tubesheet joint. Acceptable values of f_T may range from 0 to greater than 1. When the f_T value is negative, it shall be set to 0.

f_w = weld strength factor

f_y = factor for differences in the mechanical properties of tubesheet and tube materials

k = tube load factor

= 1.0 for loads due to pressure-induced axial forces

= 1.0 for loads due to thermally induced or pressure plus thermally induced axial forces on welded-only joints where the thickness through the weld throat $(0.7a_f + a_g)$ is less than the nominal tube wall thickness t

= 2.0 for loads due to thermally induced or pressure plus thermally induced axial forces on all other tube-to-tubesheet joints

l = length of the expanded portion of the tube

L_{max} = maximum allowable axial load in either direction on the tube-to-tubesheet joint

L_{test} = axial load at which failure of the test specimens occur

$L_{1,test}$ = lowest axial load at which failure occurs at operating temperature

$L_{2,test}$ = lowest axial load at which failure of heat-soaked specimen tested at room temperature occurs

P_e = tube expanding pressure

P_o = interface pressure between the tube and tubesheet that remains after expanding the tube at fabrication. This pressure may be established analytically or experimentally but shall consider the effect of change in material strength at operating temperature.

P_T = interface pressure between the tube and tubesheet due to differential thermal growth. This pressure may be established analytically or experimentally.

R_m = mean tube radius

r_o = tube outside radius

S = allowable stress for the tube material at design temperature. For a welded tube or pipe, use the allowable stress for the equivalent seamless product. When the allowable stress for the equivalent seamless product is not available, divide the allowable stress of the welded product by 0.85.

S_T = tensile strength for the tube material from the material test report

S_t = allowable stress of the material to which the tube is welded. See UW-20.5(d).

S_u = tensile strength for tube material at operating temperature taken from Section II, Part D, Subpart 1, Table U

S_{ua} = tensile strength for tube material at room temperature taken from Section II, Part D, Subpart 1, Table U

$S_{y,t}$

S_w = allowable stress in weld

S_y = yield strength for tubesheet material at tubesheet design temperature, T (see UG-23)

$S_{y,t}$ = yield strength for tube material at tubesheet design temperature, T (see UG-23)

T = tubesheet design temperature

t = nominal tube wall thickness

T_a = ambient temperature

α = mean coefficient of thermal expansion of tubesheet material at T

α_t = mean coefficient of thermal expansion of tube material at T

UW-20.3 Joint Strength by Calculation.

UW-20.3.1 Scope. These rules provide a basis for establishing weld sizes and allowable joint loads by calculation for full strength and partial strength tube-to-tubesheet welds. These rules apply to welded only joints and welded and expanded joints in which the strength of the expansion is not considered. These rules cover the welds shown in Figure UW-20.1

UW-20.3.2 Full Strength Welds. Full-strength welds shown in Figure UW-20.1 shall conform to the following requirements:

(a) The size of a full-strength weld shall be determined in accordance with UW-20.3.4.

(b) The maximum allowable axial load in either direction on a tube-to-tubesheet joint with a full-strength weld shall be $L_{max} = kF_t$.

UW-20.3.3 Partial Strength Welds. Partial-strength welds shown in Figure UW-20.1 shall conform to the following requirements:

(a) The size of a partial-strength weld shall be determined in accordance UW-20.3.4.

(b) The maximum allowable axial load in either direction on a tube-to-tubesheet joint with a partial-strength weld shall be $L_{max} = k(F_f + F_g)$, but not greater than kF_t.

UW-20.3.4 Weld Size Design Equations.

(a) The size of tube-to-tubesheet strength welds shown in Figure UW-20.1 shall conform to the following requirements:

(1) For fillet welds shown in sketch (a)

(-a) calculate the minimum required length of the fillet weld leg

$$a_r = \sqrt{(0.75d_o)^2 + 2.73t(d_o - t)f_w f_d} - 0.75d_o$$

(-b) for full strength welds, $a_f \geq \max(a_r, 1.4t)$
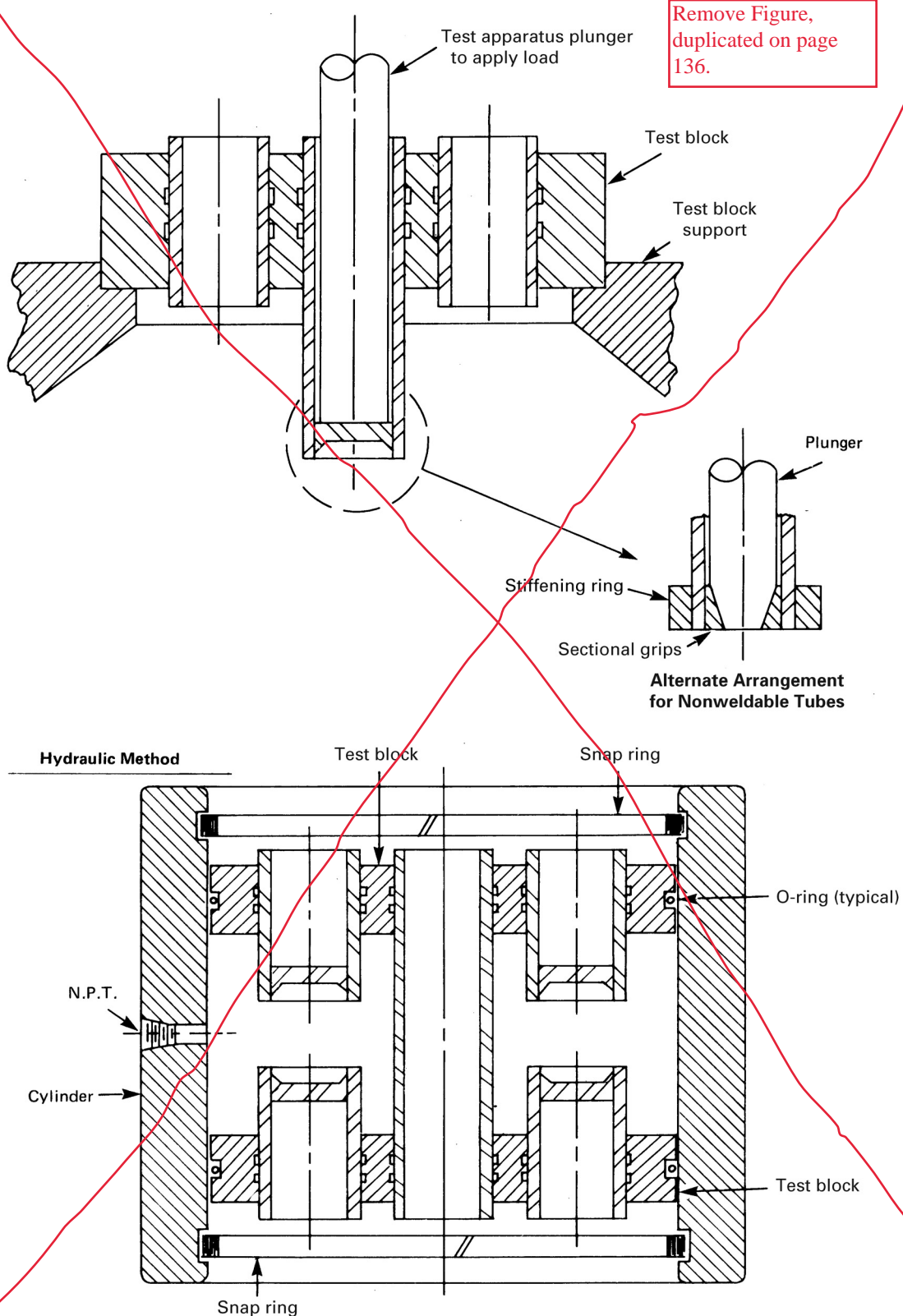
(-c) for partial strength welds, $a_f \geq a_r$

(2) For groove welds shown in sketch (b)

(-a) calculate the minimum required length of the groove weld leg

$$a_r = \sqrt{(0.75d_o)^2 + 1.76t(d_o - t)f_w f_d} - 0.75d_o$$

(-b) for full strength welds, $a_g \geq \max(a_r, t)$

Errata

Figure UW-20.3
Typical Test Fixtures for Expanded or Welded Tube-to-Tubesheet Joints

Remove Figure, duplicated on page 136.

Test apparatus plunger to apply load

Test block

Test block support

Plunger

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(-c) for partial strength welds, $a_g \geq a_r$

(3) For combined groove and fillet welds shown in sketch (c), where $a_f = a_g$

(-a) calculate the minimum required length of the combined weld legs

$$a_r = 2\left[\sqrt{\left(0.75d_o\right)^2 + 1.07t\left(d_o - t\right)f_w f_d} - 0.75d_o\right]$$

(-b) for full strength welds, $a_c \geq \max[a_r, 1.2t]$

(-c) for partial strength welds, $a_c \geq a_r$

(-d) calculate a_f and a_g

$$a_f = a_c/2$$

$$a_g = a_c/2$$

(4) For combined groove and fillet welds shown in sketch (d), where a_f is not equal to a_g

(-a) choose a_g and calculate the minimum required length of the fillet weld leg

$$a_r = \sqrt{\left(0.75d_o\right)^2 + 2.73t\left(d_o - t\right)f_w f_d f_f} - 0.75d_o$$

(-b) for full strength welds, $a_c \geq \max[(a_r + a_g),$ $(1.4t - 0.4a_g)]$

(-c) for partial strength welds, $a_c \geq (a_r + a_g)$

(-d) calculate a_f

$$a_f = a_c - a_g$$

(5) For inset fillet welds shown in sketch (e)

(-a) calculate the minimum required length of the fillet weld leg

$$a_r = 0.75d_o - \sqrt{\left(0.75d_o\right)^2 - 2.73t\left(d_o - t\right)f_w f_d}$$

(-b) full strength welds are not possible with this configuration

(-c) for partial strength welds, $t \geq a_f \geq a_r$. If $a_r > t$, joint load cannot be calculated in accordance with this section. See UW-20.4.

(6) For combined groove and inset fillet welds shown in sketch (f)

(-a) choose a_f and calculate the minimum required length of the groove weld leg

$$a_r = \sqrt{\left(0.75d_o\right)^2 + 1.76t\left(d_o - t\right)f_w f_d f_g} - 0.75d_o$$

(-b) for full strength welds, $a_c \geq \max[(a_r + a_f),$ $(t + 0.3a_f)]$

(-c) for partial strength welds, $a_c \geq (a_r + a_f)$

(b) Weld strength factors used in (a) above shall be calculated using the following equations:

$$f_f = 1 - \frac{F_g}{f_d F_t}$$

$$f_g = 1 - \frac{F_f}{f_d F_t}$$

$$f_w = \frac{S}{S_w}$$

where

f_d = 1.0 for full strength welds
  = F_d/F_t for partial strength welds
F_f = $\min[0.55\pi a_f(d_o + 0.67a_f)S_w, F_t]$ for face fillet welds as shown in Figure UW-20.1, sketches (a), (c), and (d)
  = $\min[0.55\pi a_f(d_o - 0.67a_f)S_w, F_t]$ for inset fillet welds as shown in Figure UW-20.1, sketches (e) and (f)
F_g = $\min[0.85\pi a_g(d_o + 0.67a_g)S_w, F_t]$
F = $\pi t(d_o - t)S$
S = $\min(S, S_t)$

UW-20.4   Joint Strength by Factors.

UW-20.4.1   Scope. These rules provide a basis for establishing allowable joint loads using strength factors. Some acceptable geometries and combinations of brazed, welded, and mechanical joints are described in Table UW-20.1. Some acceptable types of welded joints are illustrated in Figure UW-20.2.

(a) Geometries, including variations in tube pitch, fastening methods, and combinations of fastening methods not described or shown may be used provided qualification tests have been conducted and applied in compliance with the procedures set forth in UW-20.4.3 and UW-20.4.4.

(b) Materials for welded or brazed tube-to-tubesheet joints that do not meet the requirements of UW-5 or UB-5, but in all other respects meet the requirements of this division, may be used if qualification tests of the tube-to-tubesheet joint have been conducted and applied in compliance with the procedures set forth in UW-20.4.3 and UW-20.4.4.

UW-20.4.2   Maximum Axial Loads.

(a) The maximum allowable axial load in either direction on tube-to-tubesheet joints shall be determined in accordance with the following:

(1) For joint types a, b, c, d, and e

$$L_{\max} = kA_t S f_r$$

(2) For joint types f, g, and h

$$L_{\max} = \min\left(kA_t S f_{re}, \ kA_t S\right)$$

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(3) For joint types i, j, and k

$$L_{\max} = \min\left(kA_tSf_ef_rf_yf_T, \ \ kA_tS\right)$$

where

A_t = $\pi(d_o - t)t$

f_e = $\min[(l/d_o), 1.0]$ for tube joints made with expanded tubes in tube holes without enhancement

= 1.0 for tube joints made with expanded tubes in tube holes with enhancement

f_{re} = $\max[(f_ef_rf_yf_T), f_{r(h)}]$

$f_{r(h)}$ = 0.70 when established by shear load test per UW-20.4.4

= 0.50 without shear load test

f_y = $\min[(S_y/S_{y,t}), 1.0]$ for expanded joints. When f_y < 0.60, qualification of joint by shear load test is required

f_T = $\max\left[0, \dfrac{P_o + P_T}{P_o}\right]$

(b) P_o, P_T may be established experimentally or analytically. The following equations may be used to calculate P_o and P_T:

$$P_e = S_{y,t}\frac{t + r_o\left(\dfrac{S_y}{S_{y,t}}\right)}{t + r_o}\left(1.945 - 1.384\frac{d_i}{d_o}\right)$$

$$P_o = P_e\left[1 - \left(\frac{d_i}{d_o}\right)^2\right] - \frac{2}{\sqrt{3}}S_{y,t}\left(\ln\frac{d_o}{d_i}\right)$$

$$P_T = \frac{\dfrac{R_m}{d_o}E_t\left[\alpha_t d_o\left(T - T_a\right) - \alpha d_o\left(T - T_a\right)\right]}{\left(\dfrac{d_o{}^2}{t} - R_m\right) + R_m\left(2.9\dfrac{E_t}{E} - 0.3\right)}$$

$$R_m = r_o - \frac{t}{2}$$

UW-20.4.3   Shear Load Test.

UW-20.4.3.1   Flaws in the specimen may affect results. If any test specimen develops flaws, the retest provisions of UW-20.4.3.11 below shall govern.

UW-20.4.3.2   If any test specimen fails because of mechanical reasons, such as failure of testing equipment or improper specimen preparation, it may be discarded, and another specimen taken from the same heat.

UW-20.4.3.3   The shear load test subjects a full-size specimen of the tube joint under examination to a measured load sufficient to cause failure. In general, the testing equipment and methods are given in ASTM E8. Additional fixtures for shear load testing of tube-to-tubesheet joints are shown in Figure UW-20.3.

UW-20.4.3.4   The test block simulating the tubesheet may be circular, square, or rectangular in shape, essentially in general conformity with the tube pitch geometry. The test assembly shall consist of an array of tubes such that the tube to be tested is in the geometric center of the array and surrounded by at least one row of adjacent tubes. The test block shall extend a distance of at least one tubesheet ligament beyond the edge of the peripheral tubes in the assembly.

UW-20.4.3.5   All tubes in the test block array shall be from the same heat and shall be installed using identical procedures.

(a) The finished thickness of the test block may be less but not greater than the tubesheet it represents. For expanded joints, made with or without welding, the expanded area of the tubes in the test block may be less but not greater than that for the production joint to be qualified.

(b) The length of the tube used for testing the tube joint need only be sufficient to suit the test apparatus. The length of the tubes adjacent to the tube joint to be tested shall not be less than the thickness of the test block to be qualified.

UW-20.4.3.6   The procedure used to prepare the tube-to-tubesheet joints in the test specimens shall be the same as used for production.

UW-20.4.3.7   The tube-to-tubesheet joint specimens shall be loaded until mechanical failure of the joint or tube occurs. The essential requirement is that the load be transmitted axially.

UW-20.4.3.8   Any speed of testing may be used, provided load readings can be determined accurately.

UW-20.4.3.9   The reading from the testing device shall be such that the applied load required to produce mechanical failure of the tube-to-tubesheet joint can be determined.

UW-20.4.3.10   For determining $f_{r,\text{test}}$ for joint types listed in Table UW-20.1, a minimum of three specimens shall constitute a test. The value of $f_{r,\text{test}}$ shall be calculated in accordance with UW-20.4.4 using the lowest value of L_{test}. In no case shall the value of $f_{r,\text{test}}$ using a three specimen test exceed the value of $f_{r,\text{test}}$ given in Table UW-20.1. If the value of $f_{r,\text{test}}$ so determined is less than the value for $f_{r,\text{test}}$ given in Table UW-20.1, retesting may be performed in accordance with UW-20.4.3.11, or a new three specimen test may be performed using a new joint configuration or fabrication procedure. All previous test data shall be rejected. To use a value of $f_{r,\text{test}}$ greater than the value given in Table UW-20.1, a nine-specimen test shall be performed in accordance with UW-20.4.3.11.

Figure UW-20.3
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