the weight of an internal upset are in pounds and carried to four decimals.

## 6.11 CALCULATED WEIGHT OF EXTERNAL-INTERNAL UPSETS

The weight added by an external-internal upset is calculated as the sum of the weight of an external upset calculated from Formula 108, and the weight of an internal upset calculated from Formula 113, as given by Formula 114.

$$\begin{bmatrix}\text{calculated weight}\\ \text{external internal upset}\end{bmatrix} = \begin{bmatrix}\text{calculated weight}\\ \text{internal upset}\end{bmatrix} + \begin{bmatrix}\text{calculated weight}\\ \text{external upset}\end{bmatrix} \tag{114}$$

Note: Calculations for the weight of an external-internal upset are in pounds and carried to four decimals.

## 6.12 CALCULATED WEIGHT OF EXTREME-LINE UPSETS

The weight added by the box and pin upsets for extreme-line casing is calculated from Formulas 115 through 132 with reference to Figures 16 and 17.

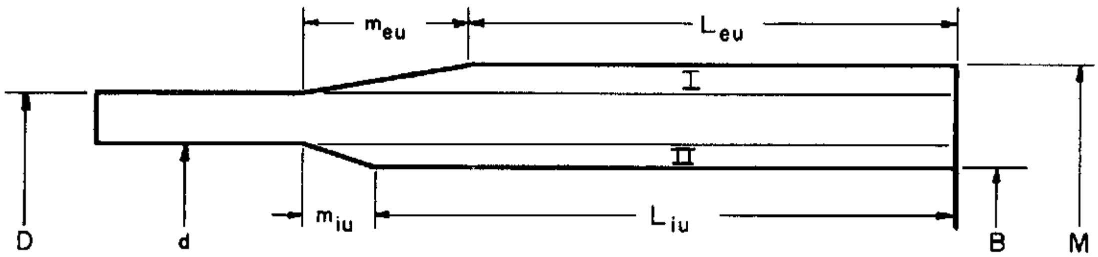



Figure 16—Pin Upset

$$m_{eu} = 6(M - D) \tag{115}$$
$$m_{iu} = 6(d - B) \tag{116}$$
$$L_{eu} = 8.000 - m_{eu} \text{ for } 5\tfrac{1}{2} \text{ through } 7\tfrac{5}{8} \text{ inch} \tag{117}$$
$$= 10.500 - m_{eu} \text{ for } 8\tfrac{5}{8} \text{ through } 10\tfrac{3}{4} \text{ inch} \tag{118}$$
$$L_{iu} = 6.625 \text{ for } 5\tfrac{1}{2} \text{ through } 7\tfrac{5}{8} \text{ inch} \tag{119}$$
$$= 8.000 \text{ for } 8\tfrac{5}{8} \text{ through } 10\tfrac{3}{4} \text{ inch} \tag{120}$$
$$\text{Vol. I} = 0.7854L_{eu}M^2 + 0.2618m_{eu}(D^2 + DM + M^2) - 0.7854(L_{eu} + m_{eu})D^2 \tag{121}$$
$$\text{Vol. II} = 0.7854(L_{iu} + m_{iu})d^2 - 0.7854L_{iu}B^2 - 0.2618m_{iu}(d^2 + dB + B^2) \tag{122}$$
$$\begin{bmatrix}\text{weight of}\\ \text{pin upset}\end{bmatrix} = 0.2833[\text{Vol.(I+II)}] \tag{123}$$

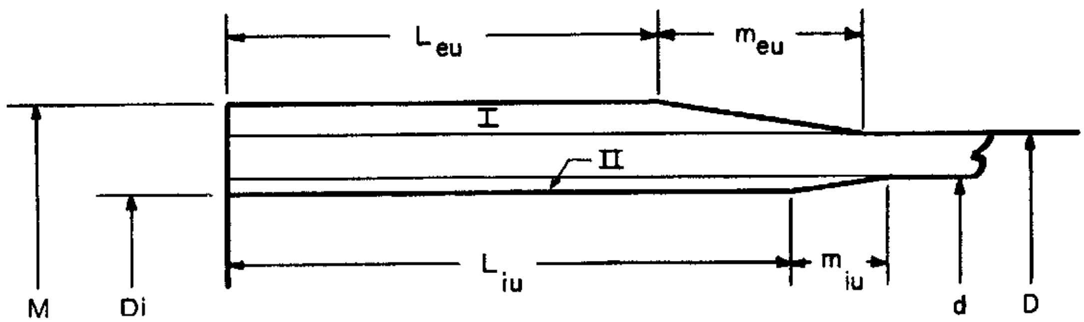



Figure 17—Box Upset

$$m_{eu} = 6(M - D) \tag{124}$$
$$m_{iu} = 6(d - D_i) \tag{125}$$
$$L_{eu} = 8.000 - m_{eu} \text{ for } 5\tfrac{1}{2} \text{ through } 7\tfrac{5}{8} \text{ inch} \tag{126}$$
$$= 10.500 - m_{eu} \text{ for } 8\tfrac{5}{8} \text{ through } 10\tfrac{3}{4} \text{ inch} \tag{127}$$
$$L_{iu} = 7.000 \text{ for } 5\tfrac{1}{2} \text{ through } 7\tfrac{5}{8} \text{ inch} \tag{128}$$
$$= 8.375 \text{ for } 8\tfrac{5}{8} \text{ through } 10\tfrac{3}{4} \text{ inch} \tag{129}$$
$$\text{Vol. I} = 0.7854L_{eu}M^2 + 0.2618m_{eu}(M^2 + MD + D^2) - 0.7854(L_{eu} + m_{eu})D^2 \tag{130}$$
$$\text{Vol. II} = 0.7854(L_{iu} + m_{iu})d^2 - 0.7854L_{iu}D_i^2 - 0.2618m_{iu}(D_i^2 + D_i d + d^2) \tag{131}$$
$$\begin{bmatrix}\text{weight of}\\ \text{box upset}\end{bmatrix} = 0.2833(\text{Vol. I + Vol. II}) \tag{132}$$

Note: Calculations for the weights of the extreme-line box and pin upsets are in pounds and carried to four decimals.

# 7 Elongation

The minimum elongation in 2 inches is calculated from Formula 133:

$$e = 625000 \frac{A^{0.2}}{U^{0.9}} \tag{133}$$

*Where:*

$e$ = minimum elongation in 2 inches, rounded to nearest $^1/_2$ percent.
$A$ = cross-sectional area of the tensile specimen, based on specified outside diameter, or nominal specimen width, and specified wall thickness, rounded to the nearest 0.01 square inch, or 0.75 square inch, whichever is smaller.
$U$ = specified tensile strength, pounds per square inch.

The formula was adopted at the June 1967 Standardization Conference as reported in API Circular PS-1340.

# 8 Flattening Tests

## 8.1 FLATTENING TESTS FOR CASING AND TUBING

The distance between plates for flattening tests for casing and tubing is calculated from the formulas shown in Table 7, and rounded to one decimal.

## 8.2 FLATTENING TESTS FOR LINE PIPE

The distance between plates for flattening tests for electric flash weld, electric resistance weld, and electric induction weld line pipe are calculated from Formulas 134 and 135, and rounded to one decimal.

Grades less than X-52:

$$S = \frac{3.07t}{0.07 + 3t/D} \tag{134}$$

Grades X-52 and higher:

$$S = \frac{3.05t}{0.05 + 3t/D} \tag{135}$$

*Where*:

$S$ = distance between flattening plates, inches.
$t$ = specified wall thickness of pipe, inches.
$D$ = specified outside diameter of pipe, inches.

The flattening test formulas were developed by the Task Group on Welding and Weld Testing and adopted at the June 1970 Standardization Conference as reported in API Circular PS-1398.

# 9 Hydrostatic Test Pressures

## 9.1 HYDROSTATIC TEST PRESSURES FOR PLAIN-END PIPE, EXTREME-LINE CASING, AND INTEGRAL-JOINT TUBING

The hydrostatic test pressures for plain-end pipe, extreme-line casing, and integral-joint tubing are calculated according to Formula 136, except for grade A-25 line pipe, grades A and B line pipe in sizes less than $2^3/_8$-inch OD, and threaded and coupled line pipe in sizes $6^5/_8$-inch OD and less, which were determined arbitrarily.

$$P = \frac{2St}{D} \tag{136}$$

Table 7—Flattening Tests—Distance Between Plates

| (1) | (2) | (3) |
|---|---|---|
| Grade | $D/t$ Ratio | Distance Between Plates, Maximum (inches) |
| H-40 | 16 and over<br>less than 16 | $0.5D$<br>$D(0.83–0.0206\ D/t)$ |
| J-55 and K-55 | 16 and over<br>3.93 to 16<br>less than 3.93 | $0.65D$<br>$D(0.98–0.0206\ (D/t)$<br>$D(1.104–0.0518\ D/t)$ |
| N-80[a] | 9 to 28 | $D(1.074–0.0194\ D/t)$ |
| C-75 and L-80 | 9 to 28 | $D(1.074–0.0194\ D/t)$ |
| C-95[a] | 9 to 28 | $D(1.080–0.0178\ D/t)$ |
| Q-125[b] | All | $D(1.092–0.014\ D/t)$ |

Notes:
1. $D$ = nominal outside diameter of pipe, in inches; $t$ = nominal wall thickness of pipe, in inches.
2. The flattening test formula for Grade H-40 was adopted at the May 1939 Standardization Conference. The formulas for Grades J-55, K-55, N-80, C-75, and C-95 were adopted at the June 1972 Standardization Conference as reported in API Circular PS-1440. The formula for L-80 was adopted at the June 1974 Standardization Conference as reported in API Circular PS-1487. The formula for Q-125 was adopted at the June 1984 Standardization Conference as reported in API Circular PS-1736.

[a] If the flattening test of C-95 or N-80 fails at 12 or 6 o'clock, the flattening shall continue until the remaining portion of the specimen fails at the 3 or 9 o'clock position. Premature failure at the 12 or 6 o'clock position shall not be considered basis for rejection.

[b] See API Specification 5CT ***[ISO 11960, In process]*** and SR11. Flattening shall be a minimum of $0.85D$.

*Where:*

$P$ = hydrostatic test pressure rounded to the nearest 10 pounds per square inch for line pipe and to the nearest 100 pounds per square inch for casing and tubing

$S$ = fiber stress corresponding to the percent of specified yield strength as given in Table 8.

$t$ = specified wall thickness, inches.

$D$ = specified outside diameter, inches.

## 9.2 HYDROSTATIC TEST PRESSURE FOR THREADED AND COUPLED PIPE

The hydrostatic test pressure for threaded and coupled pipe is the same as for plain-end pipe except where a lower pressure is required to avoid leakage due to insufficient internal yield pressure of the coupling or insufficient internal pressure leak resistance at the $E_1$ or $E_7$ plane calculated using Formulas 137 and 141 respectively.

### *9.2.1 Internal Yield Pressure for Couplings*

### 9.2.1 Maximum Hydrostatic Test Pressure for Threaded and Coupled Pipe

To avoid leakage due to insufficient coupling strength, the hydrostatic test pressure for threaded and coupled pipe must not exceed the pressure calculated using Formula 137.

The internal yield pressure for the coupling is calculated using Formula 137 and rounded to the nearest 100 pounds per square inch:

$$P = 0.8Y_c\left(\frac{W-d_1}{W}\right) \qquad (137)$$

*Where:*

$Y_c$ = minimum yield strength of coupling, pounds per square inch.

$W$ = nominal outside diameter of coupling, inches.

$d_1$ = diameter at the root of the coupling thread at the end of the pipe in the power-tight position rounded to nearest 0.001 inch.

For round thread casing and tubing:

$$d_1 = E_1 - (L_1 + A)\,T + H - 2S_m \qquad (138)$$

Table 8—Factors for Test Pressure Formulas

| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|
| | | Fiber Stress as a Percent of Specified Minimum Yield Strength | | | Maximum Test Pressure[a] (psi) | |
| Grade | Size | Standard Test Pressures | Alternative Test Pressures | Test Pressure Rounding | Standard | Alternative |
| A and B | $2^3/_8$ thru $3^1/_2$ | 60 | 75 | 10 | 2500 | 2500 |
| | over $3^1/_2$ | 60 | 75 | 10 | 2800 | 2800 |
| X grades | $4^1/_2$ and under | 60 | 75 | 10 | 3000 | 3000 |
| | $6^3/_8$ and $8^3/_8$ | 75 | [b] | 10 | 3000 | [b] |
| | $10^3/_4$ thru 18 | 85 | [b] | 10 | 3000 | [b] |
| | 20 and larger | 90 | [b] | 10 | 3000 | [b] |
| H-40, J-55, | $9^5/_8$ and under | 80 | 80 | 100 | 3000 | 10000 |
| and K-55 | $10^3/_4$ and larger | 60 | 80 | 100 | 3000 | 10000 |
| L-80 and N-80 | All sizes | 80 | [b] | 100 | 10000[c] | [b] |
| C-75 | All sizes | 80 | [b] | 100 | 10000[c] | [b] |
| C-90 | All sizes | 80 | [b] | 100 | 10000[c] | [b] |
| C-95 | All sizes | 80 | [b] | 100 | 10000[c] | [b] |
| P-105 | All sizes | 80 | 80 | 100 | 10000[c] | [d] |
| P-110 | All sizes | 80 | 80 | 100 | 10000[c] | [d] |
| Q-125 | All sizes | 80 | 80 | 100 | 10000[c] | [d] |

[a] Higher test pressures are permissible by agreement between purchaser and manufacturer.
[b] No alternative test pressure.
[c] Plain-end pipe is tested to 3000 pounds per square inch maximum unless a higher pressure is agreed upon by the purchaser and manufacturer.
[d] No maximum test pressure, except that plain-end pipe is tested to 3000 pounds per square inch unless a higher pressure is agreed upon by the purchaser and manufacturer.

For line pipe:

$$d_1 = E_1 - (L_1 + A)\,T + H - 2f_m \tag{139}$$

*Where*:

$E_1$ = pitch diameter at hand-tight plane, inches.
$L_1$ = length, from end of pipe to hand-tight plane, inches.
$A$ = hand-tight standoff, inches.
$T$ = taper
= 0.0625 inch/inch.
$H$ = thread height, inches
= 0.0321 for 27 TPI
= 0.0481 for 18 TPI
= 0.0619 for 14 TPI
= 0.0753 for $11^1/_2$ TPI
= 0.08660 for 10 TPI
= 0.10825 for 8 TPI.
$S_m$ = 0.014 inch for 10 TPI
= 0.017 inch for 8 TPI.
$f_m$ = 0.0012 for 27 TPI
= 0.0018 for 18 TPI
= 0.0024 for 14 TPI
= 0.0029 for $11^1/_2$ TPI
= 0.0041 for 8 TPI.

For buttress thread casing:

$$d_1 = E_7 - (L_7 + I)\, T + 0.62 \qquad (140)$$

*Where*:

$E_7$ = pitch diameter, inches.
$L_7$ = length of perfect threads, inches.

| | Size, inches | | |
|---|---|---|---|
| | $4\frac{1}{2}$ | $5$–$13\frac{3}{8}$ | Over $13\frac{3}{8}$ |
| $I$ = | 0.400 | 0.500 | 0.375 |
| $T$ = | 0.0625 | 0.0625 | 0.0833 |

Formula 137 bases the coupling hydrostatic pressure strength on the coupling being stressed to 80 percent of minimum yield strength at the root of the coupling thread at the end of the pipe in the power-tight position. The basis for this formula was adopted at the 1968 Standardization Conference as shown in API Circular PS-1360.

### 9.2.2 Internal Pressure Leak Resistance at $E_1$ or $E_7$ Plane

The internal pressure leak resistance at the $E_1$ or $E_7$ plane is calculated from Formula 141 and rounded to the nearest 100 pounds per square inch. Formula 141 is based on the seal being at the $E_1$ plane for round threads and the $E_7$ plane for buttress threads where the coupling is the weakest and the internal pressure leak resistance the lowest. Also, Formula 141 is based on the internal leak resistant pressure being equal to the interface pressure between the pipe and coupling threads resulting from makeup and the internal pressure itself, with stresses in the elastic range.

$$P = E\,T\,N\,p\,(W^2 - E_s^2)/2E_s W^2 \qquad (141)$$

*Where*:

$P$ = internal pressure leak resistance, in pounds per square inch, rounded to nearest 10 pounds per square inch.
$E$ = $30 \times 10^6$ (modulus of elasticity).
$T$ = thread taper, inch/inch
= 0.0625 for round thread casing
= 0.0625 for buttress thread casing $13^3/_8$ and smaller
= 0.0833 for buttress thread casing 16 and larger.
$N$ = number of thread turns makeup
= $A$ for round thread casing (API Standard 5B ***[ISO 10422]***)
= $A + 1\frac{1}{2}$ for buttress thread casing $13^3/_8$ and smaller
= $A + 1$ for buttress thread casing 16 and larger.
$p$ = thread pitch, inches
= 0.125 for round thread casing
= 0.200 for buttress thread casing.
$W$ = coupling outside diameter, inches.
$E_s$ = pitch diameter at plane of seal, inches
= $E_1$ for round thread, inches
= $E_7$ for buttress thread casing, inches.

## 10 Makeup Torque for Round Thread Casing and Tubing

The values of optimum makeup torque listed in API Recommended Practice 5C1 ***[ISO 10405]*** in foot-pounds were taken as 1 percent of the calculated joint pullout strength for round thread casing and tubing as determined from Formula 40 rounded to the nearest 10 foot-pounds. The minimum torque was taken as 75 percent and the maximum as 125 percent of the optimum torque, both rounded to the nearest 10 foot-pounds.

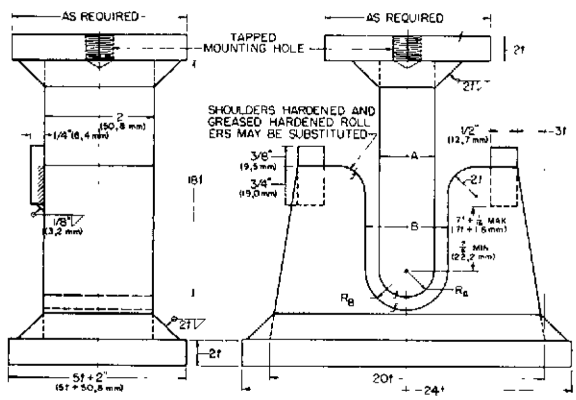
In the study of makeup torque, the Task Group on Recommended Practice 5C1 observed that the API round thread joint pullout strength formula contains several of the variables believed to affect makeup torque. The task group investigated the possibility of using a modification of the joint strength formula for establishing torque values. They found that the torque values obtained by dividing the calculated pullout value by 100 to be generally comparable to those values obtained by field makeup tests where the API modified thread compound was used.

This method for calculating makeup torque was adopted at the June 1970 Standardization Conference as reported in API Circular PS-1398. Subsequently, optimum and maximum torque was dropped for large diameter (16–20 inch) casing. Minimum torque was changed to 1 percent of pullout strength. This was adopted at the June 1980 Standardization Conference as reported in API Circular PS-1637.

**Action was taken by the API Committee on Standardization of Tubular Goods at the February 1991 meeting to eliminate minimum and maximum torque values and emphasize position on makeup.**

## 11 Guided Bend Tests for Submerged Arc Welded Line Pipe

Dimensions for the jig for guided bend tests for submerged arc welded line pipe are calculated from Formula 142 with reference to Figure 18.




t SPECIFIED WALL THICKNESS OF PIPE

Figure 18—Guided Bend Test Jig

$$A = \frac{1.15\,(D - 2t)}{eD/t - 2e - 1} - t \qquad (142)$$

*Where:*

1.15 = peaking factor.
$D$ = specified OD, inches.
$t$ = specified wall thickness, inches.
$e$ = strain, inch/inch
= 0.1675 for Grade A
= 0.1375 for Grade B
= 0.1375 for Grade X-42
= 0.1325 for Grade X-46
= 0.1275 for Grade X-52
= 0.1200 for Grade X-56
= 0.1125 for Grade X-60
= 0.1100 for Grade X-65
= 0.1025 for Grade X-70
= 0.0900 for Grade X-80.

$R_A = \frac{1}{2}A.$
$B = A + 2t + \frac{1}{8}$ inch.
$R_B = \frac{1}{2}B.$

Values for $e$ are based on Formula 143 shown in Item 4a of API Circular PS-1340 reporting the actions of the 1967 Standardization Conference except for Grade X-70, which were adopted at the June 1972 Standardization Conference and shown in API Circular PS-1440. The values calculated by means of Formula 143 are rounded to the nearest multiple of 0.0025 with the exception of the values for Grades X-52 and X-56, which are rounded to the next higher multiple of 0.0025.

$$e = 3000 \frac{(0.64)^{0.2}}{U_p^{0.9}} \tag{143}$$

*Where:*
$e$ = strain, inch/inch.
$U_p$ = minimum ultimate strength of the pipe, pounds per square inch.

The values of Diménsion A in Appendix F of API Specification 5L ***[see also ISO 3183-1]*** are calculated from Formula 142 and rounded to the next lower standard value shown as follows:

| in. | in. | in. | in. |
|---|---|---|---|
| 1.0 | 2.2 | 5.2 | 12.6 |
| 1.2 | 2.6 | 6.2 | 15.1 |
| 1.4 | 3.1 | 7.4 | 18.1 |
| 1.6 | 3.7 | 8.8 | 21.7 |
| 1.9 | 4.4 | 10.5 | 26.0 |
| | | | 31.2 |

Derivation of the guided bend test formula is covered in the paper, "Development of Requirements For Transverse Ductility of Welded Pipe" by W. H. Thomas, A. B. Wilder, and W. O. Clinedinst, presented at the June 1967 Standardization Conference.

## 12 Determination of Minimum Impact Specimen Size for API Couplings and Pipe

The following is the basis for determining the impact specimen size for API couplings and pipe.

### 12.1 CRITICAL THICKNESS

The Charpy V-Notch (CVN) absorbed energy requirements for API couplings are based on the coupling thickness at the critical thickness. The critical thickness for API couplings is defined as the thickness at the root of the thread at the middle of the coupling based on the specified coupling diameter and the specified thread dimensions. The critical thickness for all API couplings is provided in Table 9. For pipe, the critical thickness is the specified wall thickness.

### 12.2 CALCULATED COUPLING BLANK THICKNESS

The appropriate thread height is added to the critical thickness provided in Table 9, and the result is divided by 0.875 to determine the calculated thickness of the coupling blank. The calculated coupling blank thickness for all API couplings is provided in Table 10.

### 12.3 CALCULATED WALL THICKNESS FOR TRANSVERSE SPECIMENS

The calculated wall thickness necessary for full size, three-quarter size, and one-half size transverse impact test specimens for API couplings, including a 0.020-inch OD and a 0.020-inch ID machining allowance, is determined according to the following formula and provided in Table 11.

Table 9—Critical Thickness of Various API Couplings (inches)

| Pipe OD | NUE | EUE | EUE SC | BTC SC | BTC | LTC | STC |
|---|---|---|---|---|---|---|---|
| 1.050 | 0.169 | 0.211 | | | | | |
| 1.315 | 0.211 | 0.258 | | | | | |
| 1.660 | 0.239 | 0.240 | | | | | |
| 1.900 | 0.196 | 0.251 | | | | | |
| 2.375 | 0.304 | 0.300 | 0.224 | | | | |
| 2.875 | 0.380 | 0.358 | 0.254 | | | | |
| 3.500 | 0.451 | 0.454 | 0.294 | | | | |
| 4.000 | 0.454 | 0.458 | | | | | |
| 4.500 | 0.435 | 0.493 | | 0.259 | 0.322 | 0.349 | 0.337 |
| 5.000 | | | | 0.266 | 0.360 | 0.392 | 0.372 |
| 5.500 | | | | 0.268 | 0.356 | 0.389 | 0.370 |
| 6.625 | | | | 0.274 | 0.469 | 0.508 | 0.485 |
| 7.000 | | | | 0.280 | 0.420 | 0.458 | 0.430 |
| 7.625 | | | | 0.343 | 0.536 | 0.573 | 0.546 |
| 8.625 | | | | 0.352 | 0.602 | 0.647 | 0.612 |
| 9.625 | | | | 0.352 | 0.602 | 0.657 | 0.614 |
| 10.750 | | | | 0.352 | 0.602 | | 0.618 |
| 11.750 | | | | | 0.602 | | 0.618 |
| 13.375 | | | | | 0.602 | | 0.618 |
| 16.000 | | | | | 0.667 | | 0.632 |
| 18.625 | | | | | 0.854 | | 0.819 |
| 20.000 | | | | | 0.667 | 0.673 | 0.634 |

Note: The coupling blank thickness is greater than indicated above, due to the thread height and manufacturing allowance to avoid black crested threads.

$$\text{Minimum wall thickness (inches)} = (OD/2) - [(OD/2)^2 - 1.1722]^{0.5} + 0.040 \text{ in.} + f(0.3937) \qquad (144)$$

*Where*:

OD = specified coupling OD.
$f$ = 1.00 for full-size specimens.
$f$ = 0.75 for three-quarter size specimens.
$f$ = 0.50 for one-half size specimens.

## 12.4 CALCULATED WALL THICKNESS FOR LONGITUDINAL SPECIMENS

The calculated wall thickness necessary for full-size, three-quarter-size, and one-half-size longitudinal impact test specimens for API couplings, including a 0.020-inch OD and a 0.020-inch ID machining allowance, is determined according to the following formula and provided in Table 12:

$$\text{Minimum wall thickness (inches)} = (OD/2) - [(OD/2)^2 - 0.3875]^{0.5} + 0.040 \text{ in.} + f(0.3937) \qquad (145)$$

## 12.5 MINIMUM SPECIMEN SIZE FOR API COUPLINGS

The calculated wall thickness of the coupling blank (see 12.2 above) is compared to the calculated wall thickness required for an impact test specimen (see Tables 11 and 12). The minimum size impact test specimen that shall be selected from Table 11 or 12 is the largest impact test specimen having a calculated wall thickness that is less than the calculated wall thickness of the coupling blank for the connection of interest. See Table 13 for the minimum acceptable size transverse specimens and Table 14 for the minimum acceptable size longitudinal specimens. Tables 13 and 14 are used to determine the impact specimen orientation and size as required in API Specification 5CT ***[ISO 11960, in process]***.

Table 10—Calculated Couplings Blank Thickness for API Couplings (inches)

| Pipe OD | NUE | EUE | EUE SC | BTC SC | BTC | LTC | STC |
|---|---|---|---|---|---|---|---|
| 1.050 | 0.257 | 0.304 | | | | | |
| 1.315 | 0.304 | 0.358 | | | | | |
| 1.660 | 0.337 | 0.338 | | | | | |
| 1.900 | 0.288 | 0.351 | | | | | |
| 2.375 | 0.411 | 0.424 | 0.337 | | | | |
| 2.875 | 0.498 | 0.491 | 0.372 | | | | |
| 3.500 | 0.578 | 0.600 | 0.417 | | | | |
| 4.000 | 0.600 | 0.605 | | | | | |
| 4.500 | 0.578 | 0.645 | | 0.367 | 0.439 | 0.480 | 0.466 |
| 5.000 | | | | 0.375 | 0.483 | 0.529 | 0.507 |
| 5.500 | | | | 0.377 | 0.477 | 0.526 | 0.504 |
| 6.625 | | | | 0.384 | 0.607 | 0.662 | 0.636 |
| 7.000 | | | | 0.391 | 0.551 | 0.605 | 0.573 |
| 7.625 | | | | 0.469 | 0.683 | 0.736 | 0.705 |
| 8.625 | | | | 0.473 | 0.759 | 0.821 | 0.781 |
| 9.625 | | | | 0.473 | 0.759 | 0.832 | 0.783 |
| 10.750 | | | | 0.473 | 0.759 | | 0.788 |
| 11.750 | | | | | 0.759 | | 0.788 |
| 13.375 | | | | | 0.759 | | 0.788 |
| 16.000 | | | | | 0.833 | | 0.803 |
| 18.625 | | | | | 1.047 | | 1.018 |
| 20.000 | | | | | 0.833 | 0.850 | 0.806 |

## 12.6 IMPACT SPECIMEN SIZE FOR PIPE

Procedures specified in 12.3 and 12.4 are used to determine the wall thickness necessary for impact test specimens for pipe except that the OD term is the specified pipe OD. Tables specifying the calculated wall thickness necessary to machine full-size, three-quarter-size, and one-half-size transverse and longitudinal impact test specimens are provided in Sections 4 and SR16 of API Specification 5CT ***[ISO 11960, in process]***.

## 12.7 LARGER SIZE SPECIMENS

In some cases it may be possible to machine larger impact test specimens if

a. The coupling blank is thicker than that calculated in 12.2, or if

b. The full 0.020-inch-OD and 0.020-inch-ID machining allowances are not utilized.

c. The impact test specimens are partially rounded due to the OD curvature of the original tubular product. (See API Specification 5CT) ***[ISO 11960, in process]***

## 12.8 REFERENCE INFORMATION

For a discussion of fracture mechanics and the equations used in API Specification 5CT ***[ISO 11960, in process]*** to determine the absorbed energy requirements, see A. Kent Shoemaker's "Application of Fracture Mechanics to Oil Country Tubular Goods," API Pipe Symposium, June 1989. The transverse requirement is based on the above reference. The longitudinal requirement is based on the transverse requirements, and a longitudinal-to-

Table 11—Transverse Impact Specimen Size Required for API Couplings

| (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|
| | | | Calculated Wall Thickness (inches) Required to Machine Transverse Charpy Impact Specimens[a] | | |
| Pipe Outside Diameter (inches) | Connection | Coupling Outside Diameter (inches) | Full Size | $^3/_4$ Size | $^1/_2$ Size |
| 3.500 | NUE | 4.250 | 0.730 | 0.632 | 0.533 |
| 3.500 | EUE | 4.500 | 0.711 | 0.613 | 0.514 |
| 4.000 | NUE | 4.750 | 0.695 | 0.596 | 0.498 |
| 4.000 | EUE | 5.000 | 0.680 | 0.582 | 0.483 |
| 4.500 | NUE | 5.200 | 0.670 | 0.571 | 0.473 |
| 4.500 | EUE | 5.563 | 0.653 | 0.555 | 0.456 |
| 4.500 | S/L/B | 5.000 | 0.680 | 0.582 | 0.483 |
| 5.000 | S/L/B | 5.563 | 0.653 | 0.555 | 0.456 |
| 5.500 | S/L/B | 6.050 | 0.634 | 0.536 | 0.437 |
| 6.625 | S/L/B | 7.390 | 0.596 | 0.497 | 0.399 |
| 7.000 | S/L/B | 7.656 | 0.590 | 0.492 | 0.393 |
| 7.625 | S/L/B | 8.500 | 0.574 | 0.475 | 0.377 |
| 8.625 | S/L/B | 9.625 | 0.557 | 0.459 | 0.360 |
| 9.625 | S/L/B | 10.625 | 0.545 | 0.447 | 0.348 |
| 10.750 | S/B | 11.750 | 0.534 | 0.436 | 0.337 |
| 11.750 | S/B | 12.750 | 0.526 | 0.428 | 0.329 |
| 13.375 | S/B | 14.375 | 0.516 | 0.417 | 0.319 |
| 16.000 | S/B | 17.000 | 0.503 | 0.405 | 0.306 |
| 18.625 | S/B | 20.000 | 0.492 | 0.394 | 0.296 |
| 20.000 | S/L/B | 21.000 | 0.490 | 0.391 | 0.293 |

Note: S = STC; L = LTC; and B = BTC connections.
[a]Wall thicknesses provide a 0.020-inch OD and 0.020-inch ID machining allowance.

transverse ratio of 1.33 for Grades J-55 and K-55 and 2.0 for higher strength grades. See J. D. Burk's "Fracture Resistance of Casing Steels for Deep Gas Wells," *Journal of Metals*, January 1985, pages 65–70, for the correlation of $K_c$ to $CVN$ for high strength steel.

The requirement for pipe in SR16 of API Specification 5CT ***[ISO 11960, in process]*** is based on the minimum specified yield strength rather than the maximum specified yield strength used for couplings. This choice is made since the stress level of the pipe is typically expected to be less than the stress level of the couplings.

*(text continues on page 44)*

## Table 12 — Longitudinal Impact Specimen Size Required for API Couplings

| (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|
| | | | Calculated Wall Thickness (inches) Required to Machine Longitudinal Charpy Impact Specimens[a] | | |
| Pipe Outside Diameter (inches) | Connection | Coupling Outside Diameter (inches) | Full Size | 3/4 Size | 1/2 Size |
| 1.050 | NUE | 1.313 | 0.464 | 0.365 | 0.267 |
| 1.050 | EUE | 1.660 | 0.457 | 0.359 | 0.261 |
| 1.315 | NUE | 1.660 | 0.457 | 0.359 | 0.261 |
| 1.315 | EUE | 1.900 | 0.454 | 0.356 | 0.257 |
| 1.660 | NUE | 2.054 | 0.453 | 0.354 | 0.256 |
| 1.660 | EUE | 2.200 | 0.451 | 0.353 | 0.255 |
| 1.900 | NUE | 2.200 | 0.451 | 0.353 | 0.255 |
| 1.900 | EUE | 2.500 | 0.449 | 0.351 | 0.252 |
| 2.375 | NUE | 2.875 | 0.447 | 0.349 | 0.250 |
| 2.375 | EUE | 3.063 | 0.446 | 0.348 | 0.250 |
| 2.875 | NUE | 3.500 | 0.445 | 0.346 | 0.248 |
| 2.875 | EUE | 3.668 | 0.444 | 0.346 | 0.247 |
| 3.500 | NUE | 4.250 | 0.443 | 0.344 | 0.246 |
| 3.500 | EUE | 4.500 | 0.442 | 0.344 | 0.245 |
| 4.000 | NUE | 4.750 | 0.442 | 0.343 | 0.245 |
| 4.000 | EUE | 5.000 | 0.441 | 0.343 | 0.245 |
| 4.500 | NUE | 5.200 | 0.441 | 0.343 | 0.244 |
| 4.500 | EUE | 5.563 | 0.441 | 0.342 | 0.244 |
| 4.500 | S/L/B | 5.000 | 0.441 | 0.343 | 0.245 |

Note: S = STC; L = LTC; B = BTC connections.
[a]Wall thicknesses provide a 0.020-inch-OD and 0.020-inch-ID machining allowance.

## Table 13 — Minimum Size Transverse Charpy Impact Test Specimens for Various API Couplings

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|
| | Minimum Permissible Size Transverse Charpy Impact Test Specimens[a] | | | | | | |
| | | | Special Clearance[c] | | | | |
| Pipe Outside Diameter (inches) | NUE | EUE | EUE | BTC | BTC | LTC | STC |
| 3.500 | 1/2 | 1/2 | 1/2 | — | — | — | — |
| 4.000 | 3/4 | 3/4 | — | — | — | — | — |
| 4.500 | 3/4 | 3/4 | — | b | b | b | b |
| 5.000 | — | — | — | 1/2 | 1/2 | 1/2 | 1/2 |
| 5.500 | — | — | — | 1/2 | 1/2 | 1/2 | 1/2 |
| 6.625 | — | — | — | Full | Full | Full | Full |
| 7.000 | — | — | — | 3/4 | 3/4 | Full | 3/4 |
| 7.625 | — | — | — | Full | Full | Full | Full |
| 8.625 | — | — | — | Full | Full | Full | Full |
| 9.625 | — | — | — | Full | Full | Full | Full |
| 10.750 | — | — | — | Full | Full | — | Full |
| 11.750 | — | — | — | — | Full | — | Full |
| 13.375 | — | — | — | — | Full | — | Full |
| 16.000 | — | — | — | — | Full | — | Full |
| 18.625 | — | — | — | — | Full | — | Full |
| 20.000 | — | — | — | — | Full | Full | Full |

Note: Transverse specimens are not possible for couplings for pipe sizes smaller than 3.500 inches.
[a]The size of the specimen is relative to a full-size specimen that is 10 millimeters by 10 millimeters.
[b]Must use longitudinal test specimen.
[c]The Charpy impact specimen size assumes that special clearance couplings are machined from standard couplings.

## Table 14 — Minimum Size Longitudinal Charpy Impact Test Specimens for API Couplings for All Pipe Less Than $3^1/_2$-inch Outside Diameter and for Larger Sizes Where Transverse Test Specimens One-Half Size or Larger Are Not Possible

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|
| | Minimum Permissible Size Longitudinal Charpy Impact Test Specimens[a] | | | | | | |
| | | | Special Clearance[c] | | | | |
| Pipe Outside Diameter (inches) | NUE | EUE | EUE | BTC | BTC | LTC | STC |
| 1.050 | b | 1/2 | — | — | — | — | — |
| 1.315 | 1/2 | 3/4 | — | — | — | — | — |
| 1.660 | 1/2 | 1/2 | — | — | — | — | — |
| 1.990 | 1/2 | 3/4 | — | — | — | — | — |
| 2.375 | 3/4 | 3/4 | 3/4 | — | — | — | — |
| 2.875 | Full | Full | Full | — | — | — | — |
| 3.500 | N/A | N/A | N/A | — | — | — | — |
| 4.000 | N/A | N/A | — | — | — | — | — |
| 4.500 | N/A | N/A | — | 3/4 | 3/4 | Full | Full |

Note: N/A = Transverse impact test specimens shall be used for all tubing connections for pipe 3.500-inch OD and larger and for all casing 5.000-inch OD and larger.
[a]The size of the specimen is relative to a full-size specimen that is 10 millimeters by 10 millimeters.
[b]Pipe not thick enough to test based on calculations. However, if the coupling material is slightly thicker than calculated it will be possible to machine a 1/2-size longitudinal test specimen.
[c]The Charpy impact specimen size assumes that special clearance couplings are machined from standard couplings.

# 13 Metrication

## 13.1 METRIC CONVERSIONS AND CALCULATIONS

***Metric units in specifications are shown in parentheses in the text. Outside diameters and wall thicknesses are converted from inch dimensions. The converted values are rounded to the nearest 0.1 millimeter for diameters less than 18 inches and to the nearest 1.0 millimeter for diameters 18 inches and larger. Wall thicknesses are rounded to the nearest 0.1 millimeter.***

***Metric inside diameters and drift diameters are calculated from the metric outside diameters and wall thicknesses and rounded to the nearest 0.1 millimeter.***

***Metric plain-end weights are calculated from the metric outside diameters and wall thicknesses by the following formula and rounded to the nearest 0.01 kilogram per meter:***

$$W_{pe} = .02466\,(D - t)t$$

***Metric hydrostatic test pressures are calculated from the metric outside diameters and wall thicknesses and metric fiber stresses as shown in section 9.***

***The factors used where conversions are appropriate are as follows:***

| | | |
|---|---|---|
| ***1 inch (in.)*** | = | ***25.4 millimeters (mm) exactly*** |
| ***1 square inch (sq. in.)*** | = | ***645.16 square millimeters ($mm^2$) exactly*** |
| ***1 foot (ft)*** | = | ***0.3048 meters (m) exactly*** |
| ***1 pound (lb)*** | = | ***0.45359 kilograms (kg)*** |
| ***1 pound per foot (lb/ft)*** | = | ***1.4882 kilograms per meter (kg/m)*** |
| ***1 pound per square inch (psi)*** | = | ***6.895 kilopascals (kPa) for pressure*** |
| | = | ***0.006895 megapascals (MPa) for stress*** |
| ***1 foot-pound (ft-lb)*** | = | ***1.3558 Joules (J) for impact energy*** |
| | = | ***1.3558 newton-meters (N•m) for torque*** |

***The following formula was used to convert degrees Fahrenheit (°F) to degrees Celsius (°C): °C = 5/9 (°F – 32).***

The following procedures were used to make the soft conversion of US customary units to SI units in API Specification 5CT:

a. Outside Diameter. US customary values for the outside diameters of pipe and couplings are converted to SI values using the following formula:

$$D_m = 25.4 \times D$$

*Where:*

$D_m$ = SI outside diameter, mm.
$D$ = outside diameter, in.

The SI outside diameters of pipe and couplings with a specified outside diameter of 6.625 in. (168.28 mm) and smaller are rounded to the nearest 0.01 mm, and the SI outside diameters of pipe and couplings with a specified outside diameter larger than 6.625 in. (168.28 mm) are rounded to the nearest 0.1 mm.

b. Wall Thickness. US customary values for wall thickness are converted to SI values using the following formula:

$$t_m = 25.4 \times t$$

*Where:*

$t_m$ = metric wall thickness, mm.
$t$ = wall thickness, in.

SI wall thicknesses are rounded to the nearest 0.01 mm.

c. Inside Diameter. US customary values for inside diameter of pipe are converted to SI values using the following formula:

$$d_m = 25.4 \times d$$

*Where:*

$d_m$ = SI inside diameter, mm.
$d$ = inside diameter, in.

Like the outside diameter, the SI inside diameters of pipe with a specified outside diameter of 6.625 in. (168.28 mm) and smaller are rounded to the nearest 0.01 mm, and the SI inside diameters of pipe with a specified outside diameter larger than 6.625 in. (168.28 mm) are rounded to the nearest 0.1 mm.

d. Drift Diameter. The drift diameter is calculated using the following formula:

$$dd_m = 25.4 \times d - d_{cm}$$

*Where:*

$dd_m$ = drift diameter, mm.
$d$ = inside diameter, in.
$dc_m$ = drift constants, mm.

The SI drift diameter is rounded to the nearest 0.01 mm.

The US customary values for the drift diameters specified by the purchase order are converted to SI values using the following formula:

$$dds_m = 25.4 \times dds$$

*Where:*

$dds_m$ = drift diameter, mm.
$dds$ = drift diameter, in.

This SI drift diameter is also rounded to the nearest 0.01 mm.

e. Plain End Linear Density. The plain end linear density is calculated (not converted) using the following formula:

$$P_l = 0.0246615\,(D_m - t_m)\,t_m$$

*Where:*

$P_l$ = metric plain end mass/meter, kg/m.
$D_m$ = metric outside diameter, mm.
$t_m$ = metric wall thickness, mm.

The SI plain end linear density is rounded to the nearest 0.01 kg/m.

f. Yield Strength and Tensile Strength. US customary values for yield strength and tensile strength are converted to SI values using the following formula:

$$ys_m = 0.00689476 \times ys$$
$$ts_m = 0.00689476 \times ts$$

*Where:*

$ys_m$ = yield strength, N/mm².
$ys$ = yield strength, psi.
$ts_m$ = tensile strength, N/mm².
$ts$ = tensile strength, psi.

SI strengths are rounded to the nearest 1 N/mm².

g. Hydrostatic Test Pressures. SI hydrostatic test pressures are calculated (not converted) using the SI outside diameters, wall thicknesses and yield strengths, and the appropriate formula.

The calculated hydrostatic test pressures are rounded to the nearest 0.1 megapascal (MPa).

h. Temperature. The following formula is used to convert degrees Fahrenheit (°F) to degrees Celsius (°C):

$$°C = 5(°F - 32)/9$$

The SI temperature is rounded to the nearest 1°C.

i. Charpy Impact Energy. US customary values for impact energy are converted to SI values using the following formula:

$$E_m = 1.35582 \times E_c$$

*Where:*

$E_m$ = charpy impact energy, J.
$E_c$ = charpy impact energy, ft-lbs.

SI energy values are rounded to the nearest joule.

j. Recommended Makeup Torque. US customary values for recommended makeup torque are calculated, without rounding, and are converted to SI values using the following conversion factor:

1 pound-foot (lb-ft) = 1.35582 Newton-meters (N•m)

SI metric recommended makeup torques are rounded to the nearest 10 N•m.

## 13.2 ROUNDING OF METRIC UNITS

Metric units are converted or calculated in accordance with 13.1, and the number of digits shown are in accordance with Table 15.

Table 15 — Number of Decimals to Be Shown in Metric Units

| (1) Property | (2) Metric Units | (3) Number of Decimals |
|---|---|---|
| Diameter | mm | 1 |
| Thickness and imperfections | mm | 1 |
| Upset and coupling length | mm | 1 |
| Length | m | 2 |
| Weight | kg | 2 |
| Weight per foot | kg/m | 2 |
| Stress and tensile strength | N/mm² | 0 |
| Pressure | MPa | 0 |
| Guided bend A | mm | 1 |
| Thread elements | | |
| Major diameter | mm | 1 |
| Pitch diameter | mm | 3 |
| Thread length | mm | 2 |
| Thread height | mm | 3 |
| Recess depth | mm | 1 |
| J | mm | 1 |

# 14 Calculation Accuracy and Rounding

## 14.1 ACCURACY

In the calculation of pipe properties, a sufficient number of digits shall be carried throughout to give two digits beyond the last digit to be retained in rounding.

## 14.2 INTERMEDIATE ROUNDING

In the calculation of certain pipe properties, intermediate roundings are required before the final result. Instructions for calculation of the particular pipe property indicates when such intermediate roundings are required. For example, in the calculation of buttress thread joint strength, the cross-sectional areas of the pipe and the coupling are rounded to three decimals before using in the joint strength formula; and the diameter at the root of the coupling thread at the end of the pipe is rounded to three decimals before calculating the coupling cross-sectional area.

## 14.3 FINAL ROUNDING

In some of the earlier calculations, it was the practice to drop all digits beyond the last to be retained without rounding. Later, and up until 1942, the present rounding procedure was followed. For the period from 1942 until about 1968, the old ASA (now ANSI) rounding procedure was used. In this procedure the last digit retained is unchanged when the next digit is less than 5, or raised by 1 when greater than 5. When the digit following the last digit retained is exactly 5 followed by all zeros, the last digit retained remains unchanged if it is even, or is raised by 1 if it is odd.

In the present rounding rule, the last digit retained is raised by 1 when the following digit is 5 or greater. When the following digit is less than 5, the last digit retained remains unchanged. This method was adopted for simplicity in connection with computer programming. The computer programming procedure for this method consists of adding 5 to the digit column following the last to be retained, and then dropping all digits after the last one to be retained.

A variation of one rounding unit can be expected in the final calculated value, among calculations performed with different electronic computers, because of differences in handling floating point numbers.

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