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Strength of Threaded Joints for Steel Pipe

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This paper covers the analytical development of strength formulas for fracture and jumpout and determination of material constants from 162 joint tests. These formulas were adopted by API at the June, 1963, Standardization Conference, and are the basis for new joint strength values for API casing contained in the eighth edition of API Bulletin 5-C-2 on Performance Properties of Casing and Tubing. These formulas are entirely new and offer, for the first time, a rational explanation of joint failure.

THREADED joints for connecting individual lengths of steel pipe are required for many services. One of the major service uses is oil-well casing where it is important that the tensile strength of the joint be known and sufficient to withstand the tensile loads imposed.

A threaded joint can fail under tensile loading by shear of threads, fracture of the pipe or coupling in the axial direction, the coupling splitting, or the joint jumping out. For the most part, strength formulas have been developed empirically from test data. While it is not intended to be critical of the purely empirical approach, it would appear that much could be learned in regard to the mechanism of joint failures by analysis of the stresses and strains involved. It is the purpose here to consider joint strength from this viewpoint. Conceivably, this could lead to justifying presently used empirical forms or to develop more suitable empirical forms.

As mentioned, a threaded joint subjected to a tensile load can fail by the threads shearing off, by the pipe or coupling failing by fracture in the axial direction at a critical section, by the coupling splitting, or by joint jumpout where the pipe and coupling pull apart as a result of radial deformation. Generally speaking, joints used in oil-well and other steel pipe services do not fail by thread shear. For the most part, failure of the Vee-type threaded joint is by jumpout and, occasionally, by fracture of the pipe in the last engaged threads. The API round-thread casing joint falls into this category and is the particular case being considered here although the same principles can be used to analyze other types of threaded joints. With the buttress and stub-type threads used on high-strength joints, failure is usually by fracture in the pipe near the last engaged thread.

For the thread jumpout type of failure, experience has indicated that the pipe usually is the critical member and that the coupling dimensions and material strength generally are not of particular consequence within typical design limits. Also, it has been observed that the amount of stresses in the joint as a result of makeup have little, if any, effect on jumpout, shear, or fracture strength. While these characteristics may not at first be apparent, they are explained by the analysis of stress and strain.

In analyzing stresses and strains in a tapered joint, little can be accomplished without rather extensive simplifying assumptions. In this analysis, all stresses and strains will be considered on the average basis and the maximum equivalent shear stress used as the basis for determining yielding.

Let us consider the forces and stresses in a threaded joint which result from joint makeup and by loading it in tension. In addition to its function of supporting tensile loads, a joint must prevent leakage of fluids or gases which the pipe must contain or exclude. To be able to do this requires the joint to have interface pressures between mating threads sufficiently large to result in proper mating and sealing. This is accomplished generally by having the threaded members tapered and then screwing them together a sufficient number of turns to have the taper result in the required interface pressure to seal the joint. A sketch of a Vee thread joint is shown in Fig. 1.

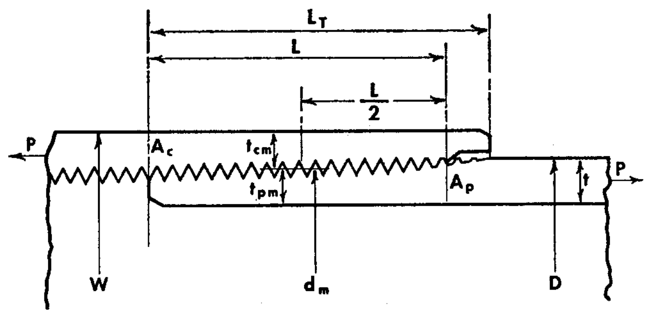

Fig. 1

Where

A_c = critical area of coupling = $0.7854[W^2 - \{(D + 0.006) - 0.0625(L_T - 0.625)\}^2]$
A_p = critical area of pipe = $0.7854\,[(D - 0.1425)^2 - (D - 2t)^2]$
D = outside diameter of pipe
L = engaged thread length
L_T = total thread length of pipe
P = tensile load
W = outside diameter of coupling
d_m = mean diameter of threads
t = thickness of pipe
t_{cm} = mean thickness of coupling
t_{pm} = mean thickness of pipe

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Nomenclature

A = log $a(2h)^b$, a regression constant
A_c = critical area of coupling
A_p = critical area of pipe
B = $-b$, a regression coefficient
D = outside diameter of pipe
E_{ec} = modulus of elasticity for coupling material
E_{cf} = modulus of plasticity for coupling material
E_f = modulus of plasticity
E_{pe} = modulus of elasticity for pipe material
E_{pf} = modulus of plasticity for pipe material
L = engaged thread length
L_T = total thread length of pipe
M_1 = interface load on flank 1
M_2 = interface load on flank 2
P = tensile load
P_{cc} = splitting (cracking) load of coupling
P_j = jumpout load
P_{sc} = shear load of coupling
P_{sp} = shear load of pipe
P_{uc} = fracture load of coupling
P_{up} = fracture load of pipe
S = separating force
U = ordinary ultimate strength
U_c = ultimate strength of coupling material

(Continued on next page)

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Fig. 2(a) illustrates an element of cross section of the thread and the interface pressures resulting from makeup indicated by the resultant loads M_1 and M_2 on the two flanks. When there is no tensile load acting on the joint, the resultant interface loads on the two thread flanks are equal ($M_1 = M_2$) as indicated.

Fig. 2(b) shows the same thread element after an increment of tensile load, ΔP, has been applied. The interface load on the left flank, M_1, which is the nonload-bearing flank, has become smaller while the interface load on the right-hand flank, M_2, has become larger by the same amount.

Fig. 2(c) shows the same thread element at the time the increment of tensile load ΔP has been increased to the extent that the interface load on the nonload-bearing flank has been eliminated and the entire interface load, both from makeup and the tensile load, is being carried on the load-bearing flank.

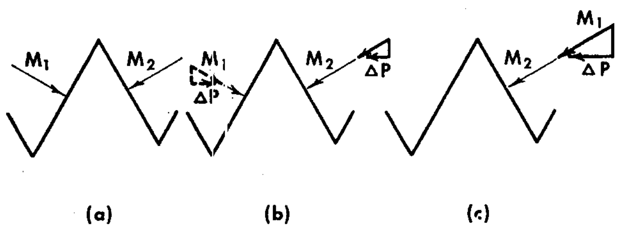

Fig. 2

where

M_1 = interface load on Flank 1
M_2 = interface load on Flank 2

where

ΔP = increment of tensile load

Until this point, the tensile load has not increased the total interface load acting between the pipe and coupling threads, but has shifted the load initially being carried on the nonload-bearing flank to the load-bearing flank. While the total interface load is being carried on only half the initial surface, it is distributed in a spiral path over the total threaded length and undoubtedly results in very little change in the average stress which initially existed due to makeup. Thus, the tensile load does not increase the average circumferential stresses in the pipe and coupling until it becomes larger than the amount required to shift all of the makeup interface loads originally on the nonload-bearing flank to the load-bearing flank. Jumpout cannot occur until this condition has been reached and the tensile load then increased sufficiently to result in strains large enough to disengage the pipe and coupling threads.

Fig. 3 shows the forces acting on the thread element for tensile loads exceeding the amount required for shifting makeup to the load-bearing flank.

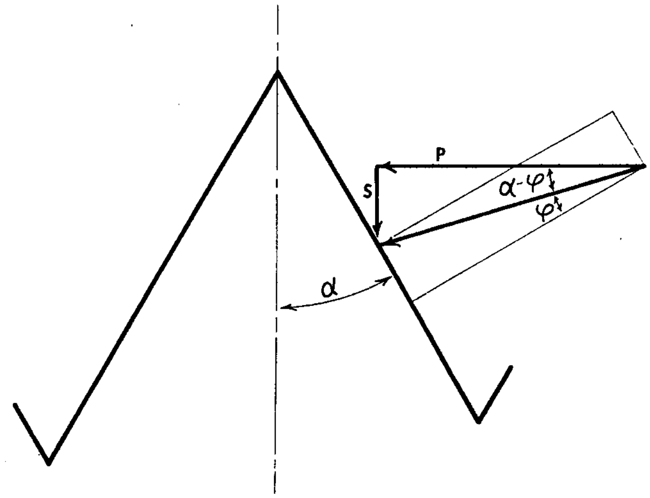

Fig. 3

$S = P \tan(\alpha - \varphi)$ when $\alpha \geq \varphi$
$S = 0$ when $\alpha < \varphi$

where

α = load-bearing flank angle (α = 30 deg for API round thread casing)
φ = friction angle
S = separating force

The pipe or coupling will fracture if the stress on its critical cross section at its last engaged thread exceeds the ultimate strength. This can occur only if the joint design is such that jumpout or shear failure will not occur first. Formulas (1) and (2) relate the fracture load of the pipe, P_{up}, and the coupling, P_{uc}, to the ultimate strengths, U_p and U_c, of the pipe and coupling materials, respectively.

Nomenclature

U_p = ultimate strength of pipe material
W = outside diameter of coupling
X = $\log D$, a regression variable
Y =

$$\left(\frac{P_j}{A_p U_p} - \frac{\frac{Y_x}{U_x}}{1 + \frac{D}{2L} \tan(\alpha - \varphi)} \right) \times \left(\frac{1}{2} + \frac{D}{2L} \tan(\alpha - \varphi) \right),$$

a regression variable
Y_c = yield strength of coupling material
Y_p = yield strength of pipe material
a = constant to be determined by test
b = constant to be determined by test
d_m = mean diameter of threads
e_{ce} = elastic circumferential and radial strain of coupling
$(e_{ce})_y$ = elastic circumferential strain of coupling at yield strength
e_{cf} = elastic circumferential and radial strain of coupling
e_f = plastic strain
e_j = jumpout strain
e_{pe} = elastic circumferential and radial strain of pipe
$(e_{pe})_y$ = elastic circumferential strain of pipe at yield strength
e_{pf} = plastic circumferential and radial strain of pipe
k = absolute value of ratio of circumferential to axial stress for pipe and coupling
k_c = ratio of circumferential to axial stress for coupling
k_p = ratio of circumferential to negative axial stress for pipe
t = thickness of pipe
t_{cm} = mean thickness of coupling
t_{pm} = mean thickness of pipe
α = load bearing flank angle (30 deg for API round threads)
Δ_c = the total coupling strain and elastic strain of pipe
ΔP = tensile load increment
σ_{ac} = axial stress in coupling
$(\sigma_{ac})_y$ = axial stress in coupling at yield strength
σ_{ap} = axial stress in pipe
$(\sigma_{ap})_y$ = axial stress in pipe at yield strength
σ_{cf} = equivalent plastic stress in coupling
σ_f = plastic stress
σ_{pf} = equivalent plastic stress in pipe
σ_{tc} = circumferential stress in coupling
$(\sigma_{tc})_y$ = circumferential stress in coupling at yield strength
σ_{tp} = circumferential stress in pipe
$(\sigma_{tp})_y$ = circumferential stress in pipe at yield strength
τ_c = ultimate shear strength of coupling material
τ_p = ultimate shear strength of pipe material
φ = friction angle

Fracture Load of Pipe

$$P_{up} = A_p U_p \tag{1}$$

Fracture Load of Coupling

$$P_{uc} = A_c U_c \tag{2}$$

where

P_{up} = fracture load of pipe
P_{uc} = fracture load of coupling
U_p = ultimate tensile strength of pipe material
U_c = ultimate tensile strength of coupling material

The strength of the joint from the viewpoint of shearing the pipe or coupling threads is the lesser of the values P_{sp} and P_{sc} determined by equations (3) and (4) from the shear strength of the pipe and coupling materials τ_p and τ_c.

Shear Load of Pipe

$$P_{sp} = \pi d_m L \tau_p \tag{3}$$

Shear Load of Coupling

$$P_{sc} = \pi d_m L \tau_c \tag{4}$$

where

P_{sp} = shear load of pipe
P_{sc} = shear load of coupling
τ_p = ultimate shear strength of pipe material
τ_c = ultimate shear strength of coupling material

Taking the ultimate shear strength as half the ultimate strength, the shear load of the joint would not be less than the fracture load unless the shear area of the threads is less than twice the critical area of either the pipe or coupling. This is approximated to sufficient accuracy for the purpose by inequalities (5) and (6).

$$\pi d_m L \leq 2\pi d_m t_{pm} \tag{5}$$

$$\pi d_m L \leq 2\pi d_m t_{cm} \tag{6}$$

Inequalities (5) and (6) can be reexpressed as shown in inequalities (5*a*) and (6*a*):

$$L \leq 2t_{pm} \tag{5a}$$

$$L \leq 2t_{cm} \tag{6a}$$

It is apparent from inequalities (5*a*) and (6*a*) that failure of pipe joints by thread shear is pretty much out of the question since it is hardly conceivable to design a joint with thread length less than twice the pipe or coupling wall thickness.

Another manner in which a pipe joint could fail is by the coupling splitting as a result of the hoop tensile stresses exceeding the ultimate tensile strength of the coupling material. Equation (7) shows the tensile load, P_{cc}, required to split the coupling. This equation can be obtained from equation (9) for the circumferential stress in the coupling which will be developed later in this paper.

Splitting Load of Coupling

$$P_{cc} = \left(\frac{\pi d_m L}{\tan(\alpha - \varphi)}\right)\left(\frac{2t_{cm}}{d_m + t_{cm}}\right) U_c \tag{7}$$

where P_{cc} = splitting (cracking) load of coupling

Joint testing experience leads to the conclusion that coupling splitting does not enter the picture in the case of API round-thread casing. However, it is conceivable that coupling splitting strength could become critical in other designs. Equation (7) with the appropriate value of friction angle φ determined by test should be used to determine this for the particular design being evaluated for strength.

The most usual type of failure for Vee-thread pipe joints typified by API round-thread casing joints is jumpout. The tensile load causes a wedging action between the threads which cause circumferential tension stresses in the coupling and circumferential compression stresses in the pipe. These circumferential stresses, coupled with the direct axial stresses, cause yielding and plastic flow to the extent that radial deformation will be sufficient to disengage the joint.

In developing stress equations for use in analyzing joint jumpout, the usual convention in designating tension stresses and outward radial deflection as positive and compression stresses and inward radial deflection as negative will be followed.

Circumferential stresses in the pipe and coupling, respectively, are given in equations (8) and (9).

Pipe Circumferential Stress

$$\sigma_{tp} = -\frac{P \tan(\alpha - \varphi)}{\pi d_m L} \cdot \frac{d_m - t_{pm}}{2t_{pm}} \tag{8}$$

Coupling Circumferential Stress

$$\sigma_{tc} = \frac{P \tan(\alpha - \varphi)}{\pi d_m L} \cdot \frac{d_m + t_{cm}}{2t_{cm}} \tag{9}$$

where

σ_{tp} = circumferential stress in pipe
σ_{tc} = circumferential stress in coupling

Axial stresses in the pipe and coupling, respectively, are shown in equations (10) and (11).

Axial Stress in Pipe

$$\sigma_{ap} = \frac{P}{A_p} \tag{10}$$

Axial Stress in Coupling

$$\sigma_{ac} = \frac{P}{A_c} \tag{11}$$

where

σ_{ap} = axial stress in pipe
σ_{ac} = axial stress in coupling

The ratios of circumferential to axial stresses in the pipe and coupling are shown in equations (12), (13), (14), and (15).

$$\frac{\sigma_{tp}}{\sigma_{ap}} = -k_p \tag{12}$$

$$\frac{\sigma_{tc}}{\sigma_{ac}} = k_c \tag{13}$$

$$k_p = \frac{A_p}{\pi d_m t_{pm}} \cdot \frac{d_m - t_{pm}}{2L} \tan(\alpha - \varphi) \tag{14}$$

$$k_c = \frac{A_c}{\pi d_m t_{cm}} \cdot \frac{d_m + t_{cm}}{2L} \cdot \tan(\alpha - \varphi) \tag{15}$$

where

$-k_p$ = ratio of circumferential to axial stress for pipe
k_c = ratio of circumferential to axial stress for coupling

Consideration of equations (14) and (15) and Fig. 1 showing a sketch of a threaded joint with dimension leads to the conclusion that k_p can be placed equal to k_c and replaced by a common value, k, with a reasonable degree of approximation. This permits replacing equations (12), (13), (14), and (15) by equations (12*a*), (13*a*), and (14*a*).

$$\frac{\sigma_{tp}}{\sigma_{ap}} = -k \tag{12a}$$

$$\frac{\sigma_{tc}}{\sigma_{ac}} = k \tag{13a}$$

$$k = \frac{D}{2L} \tan(\alpha - \varphi) \tag{14a}$$

where

k = absolute value of ratio of circumferential to axial stress for pipe and coupling

Using the maximum equivalent shear stress theory of yielding, conditions for plastic flow for the pipe and coupling can be expressed as a function of the yield strength Y_p for the pipe material and Y_c for the coupling material in the manner shown in inequalities (16) and (17).

Yielding of Pipe

$$\sigma_{ap} - \sigma_{tp} \geq Y_p \tag{16}$$

Yielding of Coupling

$$\sigma_{ac} \geq Y_c \tag{17}$$

where

Y_p = yield strength of pipe material
Y_c = yield strength of coupling material

Upon substituting the stress relationships shown in equations (12a) and (13a) in inequalities (16) and (17), inequalities (16a) and (17a) result.

Yielding of Pipe

$$\sigma_{ap} \geq \frac{Y_p}{1 + k} \tag{16a}$$

Yielding of Coupling

$$\sigma_{ac} \geq Y_c \tag{17a}$$

From equations (12a), (13a), (16a), and (17a), expressions for the axial stress $(\sigma_{ap})_y$ and circumferential stress $(\sigma_{tp})_y$ at which the pipe yields and the axial stress $(\sigma_{ac})_y$ and circumferential stress $(\sigma_{tc})_y$ at which the coupling yields are developed and shown as equations (18), (19), (20), and (21).

Axial Stress of Pipe at Yield

$$(\sigma_{ap})_y = \frac{Y_p}{1 + k} \tag{18}$$

Circumferential Stress of Pipe at Yield

$$(\sigma_{tp})_y = -\frac{kY_p}{1 + k} \tag{19}$$

Axial Stress of Coupling at Yield

$$(\sigma_{ac})_y = Y_c \tag{20}$$

Circumferential Stress of Coupling at Yield

$$(\sigma_{tc})_y = kY_c \tag{21}$$

where

$(\sigma_{ap})_y$ = axial stress of pipe at yield strength
$(\sigma_{tp})_y$ = circumferential stress of pipe at yield strength
$(\sigma_{ac})_y$ = axial stress of coupling at yield strength
$(\sigma_{tc})_y$ = circumferential stress of coupling at yield strength

Elastic circumferential strains e_{pe} and e_{ce} of the pipe and coupling, respectively, are related to elastic stresses as shown in equations (22) and (23).

Elastic Circumferential Strain of Pipe

$$e_{pe} = (\sigma_{tp} - 0.3\sigma_{ap}) \frac{1}{E_{pe}} \tag{22}$$

Elastic Circumferential Strain of Coupling

$$e_{ce} = (\sigma_{tc} - 0.3\sigma_{ac}) \frac{1}{E_{ce}} \tag{23}$$

where

e_{pe} = elastic circumferential and radial strain of pipe
e_{ce} = elastic circumferential and radial strain of coupling
E_{pe} = modulus of elasticity for pipe material
E_{ce} = modulus of elasticity for coupling material

Equations (22) and (23) can be rewritten into the more convenient form of (22a) and (23a) by substitution of equations (12a) and (13a)

Elastic Circumferential Strain of Pipe

$$e_{pe} = -(k + 0.3) \frac{\sigma_{ap}}{E_{pe}} \tag{22a}$$

Elastic Circumferential Strain of Coupling

$$e_{ce} = (k - 0.3) \frac{\sigma_{ac}}{E_{ce}} \tag{23a}$$

The values of elastic strain at the start of yielding $(e_{pe})_y$ of the pipe $(e_{pe})_y$ and coupling $(e_{ce})_y$ are shown in equations (22b) and (23b) which are obtained by substituting the stresses obtained by equations (18) and (20) into equations (22a) and (23a).

Yield Point Circumferential Strain of Pipe

$$(e_{pe})_y = -\frac{k + 0.3}{1 + k} \frac{Y_p}{E_{pe}} \tag{22b}$$

Yield Point Circumferential Strain of Coupling

$$(e_{ce})_y = (k - 0.3) \cdot \frac{Y_c}{E_{ce}} \tag{23b}$$

where

$(e_{pe})_y$ = elastic circumferential strain of pipe at yield point
$(e_{ce})_y$ = elastic circumferential strain of coupling at yield point

The plastic circumferential and radial strains e_{pf} and e_{cf} of the pipe and coupling resulting from stress above the yield strength are computed according to equations (24) and (25).

Plastic Strain of Pipe

$$e_{pf} = \left[\{\sigma_{tp} - (\sigma_{tp})_y\} - \frac{1}{2} \{\sigma_{ap} - (\sigma_{ap})_y\} \right] \frac{1}{E_{pf}} \tag{24}$$

Plastic Strain of Coupling

$$e_{cf} = \left[\{\sigma_{tc} - (\sigma_{tc})_y\} - \frac{1}{2} \{\sigma_{ac} - (\sigma_{ac})\} \right] \frac{1}{E_{cf}} \tag{25}$$

where

e_{pf} = plastic circumferential and radial strain of pipe
e_{cf} = plastic circumferential and radial strain of coupling
E_{pf} = modulus of plasticity for pipe material
E_{cf} = modulus of plasticity for coupling material

Substituting equations (18) to (21), inclusive, into equations (24) and (25), equations (24a), (25a), (26), and (27) are obtained.

Plastic Strain of Pipe

$$e_{pf} = \frac{\sigma_{pf}}{E_{pf}} \tag{24a}$$

Plastic Strain of Coupling

$$e_{cf} = \frac{\sigma_{cf}}{E_{cf}} \tag{25a}$$

Equivalent Plastic Stress in Pipe

$$\sigma_{pf} = -\left[\left(\sigma_{ap} - \frac{Y_p}{1+k}\right)\left(k + \frac{1}{2}\right)\right] \tag{26}$$

Equivalent Plastic Stress in Coupling

$$\sigma_{cf} = \left[(\sigma_{ac} - Y_c)\left(k - \frac{1}{2}\right)\right] \tag{27}$$

where

σ_{pf} = equivalent plastic stress in pipe
σ_{cf} = equivalent plastic stress in coupling

In the use of equations (24*a*) and (25*a*) appropriate values of plastic flow moduli E_{pf} and E_{cf} must be selected. If E_{pf} and E_{cf} were independent of e_{pf} and e_{cf}, respectively, the stress-strain relationship above the yield strength would be a straight line. While the stress-strain relationship above the yield strength could be approximated by a straight line, the degree of approximation could be improved by using some type of curvilinear function. Since the slope of the true stress-strain curve corresponding to the strain at ultimate load is equal to ordinary ultimate strength, it is reasonable to assume the stress to be proportional to ultimate strength and some curvilinear function of strain as shown in equation (28).

Plastic Stress-Strain Curve

$$\sigma_f = aUe_f^{\,b} \tag{28}$$

where

a = constant to be determined by test
b = constant to be determined by test
e_f = plastic strain
σ_f = plastic stress
U = ordinary ultimate strength

Equation (29) shows the general relationship between plastic stress, plastic strain, and plastic modulus shown specifically for pipe and coupling in equations (24*a*) and (25*a*).

Plastic Strain

$$e_f = \frac{\sigma_f}{E_f} \tag{29}$$

where

E_f = plastic modulus

Substituting equation (28) into equation (29) and solving for plastic modulus E_f, equation (30) for plastic modulus is obtained.

Plastic Modulus

$$E_f = aUe_f^{\,b-1} \tag{30}$$

By applying suitable subscripts for the pipe and coupling to the relationship between plastic modulus and strain shown in equation (30), and substituting into equations (24*a*) and (25*a*) equations (24*b*) and (25*b*) are obtained.

Plastic Strain of Pipe

$$e_{pf} = \left(\frac{\sigma_{pf}}{aU_p}\right)^{\frac{1}{b}} \tag{24b}$$

Plastic Strain of Pipe

$$e_{cf} = \left(\frac{\sigma_{cf}}{aU_c}\right)^{\frac{1}{b}} \tag{25b}$$

For the joint to fail by jumpout, the circumferential and radial strains of the pipe and coupling must produce a combined separation strain equal to twice the thread height divided by the mean diameter of the thread which can be referred to as jumpout strain. The jumpout strain is determined from the thread dimensions by equation (31).

Jumpout Strain

$$e_j = \frac{2h}{d_m} \tag{31}$$

where

e_j = jumpout strain

Since the final equation for joint jumpout strength will contain material coefficients which will have to be determined by test, it will not detract to replace the mean diameter of the threads by pipe diameter as an approximation. Equation (30) so approximated becomes equation (31*a*).

Jumpout Strain

$$e_j = \frac{2h}{D} \tag{31a}$$

The condition for jumpout can be expressed as equation (32) relating the strains of the pipe and coupling to the jumpout strain.

Condition for Jumpout

$$e_j = e_{ce} + e_{cf} - e_{pe} - e_{pf} \tag{32}$$

By substituting equations (10), (11), (14*a*), (16*a*), (17*a*), (22*a*), (23*a*), (24*b*), (25*b*), and (27) relating tensile load, stresses, strains, joint dimensions, and material coefficients into equation (32) giving the condition for jumpout, equation (32*a*) is obtained from which the tensile load at jumpout can be determined.

$$\begin{aligned}\frac{2h}{D} = {} & \left[\left(\frac{D}{2L}\tan(\alpha - \varphi) - 0.3\right)\frac{P_j}{A_c E_{ce}}\right]_1 \\ & + \left[\left\{\frac{\left(\frac{P_j}{A_c} - Y_c\right)\left(\frac{D}{2L}\tan(\alpha - \varphi) - \frac{1}{2}\right)}{aU_c}\right\}^{1/b}\right]_2 \\ & + \left[\left(\frac{D}{2L}\tan(\alpha - \varphi) + 0.3\right)\frac{P_j}{A_p E_{pe}}\right]_3 \\ & + \left[\left\{\frac{\left(\frac{P_j}{A_p} - \frac{Y_p}{1 + \frac{D}{2L}\tan(\alpha - \varphi)}\right) \times \left(\frac{D}{2L}\tan(\alpha - \varphi) + \frac{1}{2}\right)}{aU_p}\right\}^{1/b}\right]_4\end{aligned} \tag{32a}$$

where P_j = load resulting in jumpout.

When $\dfrac{P_j}{A_c} \leq Y_c$

$[\quad]_1$ = as shown
$[\quad]_2 = 0$

Table 1 API joint tensite tests

$\alpha = 30^{\circ}$

Item No.	Size OD	Wt. Per Ft.	Grade	Type of Joint	Av. Pipe OD D	Av. Pipe Wall t	Total Thread Length of Pipe L_t	Engaged Thread Length L	Av. Coupling OD Before Test W	Av. Coupling OD After Test	Pipe Yield Strength 1000 psi Y_p	Pipe Ultimate Strength 1000 psi U_p	Coupling Yield Strength 1000 psi Y_c	Coupling Ultimate Strength 1000 psi U_c	Joint Failure Load 1000 lbs. P	Type of Failure
1	4.50	11.6	J-55	Short	4.54	0.241	2.69	1.98	5.02	5.02	71.6	113.6	60.8	107.6	228	Jumpout
2	4.50	11.6	"	"	4.54	0.242	2.69	1.98	5.01	5.02	72.0	115.5	60.8	107.6	222	"
3	4.50	11.6	"	"	4.53	0.248	2.69	1.98	5.02	5.02	67.2	113.1	60.8	107.6	218	"
4	4.50	11.6	"	Long	4.51	0.253	3.06	2.39	5.02	5.02	66.7	111.7	58.4	102.6	242	"
5	4.50	11.6	"	"	4.50	0.250	3.06	2.39	5.02	5.02	63.0	110.3	58.4	102.6	234	"
6	4.50	11.6	"	"	4.50	0.250	3.06	2.36	5.01	5.02	62.6	105.3	58.4	102.6	218	"
7	4.50	11.6	N-80	"	4.54	0.252	3.06	2.36	5.02	5.01	89.8	124.4	89.0	114.7	278	Fracture
8	4.50	11.6	"	"	4.52	0.255	3.06	2.36	5.02	5.02	86.8	123.4	89.0	114.7	284	"
9	4.50	11.6	"	"	4.52	0.262	3.06	2.36	5.02	5.02	99.8	135.0	89.0	114.7	302	"
10	4.50	11.6	P-110	"	4.52	0.253	3.06	2.39	5.02	5.02	127.3	140.9	124.6	142.4	364	"
11	4.50	11.6	"	"	4.52	0.253	3.06	2.39	5.00	5.00	129.9	143.0	124.6	142.4	372	"
12	4.50	11.6	"	"	4.52	0.255	3.06	2.39	5.02	5.02	128.0	140.5	124.6	142.4	344	"
13	4.50	13.5	N-80	"	4.52	0.299	3.06	2.36	5.02	5.01	89.9	121.6	89.0	114.7	350	Jumpout
14	4.50	13.5	"	"	4.50	0.296	3.06	2.36	5.02	5.02	91.0	130.1	89.0	114.7	390	Fracture
15	4.50	13.5	"	"	4.52	0.289	3.06	2.36	5.02	5.02	95.1	127.7	89.0	114.7	374	Jumpout
16	4.50	13.5	P-110	"	4.52	0.283	3.06	2.33	5.02	5.02	120.2	135.9	124.6	142.4	400	Fracture
17	4.50	13.5	"	"	4.52	0.291	3.06	2.36	5.01	5.01	121.6	133.3	124.6	142.4	408	"
18	4.50	13.5	"	"	4.52	0.285	3.06	2.36	5.01	5.02	119.2	135.2	124.6	142.4	416	"
19	5.00	13.0	J-55	Short	5.02	0.252	2.81	2.11	5.60	5.61	64.7	111.6	61.4	108.0	258	Jumpout
20	5.00	13.0	"	"	5.02	0.258	2.81	2.11	5.62	5.62	68.5	110.4	61.4	108.0	268	"
21	5.00	13.0	"	"	5.02	0.255	2.81	2.17	5.61	5.61	66.7	103.7	61.4	108.0	264	"
22	5.00	13.0	"	Long	5.00	0.260	3.44	2.73	5.58	5.58	68.5	110.4	63.2	102.4	298	"
23	5.00	13.0	"	"	5.00	0.259	3.44	2.73	5.58	5.58	69.9	114.5	63.2	102.4	282	"
24	5.00	13.0	"	"	5.01	0.254	3.44	2.73	5.57	5.58	64.7	111.6	63.2	102.4	260	"
25	5.00	15.0	"	Short	5.01	0.305	2.81	2.12	5.62	5.62	68.9	96.8	61.4	108.0	300	"
26	5.00	15.0	"	"	5.00	0.301	2.81	2.11	5.60	5.60	70.9	103.0	61.4	108.0	306	"
27	5.00	15.0	"	"	5.02	0.308	2.81	2.11	5.60	5.60	71.5	106.0	61.4	108.0	310	"
28	5.00	15.0	"	Long	4.98	0.297	3.44	2.80	5.58	5.58	70.9	103.0	61.4	108.0	324	"
29	5.00	15.0	"	"	4.99	0.308	3.44	2.80	5.58	5.59	68.9	96.8	61.4	108.0	342	"

$\alpha = 30^{\circ}$

Item No.	Size OD	Wt. Per Ft.	Grade	Type of Joint	Av. Pipe OD D	Av. Pipe Wall t	Total Thread Length of Pipe L_t	Engaged Thread Length L	Av. Coupling OD Before Test W	Av. Coupling OD After Test	Pipe Yield Strength 1000 psi Y_p	Pipe Ultimate Strength 1000 psi U_p	Coupling Yield Strength 1000 psi Y_c	Coupling Ultimate Strength 1000 psi U_c	Joint Failure Load 1000 lbs. P	Type of Failure
30	5.00	15.0	J-55	Long	4.98	0.301	3.44	2.80	5.58	5.58	71.5	106.0	61.4	108.0	314	Jumpout
31	5.00	15.0	N-80	"	5.02	0.295	3.44	2.70	5.56	5.56	92.1	124.7	94.7	123.2	372	"
32	5.00	15.0	"	"	5.02	0.297	3.44	2.73	5.56	5.57	88.7	120.8	94.7	123.2	388	"
33	5.00	15.0	"	"	5.01	0.302	3.44	2.76	5.56	5.56	91.9	120.5	94.7	123.2	396	Fracture
34	5.00	15.0	P-110	"	5.03	0.299	3.44	2.76	5.58	5.58	119.0	131.8	118.5	139.1	448	"
35	5.00	15.0	"	"	5.03	0.299	3.44	2.73	5.58	5.58	113.5	125.8	118.5	139.1	426	Jumpout
36	5.00	15.0	"	"	5.03	0.297	3.44	2.73	5.59	5.59	111.6	126.8	118.5	139.1	410	"
37	5.00	18.0	N-80	"	5.02	0.360	3.44	2.70	5.57	5.58	96.2	124.6	94.7	123.2	474	"
38	5.00	18.0	"	"	4.99	0.363	3.44	2.73	5.55	5.57	96.5	126.3	94.7	123.2	494	"
39	5.00	18.0	"	"	5.02	0.357	3.44	2.73	5.57	5.57	92.2	122.2	94.7	123.2	466	"
40	5.00	18.0	P-110	"	5.03	0.351	3.44	2.73	5.58	5.58	117.5	131.4	118.5	139.1	520	"
41	5.00	18.0	"	"	5.02	0.354	3.44	2.73	5.57	5.58	115.5	130.6	118.5	139.1	524	"
42	5.00	18.0	"	"	5.02	0.346	3.44	2.73	5.58	5.58	112.7	127.0	118.5	139.1	510	"
43	5.50	15.5	J-55	Short	5.51	0.280	2.94	2.17	6.08	6.08	65.4	104.4	60.1	105.2	288	"
44	5.50	15.5	"	"	5.52	0.273	2.94	2.33	6.08	6.07	67.3	106.5	60.1	105.2	294	"
45	5.50	15.5	"	"	5.50	0.284	2.94	2.23	6.06	6.06	66.3	103.0	60.1	105.2	282	"
46	5.50	15.5	"	Long	5.50	0.276	3.56	2.76	6.06	6.08	65.0	105.0	68.7	110.9	306	"
47	5.50	15.5	"	"	5.51	0.269	3.56	2.81	6.06	6.07	71.4	111.6	68.7	110.9	290	"
48	5.50	15.5	"	"	5.49	0.282	3.56	2.76	6.06	6.06	65.5	107.7	68.7	110.9	324	"
49	5.50	17.0	"	Short	5.52	0.301	2.94	2.23	6.06	6.06	57.4	99.9	60.9	105.2	288	"
50	5.50	17.0	"	"	5.52	0.306	2.94	2.28	6.06	6.06	64.1	107.1	60.9	105.2	320	"
51	5.50	17.0	"	"	5.52	0.304	2.94	2.23	6.06	6.06	61.2	103.4	60.9	105.2	284	"
52	5.50	17.0	"	Long	5.52	0.301	3.56	2.86	6.06	6.08	60.4	99.3	68.7	110.9	310	"
53	5.50	17.0	"	"	5.52	0.300	3.56	2.86	6.07	6.07	60.5	103.5	68.7	110.9	316	"
54	5.50	17.0	"	"	5.52	0.297	3.56	2.86	6.06	6.07	62.4	106.9	68.7	110.9	328	"
55	5.50	17.0	N-80	"	5.52	0.311	3.56	2.86	6.05	6.06	93.6	117.9	92.2	120.4	444	"
56	5.50	17.0	"	"	5.52	0.307	3.56	2.86	6.05	6.05	87.4	113.8	92.2	120.4	426	"
57	5.50	17.0	"	"	5.52	0.314	3.56	2.86	6.05	6.06	87.1	116.8	92.2	120.4	470	"
58	5.50	17.0	P-110	"	5.53	0.308	3.56	2.86	6.05	6.05	117.5	131.8	125.0	142.0	510	"

$\alpha = 30^{\circ}$

Item No.	Size OD	Wt. Per Ft.	Grade	Type of Joint	Av. Pipe OD D	Av. Pipe Wall t	Total Thread Length of Pipe L_t	Engaged Thread Length L	Av. Coupling OD Before Test W	Av. Coupling OD After Test	Pipe Yield Strength 1000 psi Y_p	Pipe Ultimate Strength 1000 psi U_p	Coupling Yield Strength 1000 psi Y_c	Coupling Ultimate Strength 1000 psi U_c	Joint Failure Load 1000 lbs. P	Type of Failure
59	5.50	17.0	P-110	Long	5.52	0.299	3.56	2.87	6.03	6.05	115.7	134.9	125.0	142.0	512	Jumpout
60	5.50	17.0	"	"	5.53	0.318	3.56	2.80	6.03	6.05	118.5	132.5	125.0	142.0	508	"
61	5.50	23.0	N-80	"	5.50	0.429	3.56	2.86	6.06	6.06	83.6	109.4	91.0	125.7	586	"
62	5.50	23.0	"	"	5.50	0.421	3.56	2.89	6.06	6.06	80.7	106.9	91.0	125.7	564	"
63	5.50	23.0	"	"	5.50	0.422	3.56	2.86	6.06	6.08	86.3	111.0	91.0	125.7	592	"
64	5.50	23.0	P-110	"	5.53	0.414	3.56	2.86	6.03	6.03	127.2	140.8	125.0	142.0	772	"
65	5.50	23.0	"	"	5.53	0.413	3.56	2.86	6.03	6.03	125.4	141.2	125.0	142.0	760	"
66	5.50	23.0	"	"	5.53	0.413	3.56	2.86	6.05	6.06	122.0	135.3	125.0	142.0	744	"
67	6.62	20.0	J-55	Short	6.66	0.288	3.19	2.48	7.43	7.44	59.2	100.6	58.0	108.3	298	"
68	6.62	20.0	"	"	6.65	0.288	3.19	2.45	7.42	7.42	59.2	100.6	58.0	108.3	310	"
69	6.62	20.0	"	"	6.68	0.296	3.19	2.48	7.42	7.42	55.2	95.1	58.0	108.3	296	"
70	6.62	20.0	"	Long	6.66	0.277	3.94	3.23	7.42	7.42	51.6	96.4	66.9	113.0	298	"
71	6.62	20.0	"	"	6.68	0.299	3.94	3.23	7.42	7.42	60.5	101.2	66.9	113.0	338	"
72	6.62	20.0	"	"	6.64	0.281	3.94	3.21	7.41	7.41	62.2	96.6	66.9	113.0	302	"
73	6.62	24.0	"	Short	6.66	0.355	3.19	2.45	7.42	7.42	59.2	105.3	55.5	107.8	392	"
74	6.62	24.0	"	"	6.66	0.356	3.19	2.48	7.40	7.40	65.2	108.2	55.5	107.8	410	"
75	6.62	24.0	"	"	6.64	0.352	3.19	2.48	7.42	7.42	58.4	105.2	55.5	107.8	438	"
76	6.62	24.0	"	Long	6.64	0.352	3.94	3.23	7.42	7.42	59.2	105.3	55.5	107.8	456	"
77	6.62	24.0	"	"	6.63	0.351	3.94	3.26	7.42	7.42	58.4	105.2	55.5	107.8	454	"
78	6.62	24.0	"	"	6.64	0.363	3.94	3.23	7.40	7.40	65.2	108.2	55.5	107.8	450	"
79	6.62	24.0	N-80	"	6.66	0.364	3.94	3.30	7.42	7.42	89.2	120.1	95.1	125.3	612	"
80	6.62	24.0	"	"	6.66	0.366	3.94	3.23	7.40	7.40	88.7	121.9	95.1	125.3	600	"
81	6.62	24.0	"	"	6.66	0.352	3.94	3.23	7.40	7.40	87.1	120.1	95.1	125.3	594	"
82	6.62	24.0	P-110	"	6.67	0.349	3.94	3.20	7.38	7.38	121.1	134.2	121.8	141.8	696	"
83	6.62	24.0	"	"	6.66	0.350	3.94	3.23	7.40	7.40	117.3	131.4	121.8	141.8	676	"
84	6.62	24.0	"	"	6.68	0.348	3.94	3.23	7.38	7.40	110.2	126.0	121.8	141.8	686	"
85	6.62	32.0	N-80	"	6.65	0.492	3.94	3.23	7.42	7.42	94.4	126.2	95.1	125.3	900	"
86	6.62	32.0	"	"	6.66	0.490	3.94	3.23	7.40	7.40	97.4	126.2	95.1	125.3	886	"
87	6.62	32.0	"	"	6.64	0.490	3.94	3.23	7.42	7.42	97.4	126.2	95.1	125.3	906	"

Table 1 (Cont.)

$\alpha = 30°$

Item No.	Size OD	Wt. Per Ft.	Grade	Type of Joint	Av. Pipe OD D	Av. Pipe Wall t	Total Thread Length of Pipe L_t	Engaged Thread Length L	Av. Coupling OD Before Test W	Av. Coupling OD After Test	Pipe Yield Strength 1000 psi Y_p	Pipe Ultimate Strength 1000 psi U_p	Coupling Yield Strength 1000 psi Y_c	Coupling Ultimate Strength 1000 psi U_c	Joint Failure Load 1000 lbs. P	Type of Failure
88	6.62	32.0	P-110	Long	6.65	0.477	3.94	3.26	7.38	7.39	129.4	141.6	124.4	144.8	1,092	Jumpout
89	6.62	32.0	"	"	6.66	0.478	3.94	3.23	7.38	7.39	129.4	141.6	124.4	144.8	1,104	"
90	6.62	32.0	"	"	6.66	0.475	3.94	3.20	7.38	7.38	129.4	141.6	124.4	144.8	1,116	"
91	7.00	23.0	J-55	Short	7.02	0.321	3.19	2.48	7.67	7.67	57.6	100.1	58.2	102.1	354	"
92	7.00	23.0	"	"	7.00	0.326	3.19	2.48	7.68	7.68	59.2	99.9	58.2	102.1	376	"
93	7.00	23.0	"	"	7.02	0.319	3.19	2.48	7.68	7.68	58.2	105.6	58.2	102.1	372	"
94	7.00	23.0	"	Long	7.02	0.325	4.06	3.39	7.67	7.66	55.6	100.2	56.7	103.4	386	"
95	7.00	23.0	"	"	7.02	0.326	4.06	3.39	7.68	7.68	61.3	110.4	56.7	103.4	420	"
96	7.00	23.0	"	"	7.02	0.332	4.06	3.36	7.66	7.66	61.3	104.0	56.7	103.4	408	"
97	7.00	26.0	"	Short	7.01	0.371	3.19	2.48	7.68	7.68	59.2	110.7	58.2	102.1	446	"
98	7.00	26.0	"	"	7.00	0.367	3.19	2.51	7.65	7.66	64.6	111.3	58.2	102.1	480	"
99	7.00	26.0	"	"	7.00	0.365	3.19	2.48	7.68	7.68	57.4	107.8	58.2	102.1	442	"
100	7.00	26.0	"	Long	7.01	0.372	4.06	3.37	7.68	7.68	57.0	107.8	56.7	103.4	482	"
101	7.00	26.0	"	"	7.00	0.372	4.06	3.36	7.68	7.68	60.9	106.0	56.7	103.4	478	"
102	7.00	26.0	"	"	7.00	0.369	4.06	3.36	7.68	7.68	59.1	106.8	56.7	103.4	468	"
103	7.00	26.0	N-80	"	7.00	0.367	4.06	3.42	7.65	7.65	91.4	111.8	91.6	119.2	644	"
104	7.00	26.0	"	"	7.01	0.369	4.06	3.39	7.68	7.68	88.7	110.3	91.6	119.2	696	"
105	7.00	26.0	"	"	7.00	0.360	4.06	3.39	7.64	7.65	93.3	121.8	91.6	119.2	618	"
106	7.00	26.0	P-110	"	7.02	0.349	4.06	3.36	7.64	7.64	124.8	137.3	124.7	144.1	732	"
107	7.00	26.0	"	"	7.02	0.353	4.06	3.37	7.64	7.64	127.2	139.1	124.7	144.1	830	"
108	7.00	26.0	"	"	7.03	0.344	4.06	3.33	7.64	7.64	125.5	138.9	124.7	144.1	748	"
109	7.00	32.0	N-80	"	7.02	0.460	4.06	3.30	7.66	7.66	90.0	121.6	90.3	123.6	888	"
110	7.00	32.0	"	"	7.02	0.455	4.06	3.37	7.69	7.70	87.1	119.5	90.3	123.6	872	"
111	7.00	32.0	"	"	7.01	0.462	4.06	3.36	7.66	7.66	92.4	118.7	90.3	123.6	890	"
112	7.00	32.0	P-110	"	7.05	0.449	4.06	3.33	7.66	7.67	124.6	138.8	124.7	144.1	1,124	"
113	7.00	32.0	"	"	7.03	0.450	4.06	3.36	7.66	7.66	137.9	152.5	124.7	144.1	1,162	"
114	7.00	32.0	"	"	7.04	0.451	4.06	3.33	7.67	7.68	137.0	150.8	124.7	144.1	1,112	"
115	7.00	38.0	N-80	"	7.02	0.544	4.06	3.39	7.66	7.66	95.1	124.8	90.3	123.6	1,080	"
116	7.00	38.0	"	"	6.98	0.523	4.06	3.39	7.67	7.68	97.6	123.9	90.3	123.6	1,045	"

$\alpha = 30°$

Item No.	Size OD	Wt. Per Ft.	Grade	Type of Joint	Av. Pipe OD D	Av. Pipe Wall t	Total Thread Length of Pipe L_t	Engaged Thread Length L	Av. Coupling OD Before Test W	Av. Coupling OD After Test	Pipe Yield Strength 1000 psi Y_p	Pipe Ultimate Strength 1000 psi U_p	Coupling Yield Strength 1000 psi Y_c	Coupling Ultimate Strength 1000 psi U_c	Joint Failure Load 1000 lbs. P	Type of Failure
117	7.00	38.0	N-80	Long	7.00	0.542	4.06	3.36	7.68	7.70	101.0	125.5	90.3	123.6	1,085	Jumpout
118	7.00	38.0	P-110	"	7.04	0.541	4.06	3.36	7.65	7.66	119.7	136.1	124.7	144.1	1,250	"
119	7.00	38.0	"	"	7.02	0.526	4.06	3.36	7.68	7.69	119.8	138.2	124.7	144.1	1,220	"
120	7.00	38.0	"	"	7.02	0.532	4.06	3.39	7.68	7.68	120.7	139.7	124.7	144.1	1,355	"
121	9.62	36.0	J-55	Short	9.64	0.353	3.44	2.74	10.66	10.68	55.6	99.4	61.8	111.4	488	"
122	9.62	36.0	"	"	9.42	0.355	3.44	2.72	10.67	10.67	58.1	100.6	61.8	111.4	484	"
123	9.62	36.0	"	"	9.68	0.361	3.44	2.76	10.64	10.64	59.3	96.7	61.8	111.4	452	"
124	9.62	36.0	"	Long	9.66	0.355	4.81	4.07	10.67	10.68	57.7	99.6	64.1	100.9	532	"
125	9.62	36.0	"	"	9.66	0.360	4.81	4.01	10.63	10.63	59.2	102.5	64.1	100.9	528	"
126	9.62	36.0	"	"	9.67	0.346	4.81	4.18	10.65	10.65	58.7	102.0	64.1	100.9	538	"
127	9.62	40.0	"	Short	9.66	0.392	3.44	2.79	10.64	10.64	55.5	97.8	61.8	111.4	530	"
128	9.62	40.0	"	"	9.65	0.380	3.44	2.70	10.64	10.65	56.3	109.3	61.8	111.4	580	"
129	9.62	40.0	"	"	9.66	0.397	3.44	2.73	10.62	10.62	61.5	106.8	61.8	111.4	580	"
130	9.62	40.0	"	Long	9.61	0.394	4.81	4.10	10.64	10.64	56.5	100.9	60.0	105.3	606	"
131	9.62	40.0	"	"	9.64	0.402	4.81	4.20	10.64	10.64	57.6	103.6	60.0	105.3	622	"
132	9.62	40.0	"	"	9.66	0.402	4.81	4.17	10.64	10.62	58.0	100.8	60.0	105.3	578	"
133	9.62	43.5	N-80	"	9.68	0.436	4.81	4.10	10.64	10.63	95.8	122.2	101.2	129.1	1,104	"
134	9.62	43.5	"	"	9.68	0.422	4.81	4.04	10.64	10.64	95.2	119.8	101.2	129.1	1,032	"
135	9.62	43.5	"	"	9.68	0.428	4.81	4.10	10.63	10.64	94.7	122.6	101.2	129.1	1,120	Fracture
136	9.62	43.5	P-110	"	9.67	0.421	4.81	4.04	10.64	10.65	113.2	127.6	120.6	140.0	1,180	Jumpout
137	9.62	43.5	"	"	9.66	0.428	4.81	4.04	10.66	10.66	120.6	134.5	120.6	140.0	1,210	"
138	9.62	43.5	"	"	9.67	0.421	4.81	4.10	10.62	10.64	122.2	141.3	120.6	140.0	1,310	"
139	9.62	53.5	N-80	"	9.66	0.552	4.81	4.04	10.62	10.64	95.2	119.0	101.2	129.1	1,440	"
140	9.62	53.5	"	"	9.67	0.541	4.81	4.07	10.64	10.65	86.0	116.6	101.2	129.1	1,390	Fracture
141	9.62	53.5	"	"	9.66	0.548	4.81	4.10	10.62	10.64	91.2	115.9	101.2	129.1	1,460	Jumpout
142	9.62	53.5	P-110	"	9.68	0.536	4.81	4.12	10.66	10.66	114.0	132.9	125.7	146.4	1,652	"
143	9.62	53.5	"	"	9.68	0.540	4.81	4.07	10.66	10.66	114.3	131.4	120.6	140.0	1,720	"
144	9.62	53.5	"	"	9.68	0.551	4.81	4.01	10.66	10.65	114.6	131.9	120.6	140.0	1,650	"
145	10.75	40.5	J-55	Short	10.78	0.361	3.56	2.85	11.76	11.76	67.9	113.7	60.0	104.7	608	"

$\alpha = 30°$

Item No.	Size OD	Wt. Per Ft.	Grade	Type of Joint	Av. Pipe OD D	Av. Pipe Wall t	Total Thread Length of Pipe L_t	Engaged Thread Length L	Av. Coupling OD Before Test W	Av. Coupling OD After Test	Pipe Yield Strength 1000 psi Y_p	Pipe Ultimate Strength 1000 psi U_p	Coupling Yield Strength 1000 psi Y_c	Coupling Ultimate Strength 1000 psi U_c	Joint Failure Load 1000 lbs. P	Type of Failure
146	10.75	40.5	J-55	Short	10.80	0.350	3.56	2.92	11.76	11.76	56.0	96.7	60.0	104.7	470	Jumpout
147	10.75	40.5	"	"	10.79	0.361	3.56	2.85	11.76	11.76	57.1	101.5	60.0	104.7	520	"
148	10.75	51.0	"	"	10.80	0.446	3.56	2.79	11.80	11.81	57.6	101.9	57.8	104.0	630	"
149	10.75	51.0	"	"	10.80	0.450	3.56	2.88	11.80	11.80	57.3	102.4	57.8	104.0	668	"
150	10.75	51.0	"	"	10.79	0.441	3.56	2.85	11.80	11.80	57.1	102.2	57.8	104.0	650	"
151	10.75	51.0	N-80	"	10.82	0.459	3.56	2.85	11.78	11.78	88.2	116.5	85.9	123.7	976	"
152	10.75	51.0	"	"	10.83	0.469	3.56	2.85	11.80	11.80	90.6	121.4	85.9	123.7	1,000	"
153	10.75	51.0	"	"	10.80	0.450	3.56	2.88	11.80	11.80	86.7	116.5	85.9	123.7	1,050	"
154	10.75	51.0	P-110	"	10.82	0.451	3.56	2.82	11.84	11.84	118.2	132.2	117.4	137.4	1,166	"
155	10.75	51.0	"	"	10.80	0.445	3.56	2.85	11.81	11.82	118.0	133.8	117.4	137.4	1,215	"
156	10.75	51.0	"	"	10.81	0.445	3.56	2.85	11.83	11.84	118.1	133.0	117.4	137.4	1,120	"
157	10.75	55.5	N-80	"	10.80	0.477	3.56	2.88	11.78	11.78	90.2	123.0	85.9	123.7	1,076	"
158	10.75	55.5	"	"	10.77	0.470	3.56	2.82	11.78	11.78	87.8	121.2	85.9	123.7	1,040	"
159	10.75	55.5	"	"	10.80	0.484	3.56	2.85	11.78	11.78	91.5	125.1	85.9	123.7	1,074	"
160	10.75	55.5	P-110	"	10.80	0.492	3.56	2.85	11.83	11.83	120.4	138.2	121.2	139.8	1,360	"
161	10.75	55.5	"	"	10.78	0.491	3.56	2.79	11.86	11.86	121.7	138.5	121.2	139.8	1,400	"
162	10.75	55.5	"	"	10.80	0.500	3.56	2.82	11.82	11.83	129.0	146.8	121.2	139.8	1,530	"

When $\frac{P_j}{A_c} > Y_c$

$$[\quad]_1 = \left[\left(\frac{D}{2L}\tan(\alpha-\varphi) - 0.3\right)\frac{Y_c}{E_{ce}}\right]$$

$$[\quad]_2 = \text{as shown}$$

When $\frac{P_j}{A_p} \leq \frac{Y_p}{1+\frac{D}{2L}\tan(\alpha-\varphi)}$

$$[\quad]_3 = \text{as shown}$$

$$[\quad]_4 = 0$$

When $\frac{P_j}{A_p} > \frac{Y_p}{1+\frac{D}{2L}\tan(\alpha-\varphi)}$

$$[\quad]_3 = \left[\frac{\left(\frac{D}{2L}\tan(\alpha-\varphi)+0.3\right)}{\left(1+\frac{D}{2L}\tan(\alpha-\varphi)\right)}\frac{Y_p}{E_{pe}}\right]$$

$$[\quad]_4 = \text{as shown}$$

Although equation (32a) appears cumbersome, it could be solved explicitly for tensile load at jumpout, if all stress relationships were linear, in which case $b = 1$. For the more general curvilinear relationship that would be expected for stresses in excess of the yield strength where b is not equal to 1, solution would have to proceed on a trial-and-error basis unless equation (32a) can be simplified sufficiently.

As mentioned earlier, for thread jumpout type of failure, experience has indicated that the pipe usually is the critical member and that coupling dimension and material strength generally are not of particular consequence within typical design limits. It will be noted in Table 1 that little or no permanent deformation of the coupling occurred during joint testing. This suggests that coupling strains represented by $[\quad]_1$ and $[\quad]_2$ of equation (32a) could be ignored with some degree of approximation. Consideration of equation (22b) giving the maximum value of elastic strain for the pipe and equation (31a) showing the total strain required for jumpout indicates the possibility of being able to ignore the elastic strain of the pipe represented by $[\quad]_3$ of equation (32a) with reasonable approximation. These approximations can by represented as follows: Let the strain to be ignored be as shown in equation (33).

$$\Delta e = \sum_{q=1}^{q=3} [\quad]_q \tag{33}$$

where

Δe = the total coupling strain and elastic strain of pipe.
$[\quad]q$ = strain components of equation (32a) group.

Equating Δe as shown in equation (33) to zero, substituting into equation (32a) and rearranging, the simplified expression for jumpout shown as equation (34) is obtained.

$$P_j = \left[\frac{a\left(\frac{2h}{D}\right)^b U_p}{\frac{1}{2}+\frac{D}{2L}\tan(\alpha-\varphi)} + \frac{Y_p}{1+\frac{D}{2L}\tan(\alpha-\varphi)}\right]A_p \tag{34}$$

where

P_j = tensile load resulting in jumpout.

In order to be able to make use of equations (32a), (34), or (35) for calculating the jumpout load of a threaded joint, it first becomes necessary to determine values for friction angle and constants a and b from joint test data. This can be accomplished most readily by means of equation (34) and test data following within its scope of limitations. After the experimental coefficients have been determined both equations (32a) and (34) are then available for computing joint strength. Equation (34) provides an approximation which can be improved by trial and error in equation (32a) when necessary for joints outside the range of normal design.

While equation (32a) can be used in the form shown, a more convenient form can be derived by substituting Δe as shown in equation (33) into equation (32a) and solving for P_j as shown in equation (35).

$$P_j = \left[\frac{a\left(\frac{2h}{D}-\Delta e\right)^b U_p}{\frac{1}{2}+\frac{D}{2L}\tan(\alpha-\varphi)} + \frac{Y_p}{1+\frac{D}{2L}\tan(\alpha-\varphi)}\right]A_p \tag{35}$$

It is seen that substitution of $\Delta e = 0$ into equation (35) results in equation (35) becoming equal to equation (34). Since Δe is dependent on P_j, equation (35) must be solved by trial and error. Assuming that Δe is zero, a trial value of P_j is determined. Using this value of P_j, a value of Δe is computed. Using the computed value of Δe a new trial value of P_j is computed. This cycle is repeated until the value of P_j converges to the desired satisfactory degree of accuracy.

The American Petroleum Institute, in making preparations to issue a new bulletin of performance properties of oil country tubular goods, sponsored a test program of API standard round thread casing joints to provide a more adequate basis for joint strengths than previously available. A program of 162 joint tensile tests covering the J-55, N-80, and P-110 steel grades was conducted using the facilities of United States Steel Corporation. Of the 162 joints tested, 14 failed by fracture while the other 148 failed by jumpout. The results of these tests are shown in Table 1.

In determining the values of friction angle φ and coefficients a and b from the 148 tests of the API sponsored test program where jumpout occurred, least square statistical methods were used. To do this equation (34) can be written in a more convenient form, as shown in equation (36).

$$Y = A + BX \tag{36}$$

where

$$Y = \left(\frac{P_j}{A_p U_p} - \frac{\frac{Y_p}{U_p}}{1+\frac{D}{2L}\tan(\alpha-\varphi)}\right) \times \left(\frac{1}{2}+\frac{D}{2L}\tan(\alpha-\varphi)\right)$$

$$A = \log a(2h)^b$$

$$B = -b$$

$$X = \log D$$

By the method of least squares or statistical regression, equation (36) was fit to the data shown in the table and values for a and b determined for different values of friction angle φ. The best fit can be determined by a trial-and-error method leading to the lowest standard deviation of the ratio of test to values calculated by the equation. Applying this method to the 148 joint tensile tests failing by jumpout, the values of the experimental coefficients have been determined to be as follows:

Table 2 Comparison of formula (jumpout loads) with test values

Item No.	Size OD In.	Wt. Per Ft.	Grade	Type of Joint	Test Jumpout Load 1000 lbs. P_j Test	Formula Jumpout Load 1000 lbs. P_j	P_j Test/P_j
1	4.50	11.6	J-55	Short	228	217	1.051
2	"	"	"	"	222	220	1.008
3	"	"	"	"	218	217	1.005
4	"	"	"	Long	242	233	1.039
5	"	"	"	"	234	221	1.058
6	"	"	"	"	218	215	1.015
13	"	13.5	N-80	"	350	354	0.988
15	"	"	"	"	374	358	1.046
19	5.00	13.0	J-55	Short	258	232	1.113
20	"	"	"	"	268	246	1.091
21	"	"	"	"	264	234	1.126
22	"	"	"	Long	298	268	1.113
23	"	"	"	"	282	274	1.031
24	"	"	"	"	260	252	1.030
25	"	15.0	"	Short	300	290	1.034
26	"	"	"	"	306	297	1.031
27	"	"	"	"	310	311	0.998
28	"	"	"	Long	324	316	1.026
29	"	"	"	"	342	317	1.078
30	"	"	"	"	314	327	0.961
31	"	"	N-80	"	372	394	0.945
32	"	"	"	"	388	384	1.010
35	"	"	P-110	"	426	459	0.928
36	"	"	"	"	410	451	0.909
37	"	18.0	N-80	"	474	514	0.922
38	"	"	"	"	494	522	0.945
39	"	"	"	"	466	494	0.944
40	"	"	P-110	"	520	579	0.899
41	"	"	"	"	524	576	0.910
42	"	"	"	"	510	548	0.931
43	5.50	15.5	J-55	Short	288	275	1.046
44	"	"	"	"	294	279	1.053
45	"	"	"	"	282	284	0.995
46	"	"	"	Long	306	290	1.055
47	"	"	"	"	290	305	0.949
48	"	"	"	"	324	303	1.070
49	"	17.0	"	Short	288	277	1.040
50	"	"	"	"	320	313	1.023
51	"	"	"	"	284	295	0.962
52	"	"	"	Long	310	306	1.012
53	"	"	"	"	316	311	1.016
54	"	"	"	"	328	317	1.035
55	"	"	N-80	"	444	445	0.998
56	"	"	"	"	426	414	1.029
57	"	"	"	"	470	429	1.096
58	"	"	P-110	"	510	531	0.961
59	"	"	"	"	512	510	1.004
60	"	"	"	"	508	553	0.919
61	"	23.0	N-80	"	586	589	0.995
62	"	"	"	"	564	561	1.006
63	5.50	23.0	N-80	Long	592	593	0.998
64	"	"	P-110	"	772	811	0.952
65	"	"	"	"	760	802	0.948
66	"	"	"	"	744	776	0.959
67	6.62	20.0	J-55	Short	298	304	0.980
68	"	"	"	"	310	303	1.025
69	"	"	"	"	296	295	1.002
70	"	"	"	Long	298	284	1.049
71	"	"	"	"	338	351	0.962
72	"	"	"	"	302	323	0.934
73	"	24.0	"	Short	392	399	0.982
74	"	"	"	"	410	431	0.951
75	"	"	"	"	438	393	1.113
76	"	"	"	Long	456	431	1.059
77	"	"	"	"	454	427	1.064
78	"	"	"	"	450	478	0.941
79	"	"	N-80	"	612	611	1.001
80	"	"	"	"	600	613	0.980
81	"	"	"	"	594	575	1.033
82	"	"	P-110	"	696	734	0.948
83	"	"	"	"	676	718	0.942
84	"	"	"	"	686	674	1.018
85	"	32.0	N-80	"	900	903	0.997
86	"	"	"	"	886	917	0.966
87	"	"	"	"	906	917	0.988
88	"	"	P-110	"	1,092	1,124	0.972
89	"	"	"	"	1,104	1,124	0.982
90	"	"	"	"	1,116	1,113	1.003
91	7.00	23.0	J-55	Short	354	351	1.009
92	"	"	"	"	376	363	1.035
93	"	"	"	"	372	358	1.040
94	"	"	"	Long	386	385	1.003
95	"	"	"	"	420	426	0.986
96	"	"	"	"	408	425	0.961
97	"	26.0	"	Short	446	443	1.008
98	"	"	"	"	480	463	1.037
99	"	"	"	"	442	421	1.049
100	"	"	"	Long	482	473	1.018
101	"	"	"	"	478	488	0.980
102	"	"	"	"	468	477	0.982
103	"	"	N-80	"	644	637	1.010
104	"	"	"	"	696	625	1.114
105	"	"	"	"	618	648	0.954
106	"	"	P-110	"	732	790	0.927
107	"	"	"	"	830	816	1.018
108	"	"	"	"	748	780	0.959
109	"	32.0	N-80	"	888	834	1.064
110	"	"	"	"	872	806	1.081
111	"	"	"	"	890	850	1.047
112	"	"	P-110	"	1,124	1,059	1.061
113	7.00	32.0	P-110	Long	1,162	1,174	0.990
114	"	"	"	"	1,112	1,166	0.954
115	"	38.0	N-80	"	1,080	1,056	1.023
116	"	"	"	"	1,045	1,027	1.018
117	"	"	"	"	1,085	1,094	0.992
118	"	"	P-110	"	1,250	1,260	0.992
119	"	"	"	"	1,220	1,228	0.993
120	"	"	"	"	1,355	1,256	1.079
121	9.62	36.0	J-55	Short	488	463	1.054
122	"	"	"	"	484	481	1.006
123	"	"	"	"	452	494	0.915
124	"	"	"	Long	532	548	0.972
125	"	"	"	"	528	570	0.927
126	"	"	"	"	538	545	0.986
127	"	40.0	"	Short	530	525	1.009
128	"	"	"	"	580	524	1.107
129	"	"	"	"	580	583	0.996
130	"	"	"	Long	606	616	0.984
131	"	"	"	"	622	649	0.958
132	"	"	"	"	578	645	0.896
133	"	43.5	N-80	"	1,104	1,056	1.045
134	"	"	"	"	1,032	1,002	1.029
136	"	"	P-110	"	1,180	1,153	1.023
137	"	"	"	"	1,210	1,249	0.969
138	"	"	"	"	1,310	1,259	1.040
139	"	53.5	N-80	"	1,440	1,351	1.066
141	"	"	"	"	1,460	1,296	1.126
142	"	"	P-110	"	1,652	1,547	1.068
143	"	"	"	"	1,720	1,555	1.106
144	"	"	"	"	1,650	1,588	1.039
145	10.75	40.5	J-55	Short	608	608	1.000
146	"	"	"	"	470	492	0.956
147	"	"	"	"	520	521	0.998
148	"	51.0	"	"	630	667	0.944
149	"	"	"	"	668	682	0.980
150	"	"	"	"	650	661	0.983
151	"	"	N-80	"	976	979	0.997
152	"	"	"	"	1,000	1,035	0.966
153	"	"	"	"	1,050	948	1.107
154	"	"	P-110	"	1,166	1,229	0.949
155	"	"	"	"	1,215	1,217	0.999
156	"	"	"	"	1,120	1,216	0.921
157	"	55.5	N-80	"	1,076	1,058	1.017
158	"	"	"	"	1,040	1,007	1.032
159	"	"	"	"	1,074	1,087	0.988
160	"	"	P-110	"	1,360	1,394	0.976
161	"	"	"	"	1,400	1,391	1.007
162	"	"	"	"	1,530	1,511	1.012

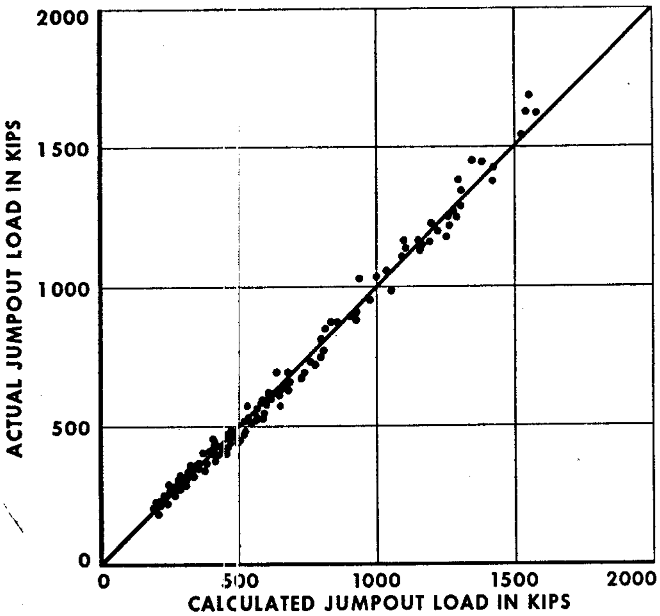

Fig. 4

Table 3 Comparison of formula fracture loads with test values

Item No.	Size OD In.	Wt. Per Ft./ Lbs.	Grade	Ult. Strength 1000 psi	Critical Area Pipe	Formula Fracture Load 1000 lbs.	Test Fracture Load 1000 lbs.	Pup Test/ Pup
				U_p	A_p	Pup	Pup Test	
7	4-1/2	11.6L	N-80	124.4	2.3944	298	278	.933
8	"	11.6L	N-80	123.4	2.4324	300	284	.947
9	"	11.6L	N-80	135.0	2.5209	340	302	.888
10	"	11.6L	P-110	140.9	2.3957	338	364	1.077
11	"	11.6L	P-110	143.0	2.3957	343	372	1.085
12	"	11.6L	P-110	140.5	2.4209	340	344	1.012
14	"	13.5L	N-80	130.1	2.9392	382	390	1.021
16	"	13.5L	P-110	135.9	2.7711	377	400	1.061
17	"	13.5L	P-110	133.3	2.8703	383	408	1.065
18	"	13.5L	P-110	135.2	2.7960	378	416	1.101
33	5	15.0L	N-80	120.5	3.3830	408	396	.971
34	"	15.0L	P-110	131.8	3.3412	440	448	1.018
135	9-5/8	43.5L	N-80	122.6	10.2894	1,261	1,120	.888
140	"	53.5L	N-80	116.6	13.3818	1,560	1,390	.891
								13.958
							Av.	0.997
							St. Dev.	0.074

$$a = 2.39$$
$$b = 0.59$$
$$\varphi = 14°21'$$

Table 2 shows a comparison of the jumpout loads calculated by means of equation (34), using these experimental coefficients with the actual test jumpout loads. The standard deviation of the ratio of test to calculated jumpout load is 0.051 which is considered highly satisfactory and certainly demonstrates that equation (34) is applicable to the data. Fig. 4 shows a plot of actual jumpout loads against calculated and further evidences the adequacy of equation (34).

Table 3 shows a comparison of the fracture loads calculated by means of equation (1) with the actual test fracture loads. The ratio of the test to calculated fracture load is seen to average 0.997 with a standard deviation of 0.074, which indicates good agreement between fact and theory.

We now have the following 4 equations for determining the tensile strength of threaded pipe joints:

Fracture Strength of Pipe

$$P_{up} = A_p U_p \tag{1}$$

Fracture Strength of Coupling

$$P_{uc} = A_c U_c \tag{2}$$

Splitting Strength of Coupling

obtained by substituting $\varphi = 14°21'$ into equation (7)

$$P_{cc} = \frac{\pi d_m L}{\tan(\alpha - 14°21')} \left(\frac{2t_{cm}}{d_m + t_{cm}}\right) U_c \tag{37}$$

Joint Jumpout Strength

obtained by substituting $a = 2.39$, $b = 0.59$, and $\varphi = 14°21'$ into equation (35)

$$P_j = \left[\frac{2.39 \left(\frac{2h}{D} - \Delta_e\right)^{0.59} U_p}{\frac{1}{2} + \frac{D}{2L}\tan(a - 14°21')} + \frac{Y_p}{1 + \frac{D}{2L}\tan(\alpha - 14°21')} \right] A_p \tag{38}$$

Where Δ_e is determined by means of equation (33) and factors shown in connection with equation (32*a*).

In order to determine the magnitude of the load causing failure and the mode of failure, failure loads are calculated by means of equations (1), (2), (7), and (35), the lowest of which is the critical value.

In application of equations (1), (2), (37), and (38) to the API list of round thread casing with standard couplings, it has been found that equations (2) and (7) covering coupling fracture and splitting strength never govern, and that ignoring Δ_e does not affect joint strength within the accuracy of the tabulated values. Summarizing these equations for use on API standard round thread casing and introducing the value of 30 deg for thread bearing flank angle α and 0.0625 for thread height h results in the following equations which have been adopted by API for their use.

Fracture Strength of Pipe Thread

$$P_{up} = A_p U_p \tag{1}$$

Joint Jumpout Strength

$$P_j = A_p L \left[\frac{0.74\, D^{-0.59} U_p}{0.5L + 0.14D} - \frac{Y_p}{L + 0.14D} \right] \tag{39}$$

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