Tank Inspection, Repair, Alteration, and Reconstruction

API STANDARD 653
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19 ADDENDUM 2, MAY 2020

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4.3.1.2 The evaluation of the existing tank shell shall be conducted by a storage tank engineer and shall include an analysis of the shell for the intended design conditions, based on existing shell plate thickness and material. The analysis shall take into consideration all anticipated loading conditions and combinations, including pressure due to fluid static head, internal and external pressure, wind loads, seismic loads, roof live loads, nozzle loads, settlement, and attachment loads.

4.3.1.3 Shell corrosion occurs in many forms and varying degrees of severity and may result in a generally uniform loss of metal over a large surface area or in localized areas. Pitting may also occur. Each case must be treated as a unique situation and a thorough inspection conducted to determine the nature and extent of corrosion prior to developing a repair procedure. Pitting does not normally represent a significant threat to the overall structural integrity of a shell unless present in a severe form with pits in close proximity to one another. Criteria for evaluating both general corrosion and pitting are defined below.

4.3.1.4 Methods for determining the minimum shell thickness suitable for continued operation are given in 4.3.2, 4.3.3, and 4.3.4 (see Section 6 for frequency of inspection).

4.3.1.5 If the requirements of 4.3.3 (welded) or 4.3.4 (riveted) cannot be satisfied, the corroded or damaged areas shall be repaired, or the allowable liquid level of the tank reduced, or the tank retired. The allowable liquid level for the continued use of a tank may be established by using the equations for a minimum acceptable thickness (see 4.3.3.1 and 4.3.4.1) and solving for height, H. The actual thickness, as determined by inspection, minus the corrosion allowance shall be used to establish the liquid level limit. The maximum design liquid level shall not be exceeded.

4.3.2 Actual Thickness Determination

4.3.2.1 For determining the controlling thicknesses in each shell course when there are corroded areas of considerable size, measured thicknesses shall be averaged in accordance with the following procedure (see Figure 4.1).

a) For each area, the authorized inspector shall determine the minimum thickness, t_2, at any point in the corroded area, excluding widely scattered pits (see 4.3.2.2).

b) Calculate the critical length, L:

$L = 3.7\sqrt{Dt_2}$, but not more than 40 in.

where

L is the maximum vertical length, in inches, over which hoop stresses are assumed to “average out” around local discontinuities;

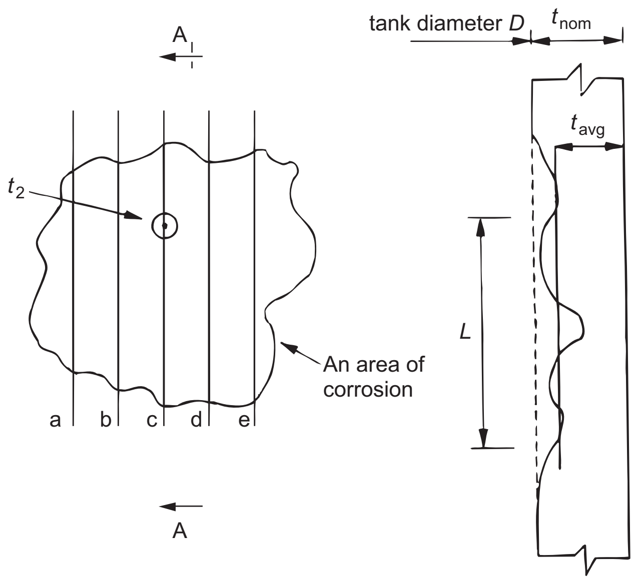
NOTE The actual vertical length of the corroded area may exceed L.

D is the tank diameter, in feet;

t_2 is the least thickness, in inches, in an area of corrosion, exclusive of pits.

c) The authorized inspector shall visually or otherwise decide which vertical plane(s) in the area is likely to be the most affected by corrosion. Profile measurements shall be taken along each vertical plane for a distance, L. In the plane(s), determine the lowest average thickness, t_1, averaged over a length of L, using at least five equally spaced measurements over length L.

d) See 4.3.3.1 for minimum permitted values for t_1 and t_2. The additional loads in 4.3.3.5 shall also be considered. 18



Key

a – e are inspection planes selected by inspector.

t_2 is the least min. thickness in entire area, exclusive of pits.

SECTION A-A

Profile along Plane c , the plane having the lowest average thickness, t_1.

Procedure

1) Determine t_2.

2) Calculate $L = 3.7\sqrt{Dt_2}$, but not more than 40 in.

3) Locate L to get minimum t_{avg}, which is t_1.

Figure 4.1—Inspection of Corrosion Areas

e) The criteria for continued operation is as follows:

i) the value t_1 shall be greater than or equal to t_{min} (see 4.3.3 or 4.3.4), subject to verification of all other loadings listed in 4.3.3.5;

ii) the value t_2 shall be greater than or equal to 60 % of t_{min}; and

iii) any corrosion allowance required for service until the time of the next inspection shall be added to t_{min} and 60 % of t_{min}.

4.3.2.2 Widely scattered pits may be ignored provided that:

a) no pit depth results in the remaining shell thickness being less than one-half the minimum acceptable tank shell thickness exclusive of the corrosion allowance; and

b) the sum of their dimensions along any vertical line does not exceed 2 in. in an 8-in. length (see Figure 4.2).

4.3.3 Minimum Thickness Calculation for Welded Tank Shell

NOTE In general, the minimum acceptable thickness (t_{min}) for an entire shell course is determined using 4.3.3.1 a) with H determined to the bottom of each shell course and the results used as a basis for judging the suitability for continued service for the tank. If locally thinned areas are identified or if specific areas are investigated (such as for a shell nozzle installation), the method of 4.3.3.1 b) may be used to complete the evaluation with H determined for that particular location.

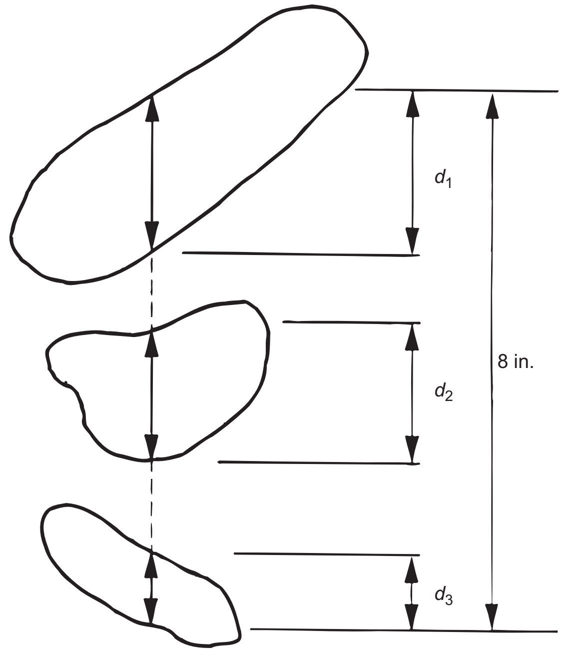


Figure 4.2—Pit Measurement

4.3.3.1 The minimum acceptable shell plate thickness for continued service shall be determined by one or more of the methods noted herein. These methods are limited to tanks with diameters equal to 200 ft or less.

a) When determining the minimum acceptable thickness for an entire shell course, t_{min} is calculated as follows:

$$t_{\min} = \frac{2.6\ (H-1)DG}{SE}$$

b) When determining the minimum acceptable thickness for any other portions of a shell course (such as a locally thinned area or any other location of interest), t_{min} is calculated as follows:

$$t_{\min} = \frac{2.6\ HDG}{SE}$$

where

t_{min} is the minimum acceptable thickness, in inches for each course as calculated from the above equation; however, t_{min} shall not be less than 0.1 in. for any tank course;

D is the nominal diameter of tank, in feet (ft);

H is the height from the bottom of the shell course under consideration to the maximum liquid level when evaluating an entire shell course, in feet (ft); or

is the height from the bottom of the length L (see 4.3.2.1) from the lowest point of the bottom of L of the locally thinned area to the maximum liquid level, in feet (ft); or

is the height from the lowest point within any location of interest to the maximum liquid level, in feet (ft);

G is the highest specific gravity of the contents;

S is the maximum allowable stress in pound force per square inch (lbf/in.^{2}); use the smaller of 0.80Y or 0.429T for bottom and second course; use the smaller of 0.88Y or 0.472T for all other courses. Allowable shell stresses are shown Table 4.1 for materials listed in the current and previous editions of API 12C and API 650;

NOTE for reconstructed tanks, S shall be in accordance with the current applicable standard;

Y is the specified minimum yield strength of the plate; use 30,000 lbf/in.^{2} if not known;

T is the smaller of the specified minimum tensile strength of the plate or 80,000 lbf/in.^{2}; use 55,000 lbf/in.^{2} if not known;

E is the original joint efficiency for the tank. Use Table 4.2 if original E is unknown. E = 1.0 when evaluating the retirement thickness in a corroded plate, when away from welds or joints by at least the greater of 1 in. or twice the plate thickness.

4.3.3.2 If the tank will be hydrostatically tested, the hydrostatic test height, H_t, shall be limited by one or more of the following methods. The tank shall not be filled above the level determined by the lesser value of H_t determined below.

a) After determining the controlling thickness of an entire shell course, H_t calculated as follows:

$$H_t = \frac{S_t E t_{\min}}{2.6D} + 1$$

b) After determining the controlling thickness by 4.3.2.1 for a locally thinned area, or at any other location of interest within a shell course, H_t is calculated as follows:

$$H_t = \frac{S_t E t_{\min}}{2.6D}$$

where

H_t is the height from the bottom of the shell course under consideration to the hydrostatic test height when evaluating an entire shell course in feet; or

is the height from the bottom of the length, L, (see 4.3.2.1) for the most severely thinned area in each shell course to the hydrostatic test height in feet; or

is the height from the lowest point within any other location of interest to the hydrostatic test height in feet;

S_t is the maximum allowable hydrostatic test stress in pound force per square inch (lbf/in.^{2}); use the smaller of 0.88Y or 0.472T for bottom and second courses; use the smaller of 0.9Y or 0.519T for all other courses.

NOTE 1 Depending on the specific gravity of the content used to determine $t_{\min}$, H_t may be less than H. Testing the tank to H may yield the corroded area.

19 NOTE 2 If H_t is less than H, owner/operator shall determine the consequence and acceptability of operating the tank to H, its maximum design liquid level. Repairs to shell sections above H_t shall comply with the requirements of 12.3.3.

NOTE 3 For reconstructed tanks, S_t shall be per the current applicable standard.

4.3.3.3 Alternatively, the minimum acceptable shell plate thickness for tanks with diameters equal to or less than 200 ft may be calculated in accordance with the variable design point method in API 650, 5.6.4, substituting "$S \times E$" for "S"; E and S may be defined as in 4.3.3.1.

4.3.3.4 The variable design point method shall be used for tanks greater than 200 ft in diameter, with all variables defined as in 4.3.3.1.

Table 4.1—Maximum Allowable Shell Stresses (Not for Use for Reconstructed Tanks, See General Note) 18

			Allowable Product Stress, S (lbf/in.^{2}) (Note 6)		Allowable Hydrostatic Test Stress, S_t (lbf/in.^{2}) (Note 6)	
Material Specification and Grade	Minimum Specified Yield Stress, Y (lbf/in.^{2})	Minimum Specified Tensile Strength, T (lbf/in.^{2})	Lower Two Courses	Upper Courses	Lower Two Courses	Upper Courses
ASTM Specifications						
A 283-C	30,000	55,000	23,600	26,000	26,000	27,000
A285-C	30,000	55,000	23,600	26,000	26,000	27,000
A36	36,000	58,000	24,900	27,400	27,400	30,100
A131-A, B, CS	34,000	58,000	24,900	27,400	27,400	30,100
A131-EH 36	51,000	71,000	30,500	33,500	33,500	36,800
A573-58	32,000	58,000	24,900	27,400	27,400	28,800
A573-65	35,000	65,000	27,900	30,700	30,700	31,500
A573-70	42,000	70,000	30,000	33,000	33,000	36,300
A516-55	30,000	55,000	23,600	26,000	26,000	27,000
A516-60	32,000	60,000	25,600	28,200	28,200	28,800
A516-65	35,000	65,000	27,900	30,700	30,700	31,500
A516-70	38,000	70,000	30,000	33,000	33,000	34,200
A662-B	40,000	65,000	27,900	30,700	30,700	33,700
A662-C	43,000	70,000	30,000	33,000	33,000	36,300
A537-Class 1	50,000	70,000	30,000	33,000	33,000	36,300
A537-Class 2	60,000	80,000	34,300	37,800	37,800	41,500
A633-C, D	50,000	70,000	30,000	33,000	33,000	36,300
A678-A	50,000	70,000	30,000	33,000	33,000	36,300
A678-B	60,000	80,000	34,300	37,800	37,800	41,500
A737-B	50,000	70,000	30,000	33,000	33,000	36,300
A841	50,000	70,000	30,000	33,000	33,000	36,300
A10 (Note 1)	30,000	55,000	23,600	26,000	26,000	27,000
A7 (Note 1)	33,000	60,000	25,700	28,300	28,300	29,700
A442-55 (Note 1)	30,000	55,000	23,600	26,000	26,000	27,000
A442-60 (Note 1)	32,000	60,000	25,600	28,200	28,200	28,800
CSA Specifications						
G40.21, 38W	38,000	60,000	25,700	28,300	28,300	31,100
G40.21, 44W (Note 7)	44,000	65,000	27,900	30,700	30,700	33,700
18 G40.21, 44W (Note 8)	44,000	64,000	27,400	30,200	30,700	33,200
G40.21, 50W	50,000	65,000	27,900	30,700	30,700	33,700
G40.21, 50WT (Note 7)	50,000	70,000	30,000	33,000	33,000	36,300
G.40.21, 50WT (Note 8)	50,000	65,000	27,900	30,700	30,700	33,700
Unknown Material Specification and Grade						
Unknown (Note 2)	30,000	55,000	23,600	26,000	26,000	27,000
Riveted Tanks:						
A7, A9 or A10 (Note 1, Note 3)	NA	NA	21,000	21,000	21,000	21,000
Known (Note 4)	Y	T	Note 4	Note 4	Note 4	Note 4
Unknown (Note 5)	NA	NA	21,000	21,000	21,000	21,000

GENERAL NOTE Allowable stresses for reconstructed tanks are tabulated in API 650, Table 5.2a or 5.2b, or calculated per 8.4.

NOTE 1 ASTM A7, ASTM A9, ASTM A10 and ASTM A442 are obsolete ASTM material specifications previously listed in API 12C and API 650.

NOTE 2 The yield stress and tensile strength values shown are per API 653 for welded ASTM material of unknown origin.

NOTE 3 This provision is for riveted tanks, constructed of any grade of material, evaluated per 4.3.4.1.

NOTE 4 This provision is for riveted tanks, constructed of known grades of material, evaluated per 4.3.4.2. For all courses, the maximum allowable shell stress for both product and hydrostatic test conditions are listed under column for allowable product stress, S.

NOTE 5 This provision is for riveted tanks, constructed of unknown grades of material, evaluated per 4.3.4.2.

NOTE 6 The allowable stresses are calculated per 4.3.3.1 and 4.3.3.2 of this standard, unless otherwise noted. The calculated allowable stresses are rounded to the nearest 100 lbf/in.^{2}.

18 NOTE 7 These stress values are valid for CSA G40.21-04 and earlier materials.

NOTE 8 These stress values are valid for CSA G40.21-13 materials.

Table 4.2—Joint Efficiencies for Welded Joints

Standard	Edition and Year	Type of Joint	Joint Efficiency E	Applicability or Limits
API 650	Seventh and Later (1980 to Present)	Butt	1.00	Basic Standard
		Butt	0.85	Annex A Spot RT
		Butt	0.70	Annex A No RT
	First to Sixth (1961 to 1978)	Butt	0.85	Basic Standard
19		Butt	1.00	Annexes D or G
API 12C	14th and 15th (1957 to 1958)	Butt	0.85	
	3rd to 13th (1940 to 1956)	Lap [a]	0.75	3/8 in. max. t
		Butt [c]	0.85	
	First and Second (1936 to 1939)	Lap [a]	0.70	7/16 in. max. t
		Lap [b]	$0.50 + k/5$	1/4 in. max. t
		Butt [c]	0.85	
Unknown		Lap [a]	0.70	7/16 in. max. t
		Lap [b]	$0.50 + k/5$	1/4 in. max. t
		Butt	0.70	
		Lap [d]	0.35	

19 [a] Full double lap-welded.

[b] Full fillet weld with at least 25 % intermittent full fillet opposite side; k = percent of intermittent weld expressed in decimal form.

[c] Single butt-welded joints with a back-up bar were permitted from the years of 1936 to 1940 and 1948 to 1954.

19 [d] Single lap-welded only.

4.3.3.5 The thickness determinations of 4.3.3.1, 4.3.3.2, and 4.3.3.3 consider liquid loading only. All other loads shall also be evaluated according to the original standard of construction; and engineering judgment shall be used to evaluate different conditions or new information. As applicable, the following loadings shall be taken into account:

a) wind-induced buckling;

b) seismic loads;

c) operation at temperatures over 200 °F;

d) vacuum-induced external pressure;

e) external loads caused by piping, tank-mounted equipment, hold down lugs, etc.;

f) wind-induced overturning;

g) loads due to settlement.

4.3.3.6 As an alternative to the procedures described above, any thinning of the tank shell below minimum required wall thickness due to corrosion or other wastage may be evaluated to determine the adequacy for continued service by employing the design by analysis methods defined in Section VIII, Division 2, Appendix 4 of the ASME Code; or API 579-1/ASME FFS-1, Section 4, Section 5, or Section 6, as applicable. When using the ASME criteria, the stress value used in the original tank design shall be substituted for the S_m value of Division 2, if the design stress is less than or equal to the lesser of $^2/_3Y$ (specified minimum yield strength) or $^1/_3T$ (specified minimum tensile strength). If the original design stress is greater than $^2/_3Y$ or $^1/_3T$, then the lesser of $^2/_3Y$ or $^1/_3T$ shall be substituted for S_m.

4.3.4 Minimum Thickness Calculation for Riveted Tank Shell

4.3.4.1 The minimum acceptable thickness for riveted tank shells shall be calculated using the equation in 4.3.3.1 except that the following allowable stress criteria and joint efficiencies shall be used:

S is 21,000 lbf/in.^{2};

E is 1.0 for shell plate 6 in. or more away from rivets. See Table 4.3 for joint efficiencies for locations within 6 in. of rivets.

4.3.4.2 The rivet joint efficiencies given in Table 4.3 are conservative minimums for riveted tank construction details and are included to simplify riveted tank evaluations. However, in some cases it may be advantageous to calculate the actual rivet joint efficiencies using computational methods applicable to lap and butt type riveted joints. When this alternative of calculated joint efficiencies is used, the following maximum allowable stresses shall apply:

a) for the maximum tensile stress in net section of plate, use the lesser of $0.80Y$ or $0.429T$; use 21,000 lbf/in.^{2} if T or Y is unknown;

b) for the maximum shear in net section of rivet, use 16,000 lbf/in.^{2};

c) for the maximum bearing stress on plates or rivets, use 32,000 lbf/in.^{2} for rivets in single shear, and 35,000 lbf/in.^{2} for rivets in double shear.

4.3.4.3 For tanks with riveted joints, consideration shall be given to whether, and to what extent, corrosion affects such joints. If calculations show that excess thickness exists, this excess may be taken as corrosion allowance.

4.3.4.4 Non-liquid loads (see 4.3.3.5) shall also be considered in the analysis of riveted tanks.

Table 4.3—Joint Efficiencies for Riveted Joints

Type of Joint	Number of Rivet Rows	Joint Efficiency E
Lap	1	0.45
Lap	2	0.60
Lap	3	0.70
Lap	4	0.75
Butt [a]	2 [b]	0.75
Butt	3 [b]	0.85
Butt	4 [b]	0.90
Butt	5 [b]	0.91
Butt	6 [b]	0.92

[a] All butt joints listed have butt straps both inside and outside.
[b] Number of row on each side of joint center line.

4.3.5 Distortions

18 **4.3.5.1** Shell distortions include out-of-roundness, buckled areas, flat spots, dents, and peaking and banding at welded joints.

4.3.5.2 Shell distortions can be caused by many conditions such as foundation settlement, over- or under-pressuring, high wind, poor shell fabrication, or repair techniques, and so forth.

4.3.5.3 Shell distortions shall be evaluated on an individual basis to determine if specific conditions are considered acceptable for continuing tank service and/or the extent of corrective action.

4.3.6 Flaws

Flaws such as cracks or laminations shall be thoroughly examined and evaluated to determine their nature and extent and need for repair. If a repair is needed, a repair procedure shall be developed and implemented. The requirement for repairing scars such as arc strikes, gouges, or tears from temporary attachment welds must be evaluated on a case-by-case basis. Cracks in the shell-to-bottom weld shall be removed.

4.3.7 Wind Girders and Shell Stiffeners

The evaluation of an existing tank shell for suitability for service must also consider the details and condition of any wind girders or shell stiffeners. Degradation by corrosion of these structural elements or their attachment welds to the shell may render these elements inadequate for the design conditions.

4.3.8 Shell Welds

The condition of the tank shell welds shall be evaluated for suitability for service using criteria from this standard, the as-built standard, or fitness-for-service assessment. Typical shell weld conditions are listed below with their
19 required evaluation and/or repair actions. Repair procedures are given in 9.7.

4.3.8.1 Cracks shall be removed. Removal areas shall be evaluated and repaired if necessary.

4.3.8.2 Excessive weld reinforcement does not require rework if the tank has a satisfactory history of service. If the
18 reinforcement will interfere with floating roof seal operation, it shall be ground as required.

4.3.8.3 Undercut of shell butt welds resulting from original construction shall not require repair if the tank has been hydrotested or will not undergo a change of service.

4.3.8.4 Weld corrosion shall be repaired if the corrosion pit cavity bottom is below the surface of the adjacent shell plate.

18 **4.3.8.5** Shell-to-bottom weld corrosion shall be repaired if the remaining fillet is less than the required weld size.

4.3.8.6 Fillet weld size on existing nozzles shall be evaluated according to the original standard of construction.

4.3.8.7 Surface defects, such as arc strikes, shall be acceptable if the tank has been hydrotested or will not undergo
18 a change of service.

4.3.9 Shell Penetrations

4.3.9.1 The condition and details of existing shell penetrations (nozzles, manways, cleanout openings, etc.) shall be
18 reviewed when assessing the integrity of an existing tank shell. Details, such as type and extent of reinforcement, weld spacing, and thickness of components (reinforcing plate, nozzle neck, bolting flange, and cover plate), are important considerations and shall be reviewed for structural adequacy and compliance with the as-built standard.
19 Existing welds on the tank shell that are not to be modified or affected by repairs and are closer than the minimum