Manual of Petroleum Measurement Standards Chapter 2.2A

Measurement and Calibration of Upright Cylindrical Tanks by the Manual Tank Strapping Method

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Measurement and Calibration of Upright Cylindrical Tanks by the Manual Tank Strapping Method

1 Scope

1.1 This standard describes the procedures for calibrating upright cylindrical tanks used primarily for the storage of petroleum liquids. It first addresses procedures for making necessary measurements to determine total and incremental tank volumes and then presents the recommended procedures for computing volumes.

1.2 Both SI (metric) and U.S. customary (USC) units are presented where appropriate in the document. SI and USC conversions may not necessarily be exact. The SI units often reflect what is available in commercial equipment.

1.3 The standard also provides guidelines for recalibration and for computerization of capacity tables.

2 Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any addenda) applies.

API *Manual of Petroleum Measurement Standards* (*MPMS)* Chapter 2.2B, *Calibration of Upright Cylindrical Tanks Using the Optical Reference Line Method*

API Standard 650, *Welded Steel Tanks for Oil Storage*

API Standard 653, *Tank Inspection, Repair, Alteration, and Reconstruction*

API Standard 2555, *Method for Liquid Calibration of Tanks*

ICS [1]/OCIMF [2]/IAPH [3], *International Safety Guide for Oil Tankers and Terminals (ISGOTT)* [4]

IP [5] *Petroleum Measurement Manual*, Part 2, "Tank Calibration," Section 1, "Vertical Cylindrical Tanks, Measurement Methods"

NFPA 306 [6], *Standard for the Control of Gas Hazards on Vessels*

3 Safety

3.1 Before entering any tank, permission shall be obtained from the terminal supervisor, authorized official, or other responsible person in charge. This responsible person should supply information regarding particular materials and conditions or the applicable Material Safety Data Sheet (MSDS).

3.2 Due consideration should be given to applicable safety procedures. Safety considerations include, but are not limited to, potential electrostatic hazards, potential personnel exposure (and associated protective

[1] International Chamber of Shipping, 38 St Mary Axe Street, London EC3A 8BH, United Kingdom, www.ics-shipping.org.
[2] Oil Companies International Marine Forum, 27 Queen Anne's Gate, London, SW1H 9BU, United Kingdom, www.ocimf.com.
[3] International Association of Ports and Harbors, 7th Floor, South Tower New Pier Takeshiba 1-16-1 Kaigan, Minato-ku, Tokyo 105-0022, www.iaphworldports.org.
[4] *ISGOTT* is available from Witherby Publishing Group Ltd. (Marine Publishing), 32/36 Aylesbury Street, London ECIR OET, United Kingdom.
[5] Institute of Petroleum, 61 New Cavendish Street, London W1M 7AR, United Kingdom, www.energyinst.org.uk.
[6] National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02169-7471, www.nfpa.org.

clothing and equipment requirements), and potential explosive and toxic hazards associated with a storage tank's atmosphere. The physical characteristics of the product and existing operational conditions should be evaluated, and applicable international, federal, state, and local regulations should be observed.

3.3 In addition, before entering a storage tank, safety procedures designated by the employer, the terminal operator, and all other concerned parties should also be observed. It shall be indicated that the tank is "Safe for Workers" and/or "Safe for Hot Work," as prescribed in NFPA 306, U.S. Coast Guard, OSHA, or other international, federal, state, or local regulations that may apply. Such testing shall be made at least every 24 hours or more frequently when conditions warrant.

3.4 Internationally, the *International Safety Guide for Oil Tankers and Terminals (ISGOTT)* should be consulted.

3.5 Furthermore, another person should stand watch at the tank entrance for the duration and sound an alarm if an emergency occurs. Appropriate protective clothing and equipment should be used. Normal safety precautions with respect to staging and ladders shall also be observed.

4 Terms and Definitions

For the purposes of this document, the following definitions apply.

4.1
capacity table
tank capacity table
Shows the capacities of or volumes in a tank for various liquid levels measured from the reference gauge point.

4.2
continuous wraparound procedure
The measurement of a tank circumference with a tape that is long enough to span the entire circumference of a tank.

4.3
deadwood
Refers to any object within the tank, including a floating roof, that displaces liquid and reduces the capacity of the tank; also any permanent appurtenances on the outside of the tank, such as cleanout boxes or manholes, that increase the capacity of the tank.

4.4
false bottom
Commonly referring to a new bottom installed on top of the previous tank bottom, which will reduce the bottom ring height and the effective inside tank height.

4.5
master tape
A tape that is used for calibrating working tapes for tank measurement and is identified with a Report of Calibration at 68 °F (20 °C) and at a specific tension designated by the National Institute of Standards and Technology (NIST) or an equivalent international standard organization.

4.6
reference gauge height
The vertical distance between the reference point on the gauge hatch and the striking point on the tank floor or on the gauge datum plate.

4.7
successive tangent method
The measurement of a circumference on a tank when the tape is not long enough to span the entire circumference of a tank.

4.8
tank strapping
The term commonly applied to the procedure for measuring tanks to provide the dimensions necessary for computing capacity tables that will reflect the quantity of product in a tank at any given depth/level.

5 Significance

5.1 Accurate tank circumference measurements are critical in determinations of liquid volume and the development of capacity table for custody transfer transactions and inventory control. This standard provides measurement and computational procedures for the development of such a capacity table.

5.2 All such measurements should be witnessed by all parties involved to ensure compliance with the procedure outlined in the standard and overall measurement integrity.

6 Equipment

6.1 General

The equipment used in dimensional tank calibration is described in 6.2 through 6.4. All equipment shall be in good working condition. All tapes shall be in one piece and free of kinks.

6.2 Tapes for Height Measurement

For height measurements, a steel tape (see Figure 1) of convenient length, $^3/_8$ in. or $^1/_2$ in. wide and 0.008 in. to 0.012 in. thick, graduated in feet and inches to eighths of an inch, or in feet, tenths, and hundredths of a foot is recommended. (For metric tapes, refer to IP's *Petroleum Measurement Manual,* Part 2, Section 1.) Graduations shall be accurate within $^1/_6$ in. or 0.005 ft (or to nearest millimeter) throughout that portion of the tape to be used.

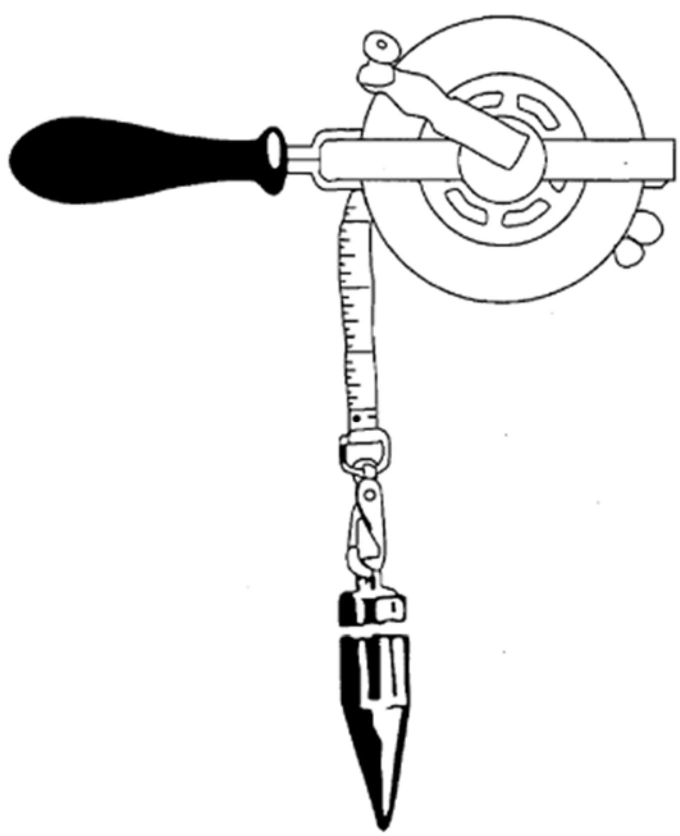


Figure 1—Height Measuring Tape and Bob

6.3 Tapes for Circumference Measurement

For circumference measurements, a mild steel tape, (see Figure 2) of convenient length relative to the tank circumference is recommended. The working tape is usually 100, 200, 300, or 500 ft long and should not be more than $^{1}/_{4}$ in. wide, and approximately 0.01 in. thick. The tape may be graduated in feet, with an extra 1 ft length at the zero end of the tape and graduated in tenths and hundredths of a foot, or it may be graduated in feet, tenths, and hundredths of a foot throughout its length (for metric tapes, refer to IP's *Petroleum Measurement Manual,* Part 2, Section 1). All working tapes should be calibrated with a master tape (refer to Section 7).

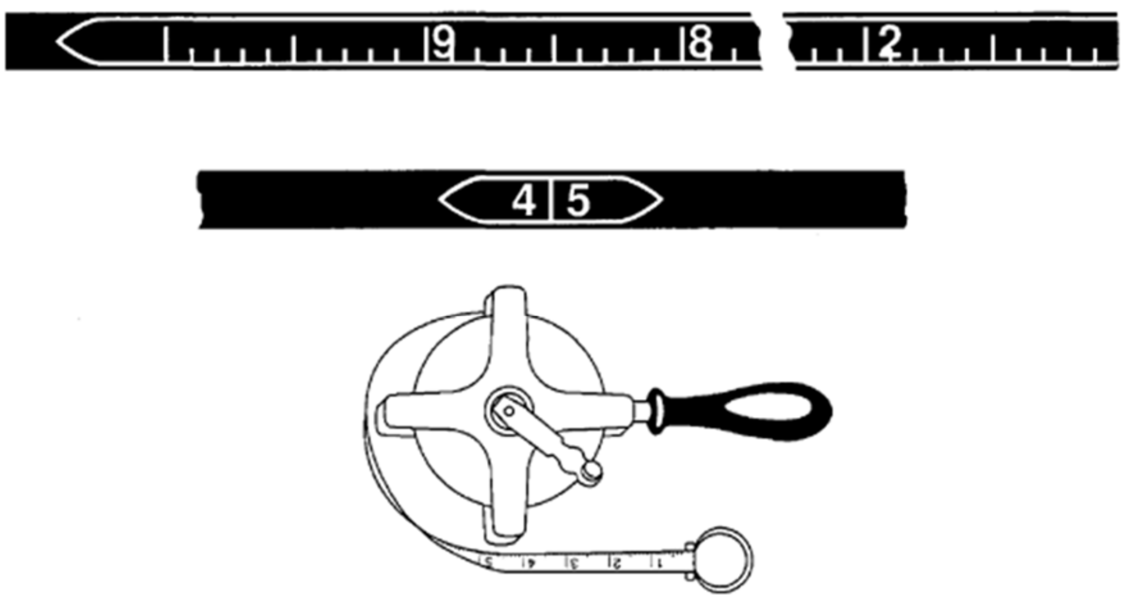


Figure 2—Strapping Tapes for Circumference Measurements

6.4 Accessory Equipment

Additional measuring equipment recommended is listed below. Other similar equipment may be used, provided it will give the same results.

a) Reels and tapes shall be equipped with appropriate reels and handles.

b) Tape clamps—For assurance of positive grip on tape, clamps shall be used.

c) A spring tension scale is needed.

d) Rope and ring—Two lengths of rope line fitted with snap and ring are to be used in raising and lowering circumference measurement tape. Alternatively, jointed-type pole guides may be used (see Figure 3).

e) Transit or level or both are used when required.

f) Ladders to facilitate handling of tapes and removal of scale, rust, dirt, etc. from the path of measurement are needed.

g) An ultrasonic thickness measurement device is used.

h) A plumb line is needed.

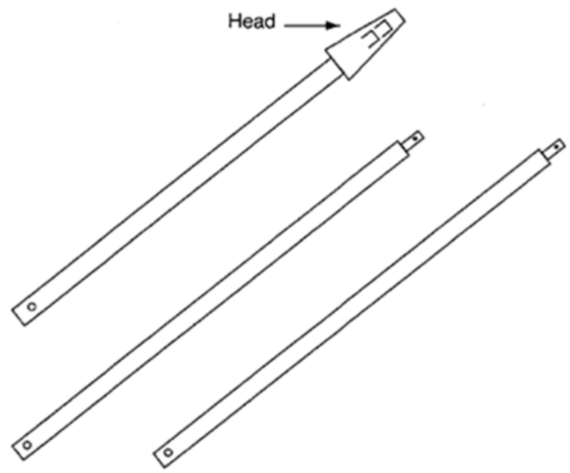


Figure 3—Jointed-type Tape Guides

i) Depth gauge—A depth gage of case-hardened steel, 6 in. in length, graduated to 1/64 in. (1 mm resolution and read to nearest 0.5 mm) is for determination of thickness of steel plates is needed.

j) Straightedge—A straightedge of appropriate length and a profile board for measuring knuckles are used.

k) Calipers and special clamps for spanning obstructions in making circumference measurements; the following are recommended:

   1) maximum expansion calipers of 6 in. (or 15 cm) for spanning the smaller obstructions, such as vertical flanges, bolt heads, etc.;

   2) maximum expansion calipers of 18 in. (45 cm) or 24 in. (61 cm) for spanning the larger obstructions, such as butt straps, etc.;

   3) special clamps may be substituted for calipers in measuring projecting flanges.

The following may be useful equipment: a 6-ft ruler for general measurements, shovel, spirit level, awl and scriber, marking crayon, record paper, and cleaning instruments, such as a putty knife and a hard bristle brush for eliminating dirt, grease, paint scale, rust particles, etc. from the path of circumference measurements.

7 Calibration of Working Tape with the Master Tape

7.1 The tape used for circumference measurements shall be calibrated (for required tension) by matching it against the master tape in the following manner.

a) Choose a convenient tape path (i.e. 20 % of ring height) on the lower ring, and place the master tape around the tank.

b) Using the successive tangent method, make a scribe mark on the shell, determining the origin of the circumference. Apply the tape, with constant application of tension at which the master tape was certified to be accurate, to the tank shell at the proper tape path with the tape's zero mark located exactly on the scribe mark designating the origin point. The tape is placed in position with required tension, and the last reading on the tape is scribed on the tank shell at each 100 ft (or 30 m) or fraction thereof. This measurement is written on the tank shell and recorded. This procedure is repeated until the entire circumference is measured.

c) Total the measurements obtained.

d) Place the working tape around the tank, using the same tape path, by the continuous “wraparound” procedure.

e) Slide the working tape to break frictional resistance, and apply tension sufficient to equal the measurement obtained with the master tape.

f) The amount of tension, in pounds, required to be pulled on the working tape to obtain the same measurement as that recorded with the master tape shall be applied to the working tape when taking circumferential measurements. If the tension determined to be proper for the working tape is insufficient to hold the tape in the proper position, additional tension should be applied and a correction made to bring the reading into agreement with that obtained with the master tape.

7.2 The preceding procedure shall be carried out when calibrating other tanks whose circumference differs by more than 20 % from the calibrated tape section and where tank surfaces are different.

7.3 Two working tape corrections are illustrated in the following examples [7]. Note that conditions 1 and 2 for application of working tape corrections apply for either case, that is, where the master tape and working tape are of equal or different lengths. The same procedure applies for metric measurements.

a) Condition No.1—If additional tension is required to be applied to the working tape to equal the measurement obtained by the master tape, then no mathematical correction is needed. The additional tension required to equal the master tape measurement shall be applied to all subsequent circumferences obtained with the working tape.

b) Condition No. 2—If the same or additional tension is applied to both the master tape and the working tape and the measurements do not agree, then a mathematical correction shall be applied as indicated in the examples below. The determined differences shall be applied to all working tape circumferences before the processing of the capacity table.

c) Examples

EXAMPLE 1

314.515 ft	Master tape at 10 lb tension per 100 ft or part thereof
314.475 ft	Working tape at 20 lb tension
0.040 ft	Correction for working tape to be *added* to each circumference measured

EXAMPLE 2

314.515 ft	Master tape at 10 lb tension per 100 ft or part thereof
314.590 ft	Working tape at 20 lb tension
0.075 ft	Correction for working tape to be *subtracted* from each circumference measured

7 The following examples are merely examples for illustration purposes only. They are not to be considered exclusive or exhaustive in nature. API makes no warranties, express or implied for reliance on or any omissions from the information contained in this document.

8 General Practices

All measurements and descriptive data taken at the tank site should be checked and immediately, legibly recorded with the recording preferably assigned to a single individual, as follows.

a) All measurements should be taken without disruption and preferably on the same day of calibration with the liquid level remaining static. If measurements have to be disrupted, interrupted tank measurement work may be continued at a later date, without repeating the work previously completed, provided all records of the work are complete and legible. Movement of liquid into or out of the tank may be tolerated, provided a clearly marked liquid gauge and average temperatures of both liquid and outside atmosphere are included as parts of these subsequent strapping operations.

b) All data and procedures necessary for the preparation of capacity tables should be supported by sound engineering principles.

c) Each tank shall be identified clearly and legibly by number or by some other suitable marking, but this identification should not be painted on tank attachments.

9 Tank Status Before Calibration

9.1 Before calibration, the tank shall have been filled at least once at its present location with liquid at least as dense as is expected to contain. The hydrostatic test (for a period of approximately 24 hours) will usually satisfy this requirement. Any hydrostatic test should be performed in accordance with applicable construction and operating standards (API 650 and API 653). When possible, the liquid in the tank should be allowed to stand still for approximately 24 hours before calibration is performed.

9.2 Tanks with a nominal capacity of 500 bbl or less may be strapped at any condition of fill, provided the tanks have been filled at least once at their present location. Small movements of oil into or out of such tanks are allowed during strapping.

9.3 Tanks with a nominal capacity of more than 500 bbl should be handled as follows.

a) Bolted tanks (usually in production service) shall have been filled at least once at their present location and shall be at least two-thirds full when strapped. Small movements of oil into or out of such tanks are allowed during strapping.

b) Riveted tanks and/or welded tanks shall have been filled at least once at their present location. They may be strapped at any condition of fill and the full capacity computed as shown in 19.6. No movement of oil into or out of such tanks is allowed during the strapping operation.

10 Descriptive Data

10.1 Complete descriptive data should be entered on the Tank Measurements Record Form being used. Suggested record forms are shown in Figure 4 and Tables 1 and 2.

10.2 The API Gravity and the temperature of the tank's contents at the time of strapping shall be obtained and recorded. The average API Gravity, average overall ambient temperature at which the tank shall operate and maximum safe fill height (refer to 13.5) shall be obtained from the tank owner and recorded.

TANK NO.

FROM	TO	PIECES	DESCRIPTION
H_1	H_2	1	NOZZLE

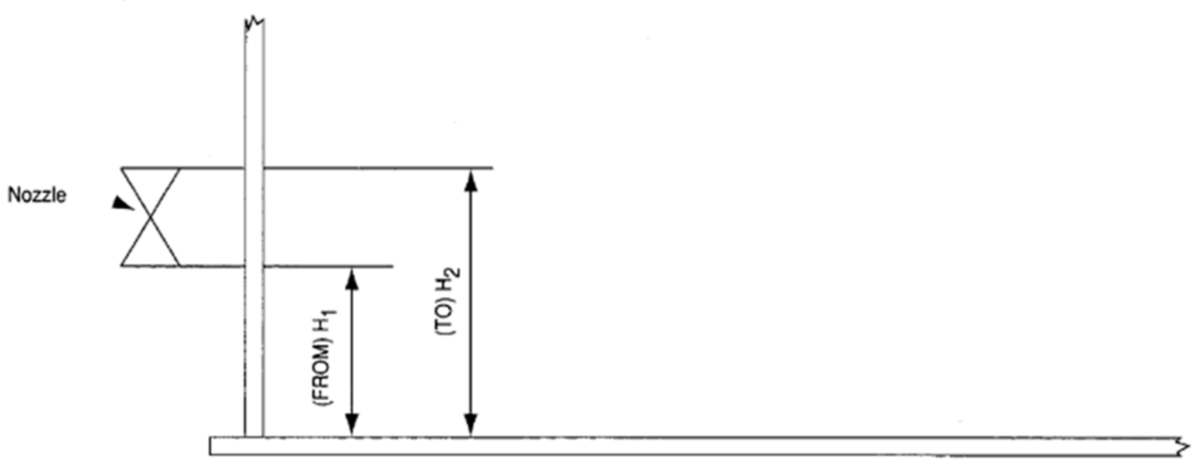


Figure 4—Record Form for Deadwood

Table 1—Suggested Record Form "A" for Measurements of Upright Cylindrical Tanks

Report No.:. . . . .
Date:. . . . .

Tank No:. . . . .
(Old Tank No.):. . . . .
Owner's Name: . . . .
Plant or Property Name:. . . . .
Location: . . . .
Manufactured by:. . . . .
Erected by:. . . . .
Prepare: . . . . .Copies:. . . . . Increments in.: . . . . .Fractions to: . . . .
Table Form or Size Desired: . . . .
Height: Shell: . . . . .Gauging: . . . .
Type of Roof:. . . . . .Weight of Floating Roof: . . . .
Tank Contents—Name:. . . . . .Avg. Liquid Temp., °F: . . . .
Gauge:. . . . . .ft. . . . . in.; Innage to: Shell Floor or Outage
Hydrometer Reading:. . . . . .at . . . . °F Sample Temperature
Gauging Reference Point to Top of Top Angle:. . . . . . ft. . . . . .in.; Normal Service. . . . .
Shell Circumferences:

A.	D	G . . . .
B.	E	H . . . .
C.	F	J. . . . .

Descriptions of Shell Plates and Joints [a]

	Ring No.	Thickness	Type of Vertical Joint	Set, in or out	Width of Lap or Strap	Thickness of Lap or Strap	No. of Joints	Inside Ring Height
	7	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .
	6	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .
	5	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .
	4	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .
	3	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .
	2	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .
(Btm. Ring)	1	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .

Shell Connections: [b]

No.	Description	Elevation—Top of Floor to Bottom of Connection
1	. . . .	. . . .
2	. . . .	. . . .
3	. . . .	. . . .
4	. . . .	. . . .
5	. . . .	. . . .
6	. . . .	. . . .

Amount of Tank Lean from Vertical: [c] . . . . . in. . . . . in . . . . ft. . . . . in.
Circumference Tape Used: . . . . Date Chk'd . . . . at . . . .
Tank Measured by: . . . . for . . . .
Deadwood and Tank Bottom—Use separate sheets. For each piece or item of deadwood record description, size, number of occurrences, and location related to other height measurement data recorded.
Explanatory Notes (such as type of bottom, height or depth of crown, etc.)
. . . .
. . . .

Note: No. = Number; Avg. Liquid Temp. = Average Liquid Temperature; ft. = foot/feet; in. = inch(es)
[a]Show sketches of vertical and horizontal joints on back of this Table.
[b]Show circumferential location on plan view sketched on back of this Table.
[c]Show direction of lean on plan view sketched on back of this Table.

Table 2—Suggested Record Form "B" for Measurements of Upright Cylindrical Tanks

Report No.: ....
Date: ....

Tank No: ....
(Old Tank No.): ....
Owner's Name: ....
Plant or Property Name: ....
Location: ....
Manufactured by: ....
Erected by:...
Prepare: .... Copies: .... Increments in :......... Fractions to:
Table Form or Size Desired:...
Height: Shell :....... .... Gauging:..
Type of Roof: .... Weight of Floating Roof: ....
Tank Contents—Name: .... Avg. Liquid Temp., °F: ....
Gauge: .... ft. .... in.; Tank Service: ....API Gravity:
Hydrometer Reading: .... at .... °F Sample Temperature

Shell Circumferences:

A. .... D .... G ....
B. .... E .... H ....
C. .... F .... J ....

Descriptions of Shell Plates and Joints:

	Ring No.	Thickness	Type of Vertical Joint	Set, in or out	Width of Lap or Strap	Thickness of Lap or Strap	No. of Joints	Inside Ring Height
	7	....	....	....	....	....	....	....
	6	....	....	....	....	....	....	....
	5	....	....	....	....	....	....	....
	4	....	....	....	....	....	....	....
	3	....	....	....	....	....	....	....
	2	....	....	....	....	....	....	....
(Btm. Ring)	1	....	....	....	....	....	....	....

Deadwood and Remarks (use reverse side if necessary):

Deadwood Description	No.	Size	Elevation From	Elevation To
....	....	....	....	....
....	....	....	....	....
....	....	....	....	....
....	....	....	....	....

Type of Bottom:........................ Height of Crown:.................................
Witness:............................. Measurements by; ....

Note: Avg. Liquid Temp.=Average Liquid Temperature; °F=degrees Fahrenheit.: in.=inches; ft=foot; Btm = Bottom

10.3 Supplemental sketches or notations, each completely identified, dated, and signed, should accompany the strapping report. These should indicate the following.

a) Typical horizontal and vertical joints.

b) Number of plates per ring.

c) Location of rings at which thickness of plates change arrangement.

d) Size of angles at top and bottom of shell.

e) Location and size of pipes and manways.

f) Dents and bulges in shell plates.

g) Amount of lean from vertical in relation to the reference gauge point.

h) Procedure used in bypassing a large obstruction, such as a cleanout box or insulation box located in the path of a circumferential measurement.

i) Location of tape path different from that shown in Figures 5 through 7.

j) Location and elevation of a possible datum plate.

k) All other items of interest and value that will be encountered.

10.4 Entries of data on a tank measurements record form or supplemental data sheets should not be erased. If alteration is necessary, the entry to be changed should be marked out with a single line and the new data recorded adjacent to the old entry.

11 Tolerances

11.1 Single circumferential measurements should be read and recorded to the nearest 0.005 ft (or nearest millimeter), which is equal to one-half of the distance between two adjacent hundredth-foot division marks on the tape. Therefore, all circumferential measurements should be recorded through the third decimal place.

11.2 Vertical tank measurements should be read and recorded to the nearest $^{1}/_{6}$ in. (or nearest 1 mm).

11.3 Thermometers should be read to the nearest 1 °F (or 0.5 °C).

11.4 Tank plate thicknesses should be determined to the nearest $^{1}/_{64}$ in. (1-mm resolution and read to nearest 0.5 mm).

11.5 Deadwood should be determined and located by measurement readings to the nearest $^{1}/_{8}$ in. (or 3 mm).

12 Shell Plate Thickness

12.1 Plate thickness should be measured by ultrasonic measurement device as the preferred method. A minimum of two measurements per ring should be obtained.

12.2 Plate thickness measurements obtained before or during construction and recorded on a properly identified strapping record may be accepted. In the absence of any direct measurements of plate thickness obtained and recorded before or during construction, the least preferred method is to use the plate thickness shown on the fabricator's drawings and so identified in the calculation records or information provided by tank owner.

12.3 The alternate method of measuring plate thickness is by depth gauge. Where the type of construction leaves the plate edges exposed, a minimum of two thickness measurements should be made on each ring. The arithmetical average of the measurements for each ring should be recorded; all thickness measurements, properly identified, should be noted on a supplemental data sheet that should form a part of the measurement record. Care should be taken to avoid plate thickness measurements at locations where edges have been distorted by caulking.

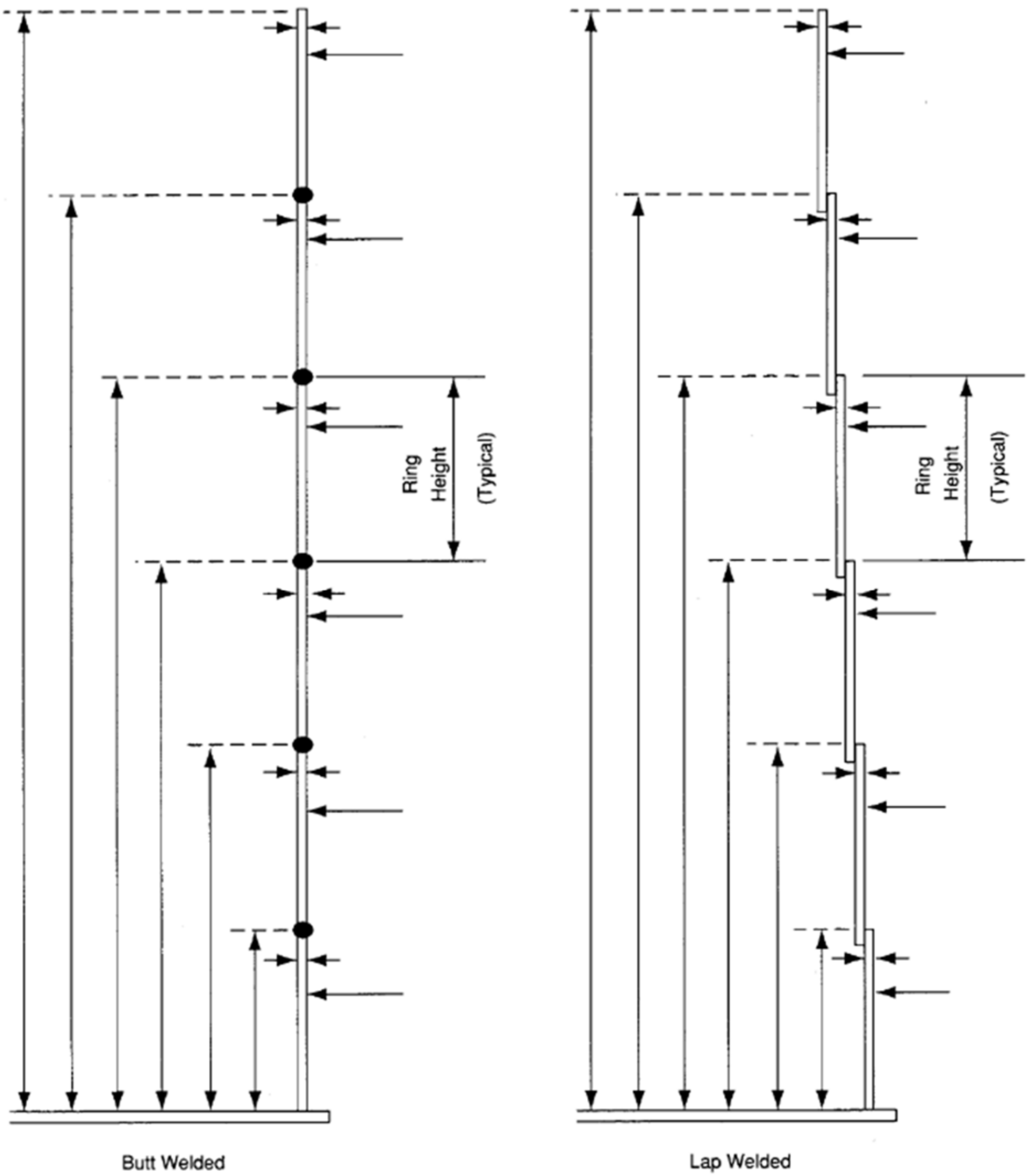


Figure 5—Measurement Locations for Welded Upright Tanks

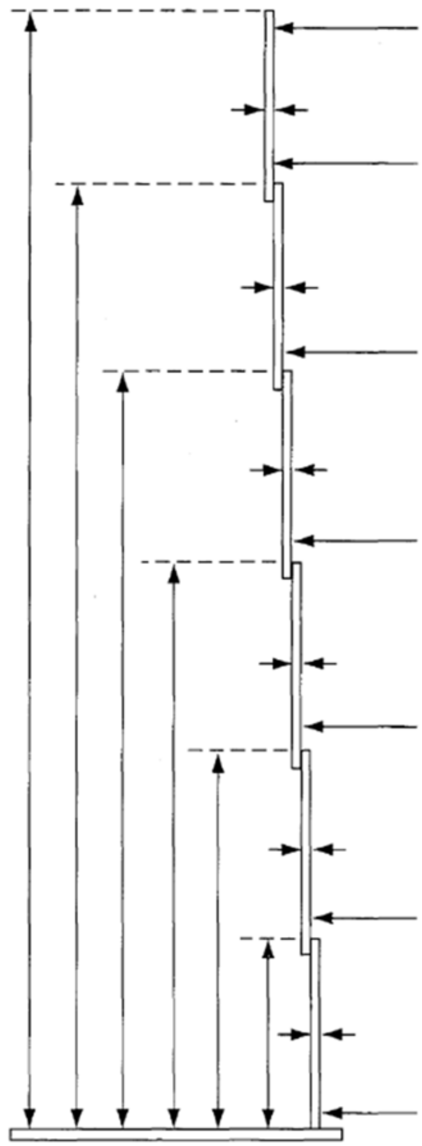


Figure 6—Measurement Locations for Riveted Shingled Arrangement

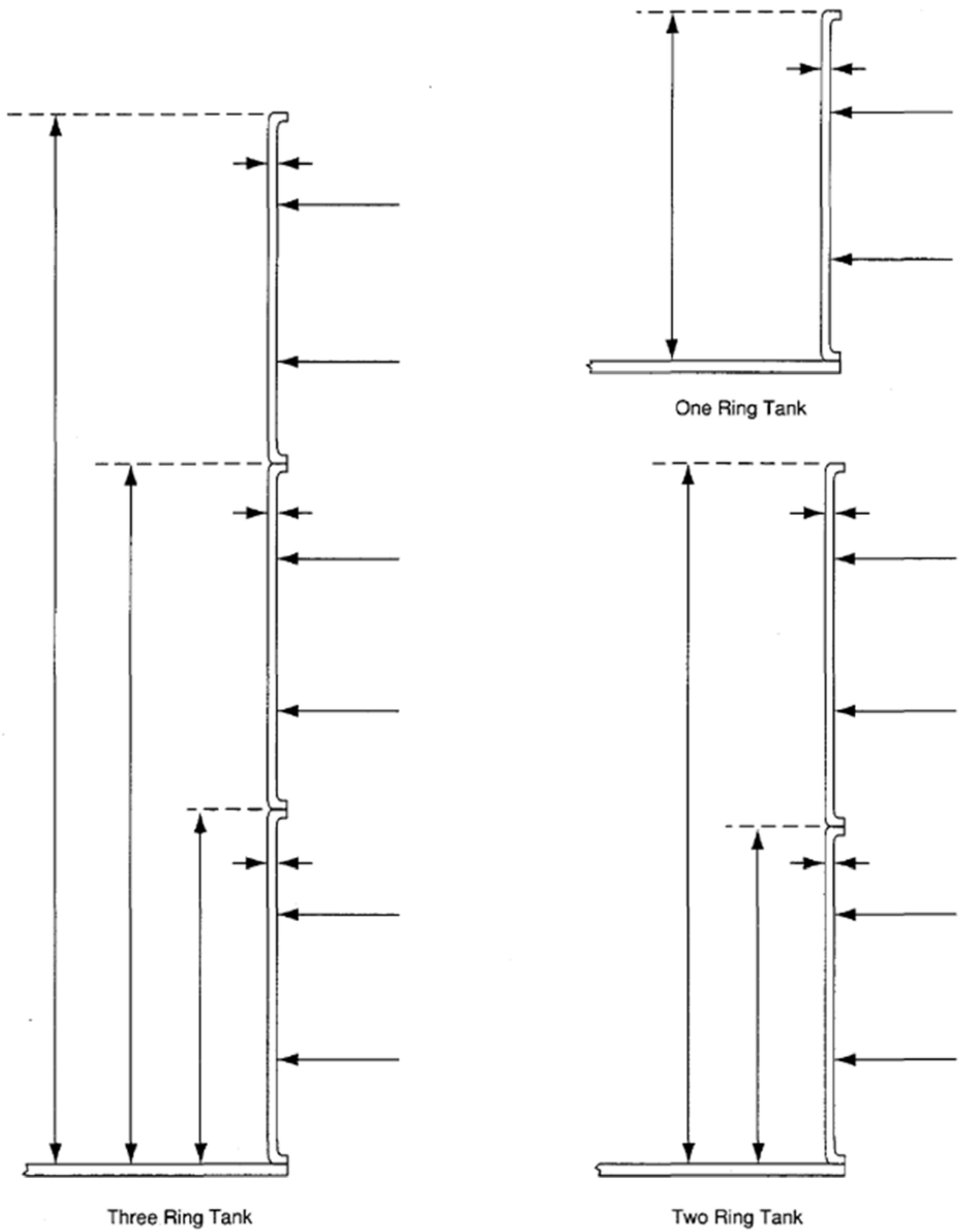


Figure 7—Measurement Locations for Bolted Tanks

13 Vertical Tank Measurements

13.1 Shell height is the vertical distance between bottom of bottom angle (or top of floor plate) and top of top angle and should be measured at a point near the reference gauge hatch (see Figures 8, 9, and 10).

13.1.1 Additional measurements should be made, as required, at other identified points sufficient to investigate and describe known or suspected conditions in the tank, such as tilt or false bottom. Locations of measurements should be marked on a supplemental sketch.

13.1.2 The amount of tilt in shell height should be measured and recorded. The measurements for possible tilt may be made in conjunction with measurements of shell heights using a theodolite, an optical plummet, or a plumb bob.

13.2 A description of the reference gauge point should be included in the record, for example: to top lip of 8-in. (or 20-cm) diameter hatch, opposite hinge.

13.3 A comparison should be made immediately of the reference gauge height with the sum of the shell height plus the height from the top of the top angle of the tank shell to the level of the reference gauge point on the hatch rim, in order to investigate the possible existence of a datum plate or false bottom.

13.3.1 The result of this field investigation should be recorded by identifying the reference gauge height as a distance to the floor or to the datum plate. The measurements and calculations involved should be attached to, and become a part of, the measurement record.

13.3.2 If a false bottom is known or suspected to be present, the record should be so marked.

13.4 Effective inside tank height is a vertical distance along the gauging path (see Figures 11 and 12). This is of primary concern to the capacity table calculations, establishing the upper and lower limits of variable gauges to be provided for in the capacity table.

13.4.1 The maximum upper limit of the capacity table can be one of the following two items:

a) effective inside tank height,

b) maximum fill height requested by the tank owner, such as at the underside of an overflow.

13.4.2 If the effective inside tank height should be obtained directly on the tank, this height should be measured and reported as such. If effective inside tank height cannot be measured directly, the person responsible for obtaining the measurements should obtain as-built blueprints to enable calculation of the effective inside tank height.

13.5 In some installations, an overflow line or other appurtenance is connected to the tank shell just below the top angle and provides a potential liquid overflow level at some point below the top of the shell (see Figure 12).

13.5.1 The measurement record should include a complete description of such a connection, including size and location and whether or not a valve that can be closed and sealed is included in the line. If such a valve is present, its location should be included in the record.

13.5.2 If the connection cannot be closed and sealed against overflow, then the effective inside tank height is the vertical distance from the striking point on the tank floor, or datum plate, upward to the level at which the tank's contents will begin to overflow; the tank capacity between the point of overflow and the tank roof should be disregarded in the capacity table.

13.5.3 If the connection can be closed and sealed against overflow, then the effective inside tank height and the capacity table should extend upward to the top of the top angle.

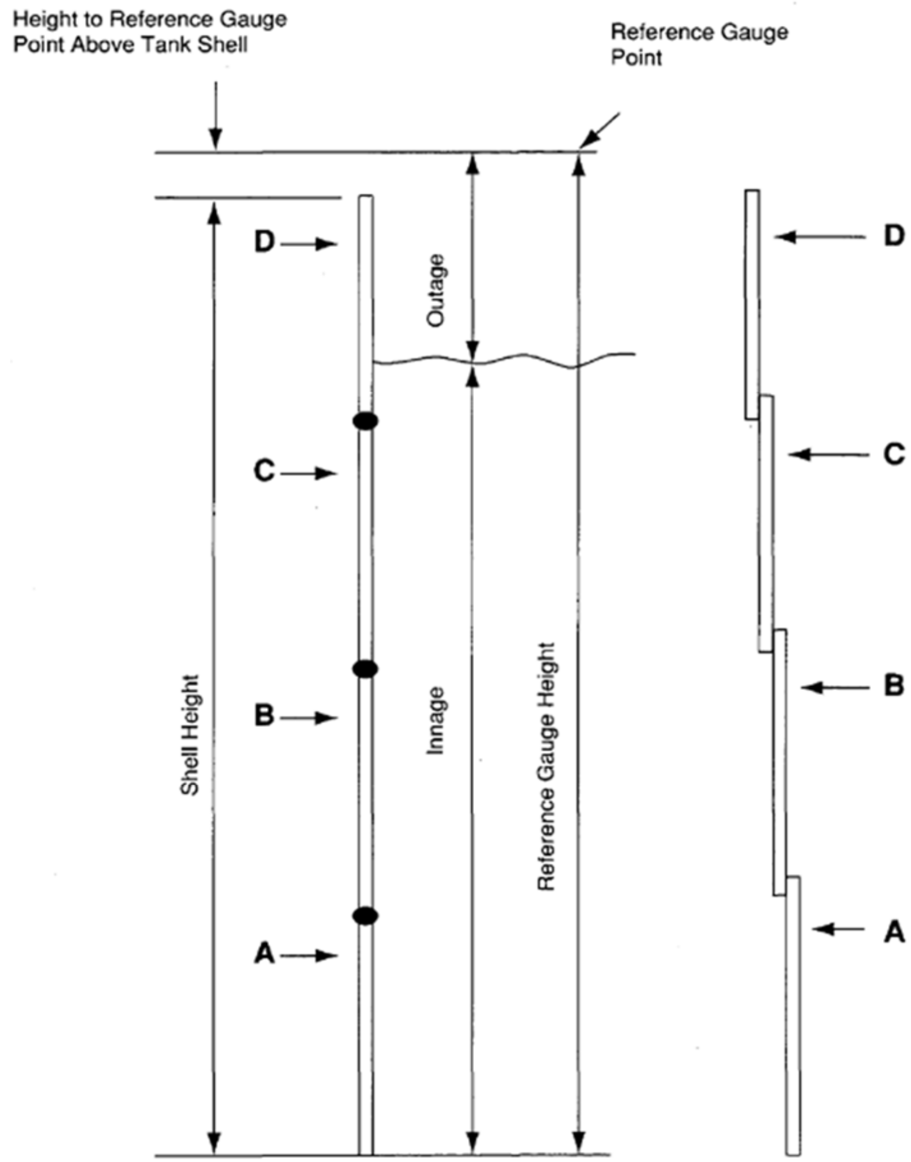


Figure 8—Vertical Tank Measurements (Welded)

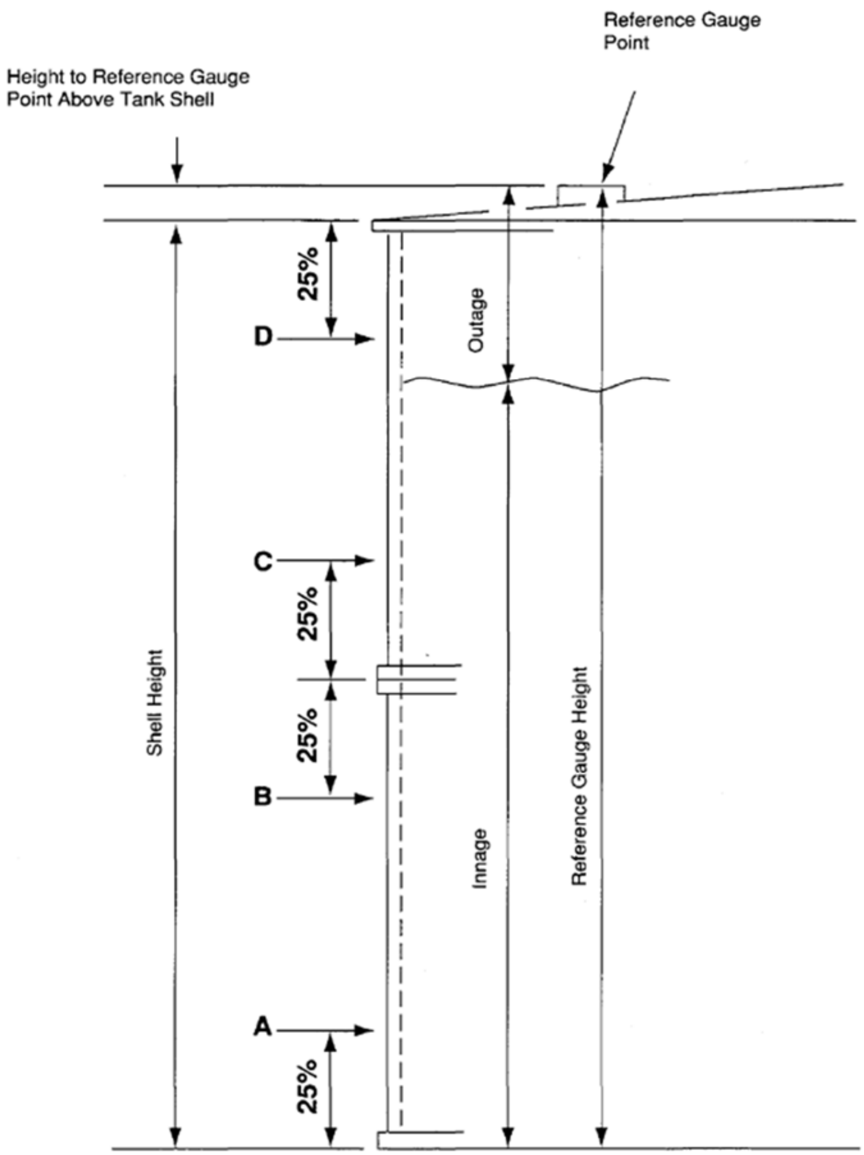


Figure 9—Vertical Tank Measurements (Bolted)

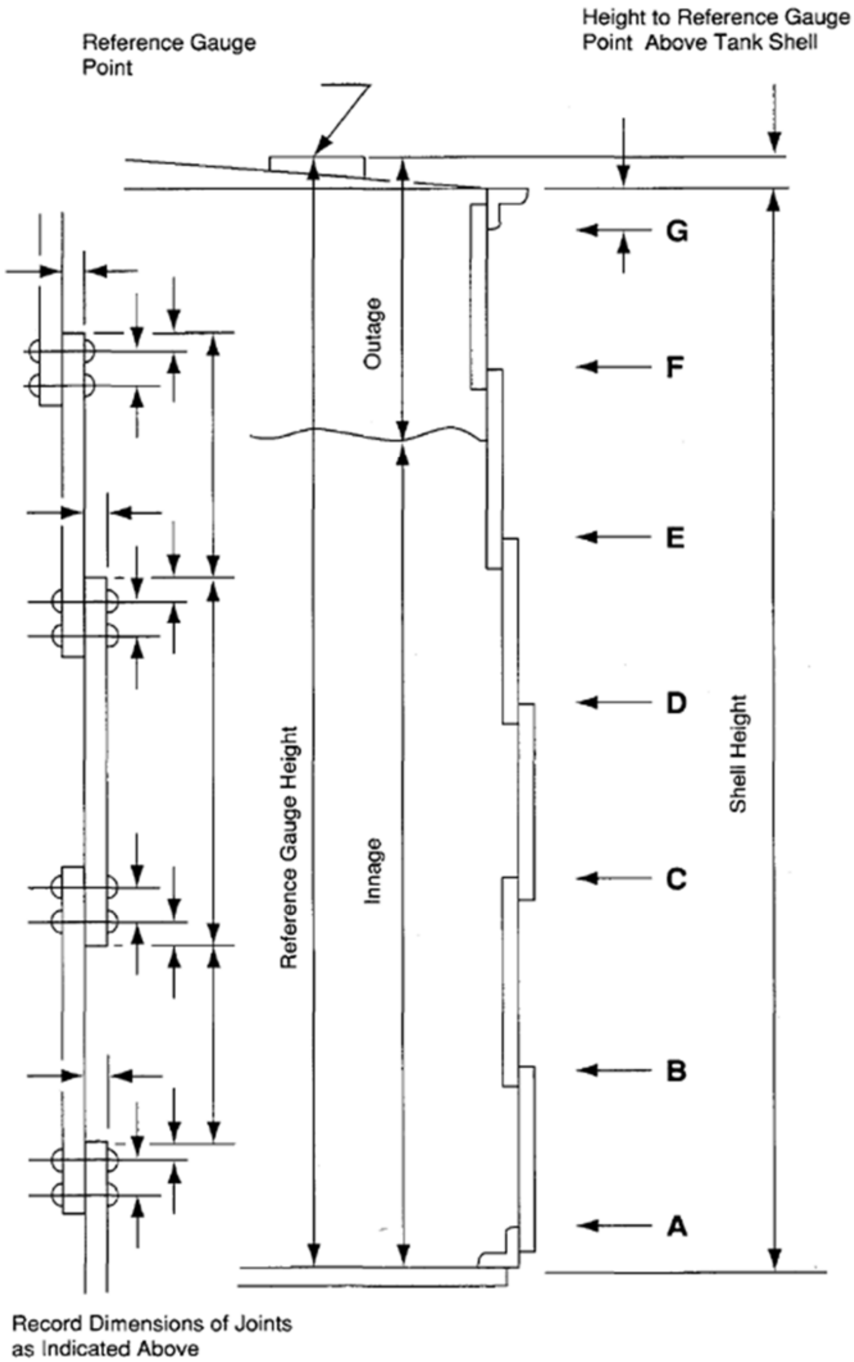


Figure 10—Vertical Tank Measurements (Riveted)

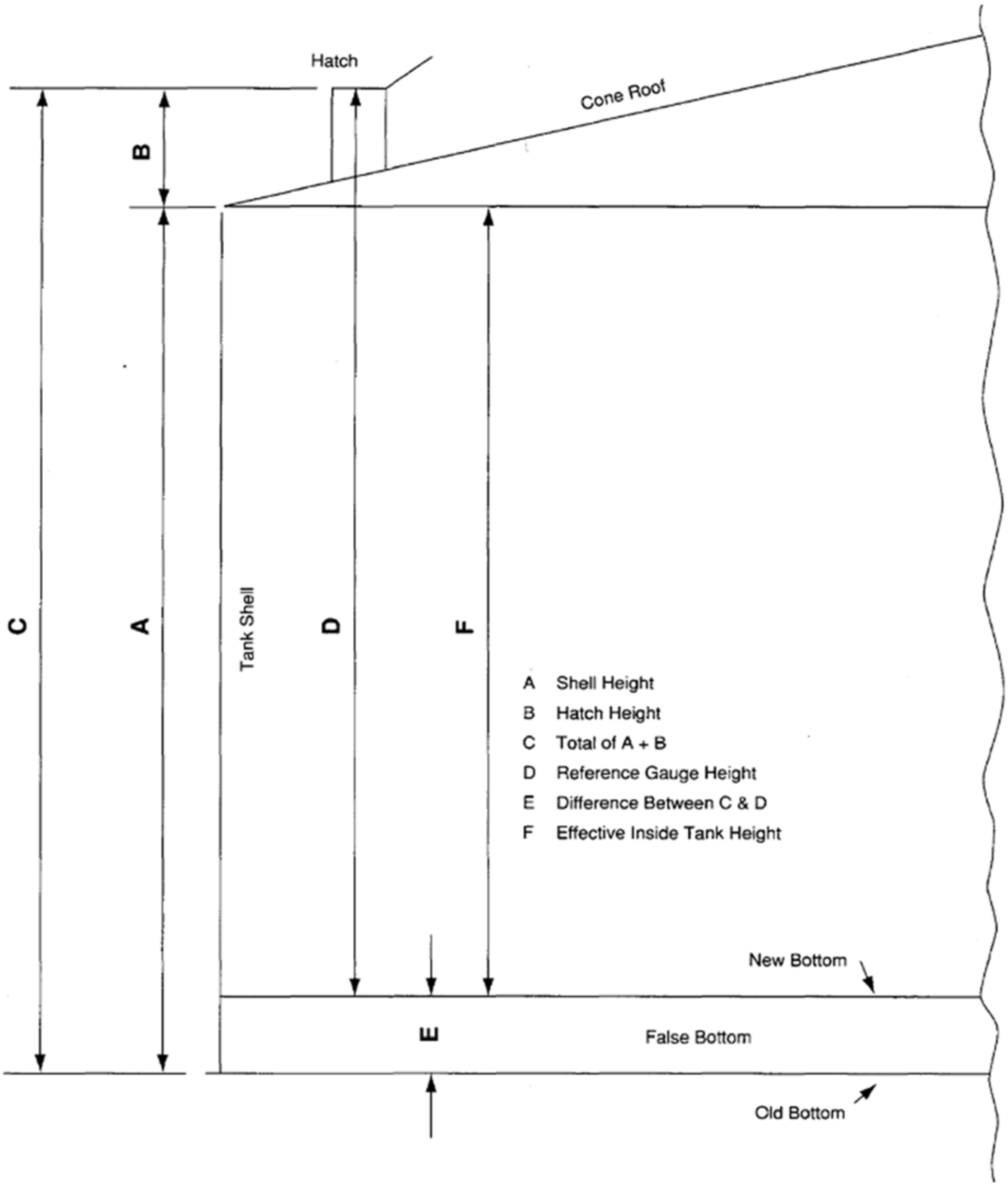


Figure 11—Effective Inside Tank Height (Cone Roof)

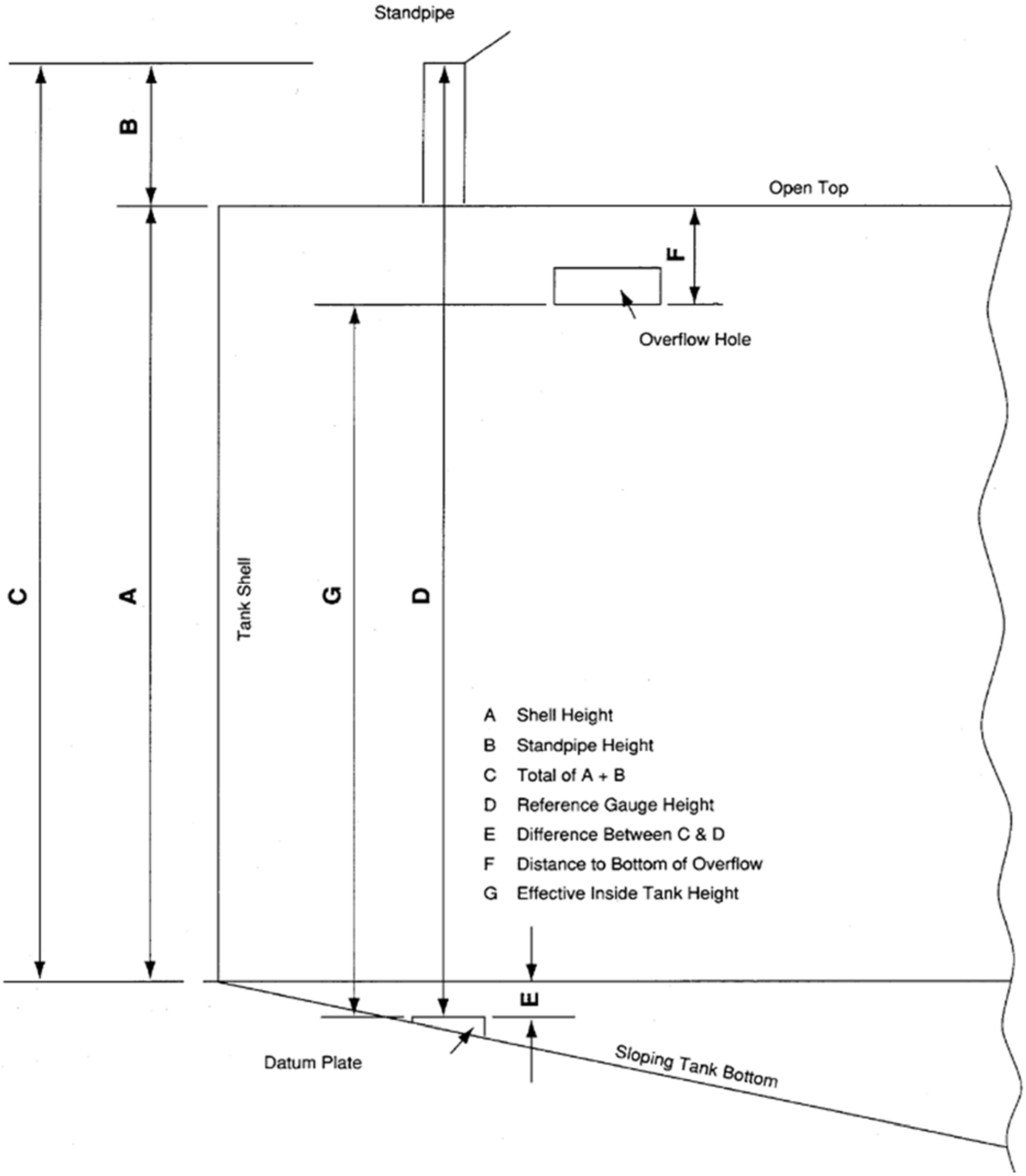


Figure 12—Effective Inside Tank Height (Floating Roof)

13.5.4 In this latter case, in which the capacity table is extended upward beyond the connection, the capacity table should include a note at the elevation of the connection citing its presence and stipulating the condition under which that portion of the capacity table may be used.

13.5.5 The safe fill height, when required to be indicated in the capacity table, shall be so specified by the owner. The safe fill height in most instances will be less than maximum fill height.

13.5.6 Each ring height shall be measured and recorded (see Figure 5).

13.5.7 Where rings are lapped horizontally, the lap shall be reported so that the inside height of the ring can be developed by calculations.

14 Circumferential Measurements

14.1 Preparation

14.1.1 The calibration technician responsible for measuring the tank should first determine where circumferential measurements are to be taken. Circumferential measurements are to be taken on the tank shell. No circumferential measurements are to be taken over insulation. A summary of elevations for circumference measurements on various types of upright cylindrical tanks is shown in Table 3.

Table 3—Elevations for Circumference Measurements on Various Types of Upright Cylindrical Tanks

Type of Tank Construction	Circumference Measurement Elevations
Welded steel, one or more rings	20 % down from top of each ring whether butt or lap joints [a]
Riveted steel, shingled arrangement	Lowest point on each ring and 1 ft (or 300 mm) below top of top ring [b]
Riveted steel, in-and-out arrangement	Lowest point above horizontal rivet rows on each ring, and 1 ft (or 300 mm) below top of top ring [b]
Riveted steel, combination shingled and in-and-out arrangement	Lowest point above horizontal rivet rows on each ring, and 1 ft (or 300 mm) below top of top ring [b]
Steel tank one ring high, riveted lap joints on bottom of shell	25 % and 75 % above
Bolted steel, lapped vertical joints	25 % and 75 % above bottom of each ring
Bolted steel, flanged vertical joints	75 % above bottom of each ring

[a] For one-ring tanks, two circumferential measurements shall be taken at 20 % and 80 % down from top of the ring. For tanks of more than one ring, if obstructions block the tape path at the 20 % down plane, the measurement may be taken at a point 80 % down. If circumference measurements taken on successive rings indicate unusual variations or distortions, sufficient additional measurements should be taken to satisfy the requirements of all concerned.

[b] When bottom angle is welded, take lowermost circumference 1 ft (or 300 mm) above bottom of bottom ring. Where tank shells are of composite construction, take measurements in accordance with instructions above for each type of construction.

14.1.2 Circumferential tape paths located at elevations shown in the appropriate illustration in Figures 5 through 10 should be examined for obstructions and type of upright joints. Dirt, scale, and insulation should be removed along each path.

14.1.3 Occasionally, some feature of construction, such as a manway or insulation box, may make it impractical to use a circumference elevation prescribed on the appropriate illustration. Then a substitute tape path located nearer to the center of the ring may be chosen. The strapping record should include the location of the substitute path and the reason for the departure.

14.1.4 The type and characteristics of upright joints should be determined by close examination in order to establish the procedure of measurement and equipment required. In the case of butt strap or lap joints at which voids between tape and shell occur, the joints will be caused only by butt strap or plate thickness, uniform at each joint; then circumferences may be measured in accordance with the procedure described in 14.2.

14.2 Physical Measurements

14.2.1 For the measurements described in 14.1, a circumference tape of sufficient length to encircle the tank completely should be used, in which case measurement of total circumference with one reading should be taken. In the event that the tank circumference is too great to be completely encircled by the tape, alternate methods may be adopted (see Annex F).

14.2.2 All points at which circumferential measurements are read should be located at least 2 ft (or 600 mm) from an upright joint. After a circumferential measurement has been taken, the tension should be reduced sufficiently to permit the tape to be shifted. Before reading, the tape position should be verified. It should then be returned to position and required tension, and two successive readings should be taken within specified tolerances as per Table 4. The average of the two readings should be recorded as the circumferential measurement at that location.

Table 4—Circumferential Tolerances

USC	SI
Up to 150 ft ± 0.01 ft	Up to 30 m ± 2 mm
150 ft to 300 ft ± 0.02 ft	30 m to 50 m ± 4 mm
Over 150 ft ± 0.03 ft	50 m to 70 m ± 6 mm
	70 m to 90 m ± 8 mm
	Over 90 m ± 10 mm
NOTE ft = feet; m = meter; mm = millimeter.	

14.2.3 When butt strap or lap joints cause uniform voids between the tape and tank shell at each joint, circumference measurements should be made in accordance with 14.2.1. The proper procedure is to measure and record the width and thickness of butt straps and record the number of butt straps in each ring.

14.2.4 In the case of lapped joints, one should measure and record the thickness of exposed lapped plate (see Figure 10) in each ring about the circumference and record the number of such joints in each ring. The measured circumferences, properly checked and recorded, should be corrected later for tape rise as described in 19.4.

14.2.5 When obstructions are encountered in the tape path over which it is impracticable to place the tape (e.g. features that exert uneven effects on the resultant void between the tape and tank, from joint to joint), then alternate methods may be adopted (see Annex F).

14.2.6 For spanning obstructions in making circumference measurements, the following is recommended. To measure the span of an obstruction, apply the caliper in a horizontal position, as determined by use of a level, against the shell of the tank being strapped, near the center of a shell plate, and scribe marks on the shell with the two scribing points. Apply the circumferential working tape under required tension to the tank shell in such a position that the distance between the scribed lines along the shell surface may be estimated to the nearest 0.001 ft or to the nearest 0.5 mm.

15 Deadwood Management

15.1 The calibration procedures that are outlined herein are based upon internal cleanliness of the tank. The interior upright cylindrical surface and roof-supporting members, such as columns and braces in the tank, should be clean and free from any foreign substance including, but not limited to, residue of commodities adhering to the sides, rust, dirt, emulsion, and paraffin. Examination and inspection of a tank may indicate the need for thorough cleaning if accuracy in the calibration is to be achieved.

15.2 Deadwood should be accurately accounted for, as to size and location, to the nearest $^1/_8$ in. (or 3 mm) in order to permit the following.

a) Adequate allowance for the volumes of liquid displaced or admitted by the various parts (see Annex B for example calculations).

b) Adequate allocation of the effects at various elevations within the tank.

15.3 Deadwood should be measured, if possible, within the tank. Dimensions shown on the builder's drawings or dimensions furnished by the tank owner may be accepted if actual measurement is impossible.

15.4 Measurements of deadwood should show the lowest and highest levels, measured from the tank bottom adjacent to the shell, at which deadwood affects the capacity of the tank (see Figure 4). Measurements should be increments that permit allowance for deadwood's varying effect on tank capacity at various elevations.

15.5 Worksheets on which details of deadwood are sketched, dimensioned, and located should be clearly identified and should become a part of the strapping record.

16 Tank Bottoms

16.1 Tank bottoms that are flat, level, and stable under varying liquid loads will have no effect on tank capacity.

16.2 Tank bottoms conforming to geometric shapes (e.g. sloping, cone down, crown up, hemispherical, semiellipsoidal, and spherical segment) have volumes that may be either computed from linear measurements or measured by liquid calibration by incremental filling, as desired.

16.2.1 When volumes are to be computed, measurements should be made at the points shown on the applicable illustration in Figures 13 and 14.

16.2.2 Any detailed differences in shape affecting the volume, not shown on the strapping report, such as knuckle radii, should be measured and recorded in sufficient detail to permit computation of the true volume.

16.3 Where tank bottom conditions of irregular slope or shape and/or instability exist and where correct capacities cannot be determined accurately from linear measurements, liquid calibration is preferred.

16.4 If liquid calibration is used, incremental filling of volumes are introduced into the tank, from the lowest point in the bottom to a point above which computations can be made from dimensional measurements. The procedure should be continued to a depth in the tank sufficient to overcome all irregular shapes or unstable conditions as described in API 2555.

16.5 For tanks operated with the bottom completely and continuously covered with water, any slope or irregularity, but not instability, of the bottom may be disregarded.

16.6 An alternative method of calibrating the bottom zone is by taking level elevations at various points along the bottom through a bottom survey. A physical bottom survey of the tank bottom should be made, whenever possible, after the tank has been hydrotested, in order to establish the amount of slope from the tank shell to the tank center. The elevation at the strike point directly under the gauging hatch should also be measured.

16.7 Due to the nature of some bottoms being very irregular, survey readings should be taken at many points to better determine the shape. When performing a complete bottom survey, elevations should be sighted along radii every 45°. Along these radii, obtain elevations at equally spaced intervals not more than 10 ft (or 3 m) from the tank's center to its shell.

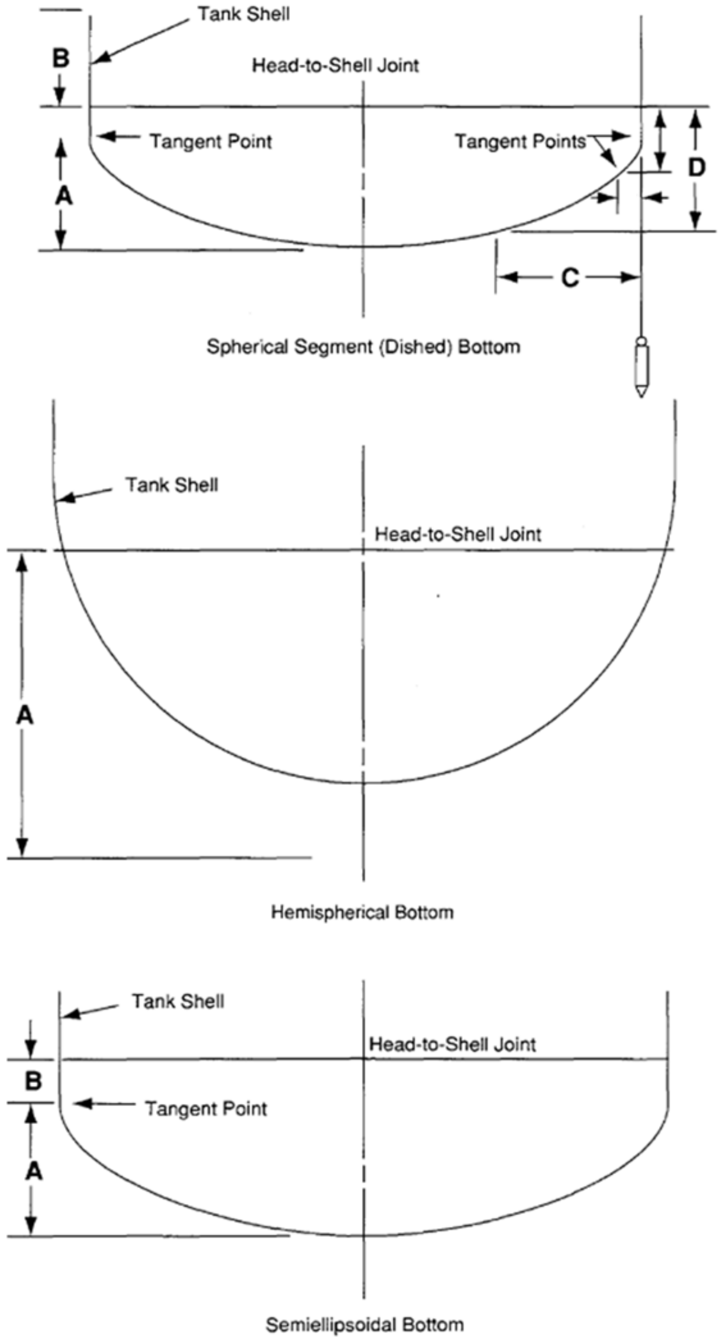
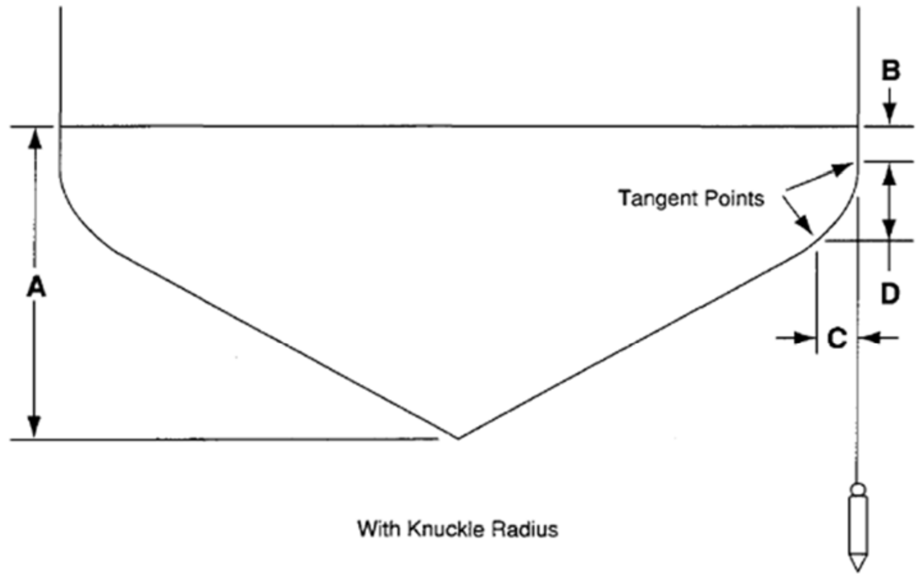
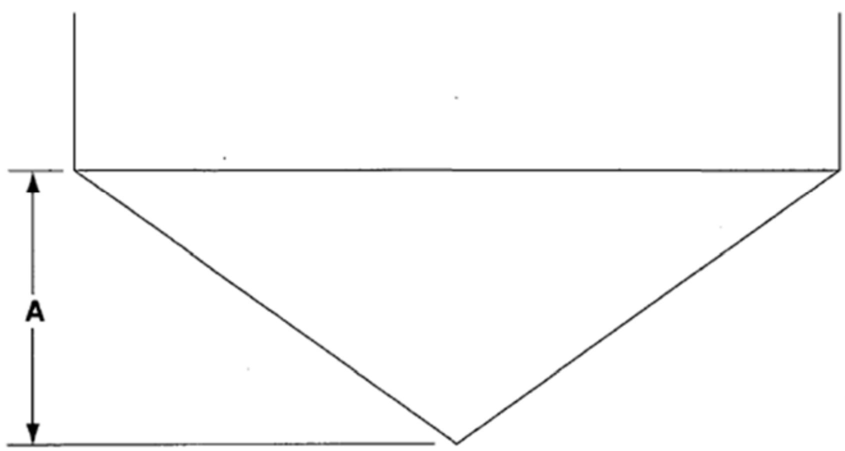


Figure 13—Spherical Segment (Dished), Hemispherical and Semiellipsoidal Bottoms Convex, and Accessible Measurements of Upright Tanks



With Knuckle Radius



Without Knuckle Radius

Figure 14—Coned Downward Bottom and Accessible Measurements of Upright Tanks

17 Floating Roofs

17.1 General

Floating roofs, illustrated in Figures 15 and 16, are installed in tanks with upright cylindrical shells. Floating roof displacement, however, gives rise to special deductions for floating weight and deadwood. Position A (see Figure 15) is the liquid level at which the liquid first touches the contact deck of the roof. Position B is the liquid level at which the last support of the roof lifts free of the tank bottom and the roof is fully buoyant.

17.2 Floating Roof Weight

When a roof is fully buoyant, it displaces an amount of liquid equal in weight to the floating weight of the roof. The floating weight should include the roof plus any appurtenances that are carried up and down in the tank with the roof, including 50 % of the weight of the stairway. The roof weight is calculated by the builder and should be reported by the strapper.

17.3 Deadwood Determination

When all or part of the weight of a roof is resting on the roof supports, the roof and all appurtenances should be deducted as deadwood as they become immersed in liquid. Deadwood includes such parts as the swing joint, the drain, and other items that are attached to the tank shell or bottom. Since a swing pipe is normally full of liquid, only the metal volume is deadwood. On the other hand, a closed drain is normally empty, and the total pipe or hose volume is included as deadwood. Deadwood also includes parts that eventually move with the roof. The roof itself is deadwood, and as the liquid level rises around the roof, its geometric shape determines how it should be deducted. The geometric shape should be taken from the builder's drawings or measured in the field while the roof is resting on its supports.

17.4 Deducting Floating Roof Displacement

Two methods of deducting floating roof displacement from capacity tables are as follows:

a) liquid calibration,

b) mathematical calculation of roof displacement (see Annex B).

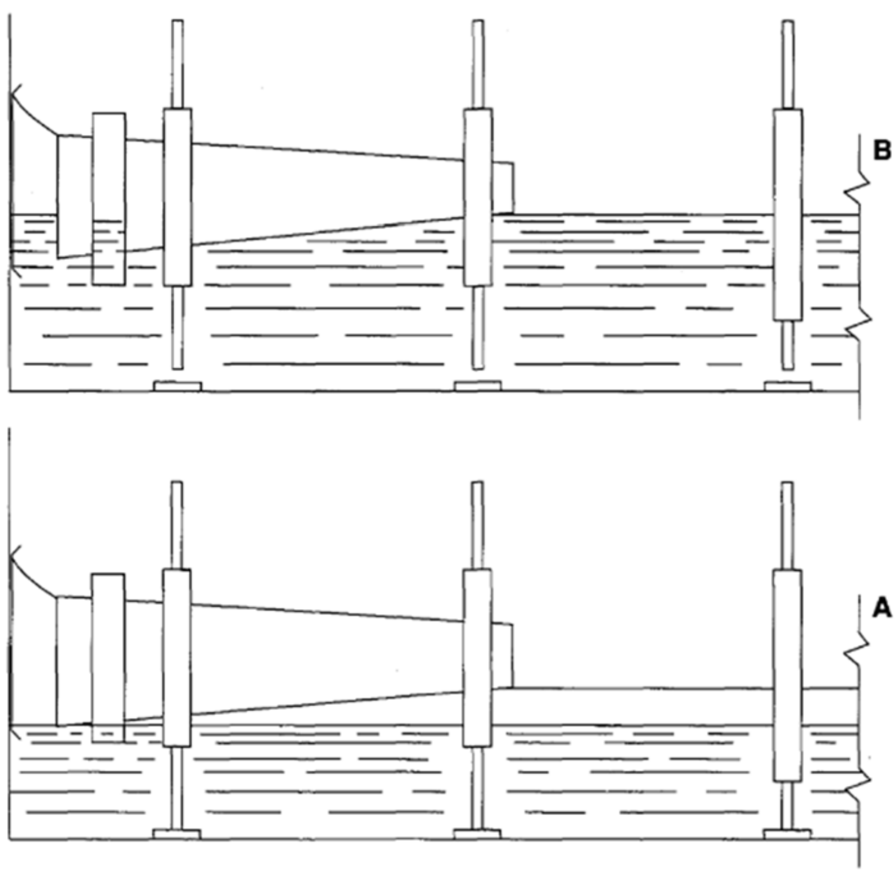


Figure 15—Diagram of Floating Roof at Rest (A) and Floating (B)

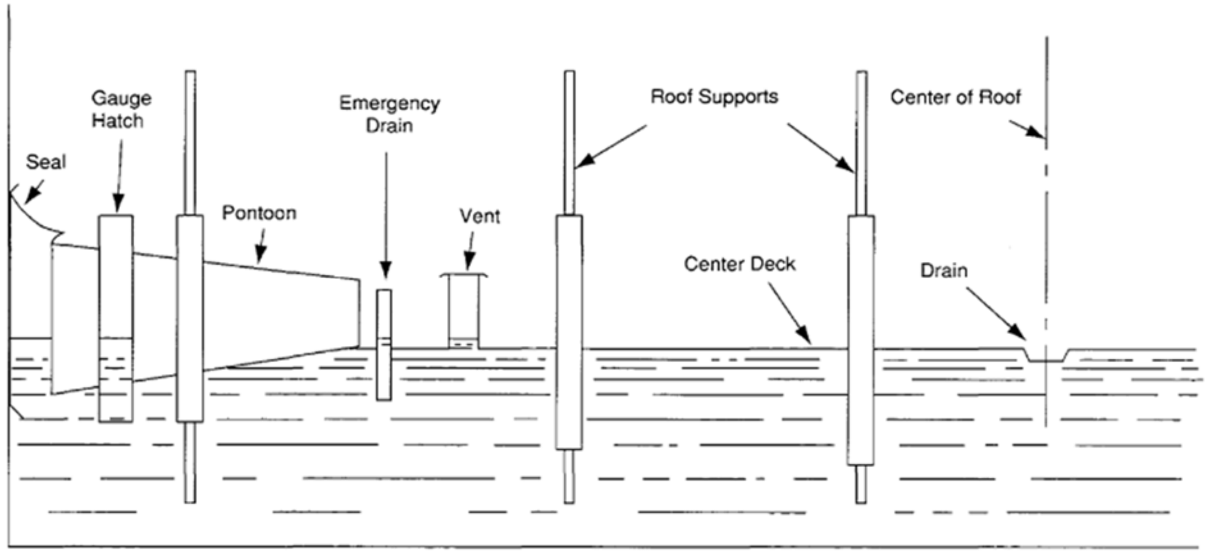


Figure 16—Typical Steel Pontoon Floating Roof with Single Center Deck

18 Insulated Tanks

The following procedures may be used in determining the data necessary for the preparation of capacity tables. Calibration of outside insulated tanks may be completed before the insulation is applied by following the procedures for outside measurements specified in this standard for aboveground tanks of the same type. If the tank is insulated, the following procedures apply. Alternate procedures, however, may be applied as here indicated.

a) *Liquid Calibration*—Insulated tanks may be calibrated by the introduction of measured quantities of liquid in accordance with API 2555.

b) *Calibration Based on Inside Measurements*—Calibration of insulated tanks may be based on inside measurements by application of API *MPMS* Ch. 2.2B.

c) *Calibration Based on Drawings*—Calibration may be based on the data given in the drawings and in the specifications of the tank builder if none of the preceding methods can be used. This alternative is the least preferred method and is not recommended for tanks used for custody transfer.

d) *Application of New Technologies*—New technologies such as optical triangulation method and electro optical distance ranging (EODR method) are described under Annex F.

19 Tank Capacity Table Development—Calculation Procedures

19.1 General

Sound engineering and mathematical principles should be used in all calculations for development of capacity tables. These principles should include those given herein for application to this particular type of work.

a) The capacity tables should be prepared at 60 °F (15 °C) and should take into account liquid head stress correction, deadwood, tilt correction, and if applicable floating roof allowance.

NOTE Even though the base temperature of the tanks is 60 °F (or 15 °C), the liquid density used in calculating the liquid head stress correction and floating roof allowance should be the average observed density for that given tank.

b) For temperature allowance, the temperature expansion factor should be applied as a separate factor (see Annex D).

c) All incremental or total volume calculations should be carried to seven significant figures. (Refer to Annex C for Guidelines for Computer Input.)

d) All deadwood should be accurately accounted for as to volume and location, in order to permit adequate allowance for volumes of liquid displaced by various objects or appurtenances and the allocation of these effects at various elevations within the tank.

e) The preparation of capacity tables for upright tanks is based on a maximum liquid height not greater than the shell height. The volume within the tank that is above that level shall be disregarded in capacity tables. An example of this disregarded volume is the space under a cone roof down to the level of the top edge of the top ring.

f) Tank capacities should be expressed in gallons, barrels, cubic meters, liters, or other (Tables 5 and 6 and Annex B).

g) Each item on the strapping report is evaluated for accuracy before processing.

h) As a matter of principle, it is recommended that all newly prepared capacity tables show thereon the date on which they are effective. The basis for establishing such a date, in specific cases, is dependent upon individual circumstances and the needs of the parties concerned. However, it is intended that the effective date be established, taking into consideration circumstances including, but not limited to, the following:

   1) the date a new tank was first calibrated,

   2) the date an old tank was recalibrated,

   3) the date the tank was recomputed.

19.2 Capacity Table Requirements

The following parameters shall be considered for the development of capacity tables.

a) Expansion and contraction of steel tank shell due to liquid head (see 19.6).

b) Expansion and contraction of steel tank shell with temperature [recommended to be applied independent of capacity table computations (see 19.7)].

c) Tilt from a vertical position (see 19.8).

d) Tank bottoms that are irregular in shape (see Section 16).

e) Effective inside tank height (see Figure 12).

Table 5—Customary Version Capacity Table—Example Capacity Table—Tank No. 117 Floating Roof

CAPACITIES GIVEN IN WHOLE BARRELS OF 42 US GALLONS
•MAXIMUM SAFE FILL HEIGHT = 45'-5 3/4" DUE TO OVERFLOW
GAUGE HEIGHT = 48'-6 3/8"

FT. IN.	BARRELS	FT. IN.	BARRELS	FT. IN.	BARRELS	FT. IN.	BARRELS	FT. IN.	BARRELS	FT. IN.	BARRELS	FT. IN.	BARRELS	FT. IN.	BARRELS	FT. IN.	BARRELS	FT. IN.	BARRELS
0	1	5	3.068	10	6.202	15	9.332	20	12.471	25	15.610	30	18.750	35	31.890	40	25.031	45	28.172
1	21	1	3.121	1	6.254	1	9.385	1	12.523	1	15.663	1	18.802	1	21.942	1	25.083	1	28.224
2	59	2	3.173	2	6.306	2	9.437	2	12.575	2	15.715	2	18.854	2	21.994	2	25.135	2	28.277
3	109	3	3.225	3	6.358	3	9.489	3	12.628	3	15.767	3	18.906	3	22.047	3	25.188	3	28.329
4	161	4	3.277	4	6.410	4	9.541	4	12.680	4	15.820	4	18.959	4	22.099	4	25.240	4	28.382
5	213	5	3.330	5	6.463	5	9.593	5	12.732	5	15.872	5	19.011	5	22.151	5	25.292	5	28.434
6	265	6	3.382	6	6.515	6	9.645	6	12.785	6	15.924	6	19.063	6	22.204	6	25.345	3/4	28.473
7	317	7	3.434	7	6.567	7	9.698	7	12.837	7	15.977	7	19.116	7	22.256	7	25.397		
8	369	8	3.486	8	6.619	8	9.750	8	12.889	8	16.029	8	19.168	8	22.309	8	25.449		
9	422	9	3.539	9	6.671	9	9.802	9	12.972	9	16.081	9	19.220	9	22.361	9	25.502		
10	474	10	3.591	10	6.723	10	9.854	10	12.994	10	16.133	10	19.273	10	22.413	10	25.554		
11	526	11	3.643	11	6.776	11	9.906	11	13.046	11	16.186	11	19.325	11	22.466	11	25.607		
1	578	6	3.695	11	6.828	16	9.959	21	13.099	26	16.238	31	19.377	36	22.518	41	25.659		
1	631	1	3.748	1	6.880	1	10.011	1	13.151	1	16.290	1	19.430	1	22.570	1	25.711		
2	683	2	3.800	2	6.932	2	10.063	2	13.203	2	16.343	2	19.482	2	22.623	2	25.764		
3	735	3	3.852	3	6.984	3	10.116	3	13.256	3	16.395	3	19.534	3	22.675	3	25.816		
4	787	4	3.904	4	7.037	4	10.166	4	13.308	4	16.447	4	19.587	4	22.727	4	25.868		
5	840	5	3.957	5	7.089	5	10.220	5	13.360	5	16.500	5	19.639	5	22.780	5	25.921		
6	892	6	4.009	6	7.141	6	10.273	6	13.413	6	16.552	6	19.691	6	22.832	6	25.973		
7	944	7	4.061	7	7.193	7	10.325	7	13.465	7	16.604	7	19.744	7	22.884	7	26.025		
8	997	8	4.113	8	7.245	8	10.377	8	13.517	8	16.657	8	19.796	8	22.937	8	26.078		
9	1.049	9	4.166	9	7.297	9	10.430	9	13.570	9	16.709	9	19.848	9	22.989	9	26.130		
10	1.101	10	4.218	10	7.350	10	10.482	10	13.622	10	16.761	10	19.901	10	23.041	10	26.182		
11	1.153	11	4.270	11	7.402	11	10.534	11	13.674	11	16.814	11	19.953	11	23.094	11	26.235		
2	1.206	7	4.322	12	7.454	17	10.587	22	13.727	27	16.866	32	20.005	37	23.146	42	26.287		
1	1.258	1	4.375	1	7.506	1	10.639	1	13.779	1	16.918	1	20.058	1	23.198	1	26.340		
2	1.310	2	4.427	2	7.558	2	10.691	2	13.831	2	16.971	2	20.110	2	23.251	2	26.392		
3	1.362	3	4.479	3	7.611	3	10.744	3	13.884	3	17.023	3	20.162	3	23.303	3	26.444		
4	1.415	4	4.531	4	7.663	4	10.796	4	13.936	4	17.075	4	20.215	4	23.355	4	26.497		
5	1.467	5	4.584	5	7.715	5	10.848	5	13.988	5	17.128	5	20.267	5	23.408	5	26.549		
6	1.519	6	4.636	6	7.767	6	10.901	6	14.040	6	17.180	6	20.319	6	23.460	6	26.601		
7	1.572	7	4.688	7	7.819	7	10.953	7	14.093	7	17.232	7	20.372	7	23.512	7	26.654		
8	1.624	8	4.740	8	7.871	8	11.005	8	14.145	8	17.285	8	20.424	8	23.565	8	26.706		
9	1.676	9	4.793	9	7.924	9	11.058	9	14.197	9	17.337	9	20.476	9	23.617	9	26.758		
10	1.728	10	4.845	10	7.976	10	11.110	10	14.250	10	17.389	10	20.529	10	23.670	10	26.811		
11	1.781	11	4.897	11	8.028	11	11.162	11	14.302	11	17.441	11	20.581	11	23.722	11	26.863		
3	1.833	8	4.949	13	8.080	18	11.215	23	14.354	28	17.494	33	20.633	38	23.774	43	26.916		
1	1.885	1	5.002	1	8.132	1	11.267	1	14.407	1	17.546	1	20.686	1	23.827	1	26.968		
2	1.938	2	5.054	2	8.184	2	11.319	2	14.459	2	17.598	2	20.738	2	23.879	2	27.020		
3	1.990	3	5.106	3	8.237	3	11.372	3	14.511	3	17.651	3	20.790	3	23.931	3	27.073		
4	2.042	4	5.158	4	8.289	4	11.424	4	14.564	4	17.703	4	20.843	4	23.984	4	27.125		
5	2.094	5	5.210	5	8.341	5	11.476	5	14.616	5	17.755	5	20.895	5	24.036	5	27.177		
6	2.147	6	5.262	6	8.393	6	11.529	6	14.668	6	17.808	6	20.947	6	24.088	6	27.230		
7	2.198	7	5.315	7	8.445	7	11.581	7	14.721	7	17.860	7	21.000	7	24.141	7	27.282		
8	2.246	8	5.367	8	8.498	8	11.633	8	14.773	8	17.912	8	21.052	8	24.193	8	27.334		
9	2.293	9	5.419	9	8.550	9	11.686	9	14.825	9	17.965	9	21.105	9	24.245	9	27.387		
10	2.337	10	5.471	10	8.602	10	11.738	10	14.878	10	18.017	10	21.157	10	24.298	10	27.439		
11	2.389	11	5.523	11	8.654	11	11.790	11	14.930	11	18.069	11	21.209	11	24.350	11	27.491		
4	2.441	9	5.576	14	8.706	19	11.843	24	14.982	29	18.122	34	21.262	39	24.402	44	27.544		
1	2.493	1	5.628	1	8.758	1	11.895	1	15.035	1	18.174	1	21.314	1	24.455	1	27.596		
2	2.546	2	5.680	2	8.811	2	11.947	2	15.087	2	18.226	2	21.366	2	24.507	2	27.649		
3	2.598	3	5.732	3	8.863	3	12.000	3	15.139	3	18.279	3	21.419	3	24.559	3	27.701		
4	2.650	4	5.784	4	8.915	4	12.052	4	15.192	4	18.331	4	21.471	4	24.612	4	27.753		
5	2.702	5	5.836	5	8.967	5	12.104	5	15.244	5	18.383	5	21.523	5	24.664	5	27.806		
6	2.755	6	5.889	6	9.019	6	12.157	6	15.296	6	18.436	6	21.576	6	24.716	6	27.858		
7	2.807	7	5.941	7	9.071	7	12.209	7	15.349	7	18.488	7	21.628	7	24.769	7	27.910		
8	2.859	8	5.993	8	9.124	8	12.261	8	15.401	8	18.540	8	21.680	8	24.821	8	27.963		
9	2.912	9	6.045	9	9.176	9	12.314	9	15.453	9	18.593	9	21.733	9	24.874	9	28.015		
10	2.964	10	6.097	10	9.228	10	12.366	10	15.506	10	18.645	10	21.785	10	24.926	10	28.067		
11	3.016	11	6.150	11	9.280	11	12.418	11	15.558	11	18.697	11	21.837	11	24.978	11	28.120		

A total of 18.97 barrels has been deducted from this table between 3'-6" and 3'-10" for roof displacement based upon a floating weight of 4,900 lbs. and observed API gravity of 60.0. Gauged levels above 3'-10" reflect this deduction. For gravities other than 60.0 API/observed adjust quantities about 3'-10" as follows. Add 0.10 barrels per degree below 60.0 API/observed. Subtract 0.10 barrels per degree above 60.0 API/observed

1) A 3½" crown has been deducted from the first 4" of capacity table.
2) Tank strapped and computed in accordance with API MPMS Chapter 2.2A.
3) Liquid head stress has been applied to table at API gravity 60.0.
4) For precise fractional values, interpolate between incremental volumes.
5) Capacity table stops at 45'-5½" due to overflow.
6) Nominal tank diameter = 67'-0", shell height = 48'-0".

Strapped by: WS-SL 5/19/92
Computed by: MH 5/19/92
Checked by: MH 5/19/92

Table 6—SI Version Capacity Table—Example Capacity Table—Tank No. 117 Floating Roof

CAPACITIES GIVEN IN CUBIC METERS
GAUGE HEIGHT = 48'-6 3/8"

FT. IN.	METERS	FT. IN.	METERS	FT. IN.	METERS	FT. IN.	METERS	FT. IN.	METERS	FT. IN.	METERS	FT. IN.	METERS	FT. IN.	METERS	FT. IN.	METERS	FT. IN.	METERS
0	0.211	5	487.809	10	985.977	15	1483.713	20	1982.643	25	2481.804	30	2980.896	35	3480.147	40	3979.494	45	4478.952
1	3.301	1	496.117	1	994.273	1	1492.009	1	1990.962	1	2490.123	1	2989.215	1	3488.470	1	3987.818	1	4487.276
2	9.445	2	504.425	2	1002.569	2	1500.305	2	1999.282	2	2498.441	2	2997.533	2	3496.792	2	3996.143	2	4495.601
3	17.284	3	512.733	3	1010.864	3	1508.600	3	2007.602	3	2506.759	3	3005.851	3	3505.115	3	4004.467	3	4503.925
4	25.557	4	521.040	4	1019.160	4	1516.896	4	2015.921	4	2515.007	4	3014.169	4	3513.437	4	4012.791	4	4512.249
5	33.833	5	529.348	5	1027.455	5	1525.191	5	2024.241	5	2523.395	5	3022.487	5	3521.760	5	4021.115	5	4520.573
6	42.118	6	537.656	6	1035.751	6	1533.487	6	2032.560	6	2531.714	6	3030.806	6	3530.082	6	4029.440	3/4	4526.819
7	50.425	7	545.964	7	1044.047	7	1541.783	7	2040.880	7	2540.032	7	3039.124	7	3538.405	7	4037.764		
8	58.732	8	554.272	8	1052.342	8	1550.078	8	2049.200	8	2548.350	8	3047.442	8	3546.727	8	4046.088		
9	67.040	9	562.579	9	1060.638	9	1558.374	9	2057.519	9	2556.668	9	3055.760	9	3555.050	9	4054.413		
10	75.347	10	570.887	10	1068.933	10	1566.669	10	2065.839	10	2564.986	10	3064.078	10	3563.372	10	4062.737		
11	83.655	11	579.195	11	1077.229	11	1574.982	11	2074.158	11	2573.305	11	3072.397	11	2571.695	11	4071.061		
1	91.962	6	587.503	11	1085.525	16	1583.302	21	2082.478	26	2581.623	31	3080.175	36	3580.017	41	4079.386		
1	100.270	1	595.811	1	1093.80	1	1591.622	1	2090.798	1	2589.941	1	3089.033	1	3588.340	1	4087.710		
2	108.578	2	604.118	2	1102.116	2	1599.941	2	2099.117	2	2598.259	2	3097.351	2	3596.662	2	4096.034		
3	116.886	3	612.426	3	1110.411	3	1608.261	3	2107.437	3	2606.577	3	3105.669	3	3604.985	3	4104.358		
4	125.193	4	620.734	4	1118.707	4	1616.580	4	2115.756	4	2614.896	4	3113.988	4	3613.307	4	4112.683		
5	133.501	5	629.042	5	1127.003	5	1624.900	5	2124.076	5	2623.214	5	3122.306	5	3621.630	5	4121.007		
6	141.810	6	637.350	6	1135.298	6	1633.220	6	2132.396	6	2631.532	6	3130.624	6	3629.952	6	4129.331		
7	150.122	7	645.657	7	1143.594	7	1641.539	7	2140.715	7	2639.850	7	3138.942	7	3638.275	7	4137.656		
8	158.433	8	653.965	8	1151.889	8	1649.859	8	2149.035	8	2648.168	8	31472.260	8	3646.597	8	4145.980		
9	166.745	9	662.273	9	1160.185	9	1658.178	9	2157.354	9	2656.487	9	3155.579	9	3654.920	9	4154.304		
10	175.056	10	670.581	10	1168.481	10	1666.498	10	2165.674	10	2664.805	10	3163.897	10	3663.242	10	4162.629		
11	183.368	11	678.889	11	1176.776	11	1674.818	11	2173.994	11	2673.123	11	3172.215	11	3671.565	11	4170.953		
2	191.679	7	687.196	12	1185.072	17	1683.137	22	2182.313	27	2681.441	32	3180.537	37	3679.887	42	4179.277		
1	199.991	1	695.504	1	1193.367	1	1691.457	1	2190.633	1	2689.759	1	3188.860	1	3688.210	1	4187.601		
2	208.302	2	703.812	2	1201.663	2	1699.776	2	2198.952	2	2698.078	2	3197.182	2	3696.532	2	4195.926		
3	216.614	3	712.120	3	1209.959	3	1708.096	3	2207.272	3	2706.396	3	3205.505	3	3704.855	3	4204.250		
4	224.925	4	720.428	4	1218.254	4	1716.416	4	2215.592	4	2714.714	4	3213.827	4	3713.177	4	4212.574		
5	233.237	5	728.735	5	1226.550	5	1724.735	5	2223.911	5	2723.032	5	3222.150	5	3721.500	5	4220.899		
6	241.548	6	737.043	6	1234.845	6	1733.055	6	2232.231	6	2731.350	6	3230.472	6	3729.822	6	4229.223		
7	429.860	7	745.351	7	1243.141	7	1741.374	7	2270.550	7	2739.669	7	3238.795	7	3738..145	7	4237.547		
8	258.171	8	753.659	8	1251.437	8	1749.694	8	2248.870	8	2747.987	8	3247.117	8	3746.467	8	4245.872		
9	266.483	9	761.967	9	1259.732	9	1758.014	9	2257.190	9	2756.305	9	3255.440	9	3754.790	9	4254.196		
10	274.794	10	770.274	10	1268.028	10	1766.333	10	2265.509	10	2764.623	10	3263.762	10	3763.112	10	4262.520		
11	283.106	11	778.584	11	1276.323	11	1774.653	11	2273.829	11	2772.941	11	3272.085	11	3771.435	11	4270.844		
3	291.417	8	786.883	13	1284.619	18	1782.972	23	2282.148	28	2781.260	33	3280.407	38	3779.757	43	4279.169		
1	299.729	1	795.179	1	1292.915	1	1791.292	1	2290.468	1	2789.578	1	3228.730	1	3788.080	1	4287.493		
2	308.040	2	803.474	2	1301.210	2	1799.612	2	2298.788	2	2797.896	2	3297.052	2	3796.402	2	4295.817		
3	316.352	3	811.770	3	1309.506	3	1807.931	3	2307.107	3	2806.214	3	3305.375	3	3804.725	3	4304.142		
4	324.663	4	820.065	4	1317.801	4	1816.251	4	2315.427	4	2814.532	4	3313.697	4	3813.047	4	4312.466		
5	332.975	5	828.361	5	1326.097	5	1824.570	5	2323.746	5	2822.851	5	3322.020	5	3821.370	5	4320.790		
6	341.294	6	836.657	6	1334.393	6	1832.890	6	2332.066	6	2931.169	6	3330.342	6	3827.692	6	4329.115		
7	349.404	7	844.952	7	1342.688	7	1841.210	7	2340.386	7	2839.487	7	3338.665	7	3838.015	7	4337.439		
8	357.146	8	853.248	8	1350.984	8	1849.529	8	2348.705	8	2847.805	8	3346.987	8	3846.337	8	4345.763		
9	364.511	9	861.543	9	1359.279	9	1857.849	9	2357.025	9	2856.123	9	3355.310	9	3854.660	9	4354.087		
10	371.500	10	869.839	10	1367.575	10	1866.168	10	2365.344	10	2864.442	10	3363.632	10	3862.982	10	4362.412		
11	379.808	11	878.135	11	1375.871	11	1874.488	11	2373.664	11	2972.760	11	3371.9855	11	3871.305	11	4370.736		
4	399.116	9	886.430	14	1384.166	19	1882.808	24	2381.984	29	2881.078	34	3380.277	39	3879.627	44	4379.060		
1	396.423	1	894.726	1	1392.462	1	18911.127	1	2390.304	1	2889.396	1	3388.600	1	3887.950	1	4387.385		
2	404.731	2	903.021	2	1400.757	2	1899.447	2	2398.622	2	2897.714	2	3396.922	2	3896.272	2	4395.709		
3	413.039	3	911.317	3	1409.053	3	1907.766	3	2406.941	3	2906.033	3	3405.245	3	3904.595	3	4404.033		
4	421.347	4	919.613	4	1417.349	4	1916.086	4	2415.259	4	2914.351	4	3413.567	4	3912.917	4	4412.358		
5	729.655	5	927.908	5	1425.644	5	1924.406	5	2423.577	5	2922.669	5	3421.890	5	3921.240	5	4420.682		
6	437.962	6	936.204	6	1433.940	6	1932.725	6	2431.895	6	2930.987	6	3430.212	6	3929.562	6	4429.006		
7	446.270	7	944.499	7	1442.235	7	1941.045	7	2440.213	7	2939.305	7	3438.535	7	3937.885	7	4437.330		
8	454.578	8	952.795	8	1450.531	8	1949.364	8	2448.532	8	2947.624	8	3446.857	8	3946.207	8	4445.655		
9	462.886	9	961.091	9	1458.827	9	1957.684	9	2456.850	9	2955.742	9	3455.180	9	3954.530	9	4453.979		
10	471.194	10	969.386	10	1467.122	10	1966.004	10	2465.168	10	2964.260	10	3463.502	10	3962.852	10	4462.303		
11	479.501	11	977.682	11	1475.418	11	1974.323	11	2473.486	11	2972.578	11	3471.825	11	3971.175	11	4470.628		

A total of 3.016 cubic meters has been deducted from this table between 3'-6" and 3'-10" for roof displacement based upon a floating weight of 4,900 lbs. and observed API gravity of 60.0. Gauged levels above 3'-10" reflect this deduction. For gravities other than 60.0 API/observed adjust quantities about 3'-10" as follows: Add 0.016 cubic meters per degree below 60.0 API/observed; Subtract 0.016 cubic meters per degree above 60.0 API/observed

1)A 3½" crown has been deducted from the first 4" of capacity table. Strapped by: WS-SL 5/19/92
2)Tank strapped and computed in accordance with API MPMS Chapter 2.2A.
3)Liquid head stress has been applied to table at API gravity 60.0.
4)Capacity table reflects expansion of tank shell due to ambient temperature of 15°C.
5)For more precise fractional values, interpolate between incremental volumes.
6)Capacity table stops at 45'-5½" due to overflow.
7)Nominal tank diameter = 67'-0", shell height = 48'-0".

Computed by: MH 5/19/92
Checked by: MH 5/19/92
'Show sketches of vertical and horizontal joints on back of this Table.
'Show circumferential location on plan view sketched on back of this Table.
'Show direction of lean on plan view sketched on back of this Table.

19.3 Calibration of the Master Tape to 60 °F

19.3.1 The master tape for calibrating tank measuring (working) tapes shall be identified with a Report of Calibration at 68 °F by NIST attesting to the master tape accuracy within 0.001 ft (approximately 1/64 in., 1-mm resolution and read to the nearest 0.5 mm) per 100 ft of length. The Report of Calibration shall include the factors and formulas necessary to correct tape length for use at 60 °F (15 °C) under tension differing from that used during calibration.

$$\text{Correction Factor} = 1 + [(T_S - T_C) \times C] \quad (1)$$

$$\text{Correction Factor} = 1 + [(60 - 68) \times 0.00000645]$$

$$= 1 + (-8 \times 0.00000645)$$

$$= 0.9999484$$

where

T_C is calibration temperature of master tape (normally 68 °F);

T_S is standard reference temperature (normally 60 °F);

C is coefficient of expansion for mild steel 0.00000645 ft/ft/°F.

19.4 Conversion of Outside to Inside Circumferences

Plate thicknesses used in calculations should be those reported on field measurement records. Where possible, thickness should be measured by ultrasonic thickness method. Values for plate thicknesses taken from drawings may be used where necessary.

$$\text{Inside Circumference} = \pi \times (D - 2t) \quad (2)$$

where

t is steel thickness;

D is outside diameter, both in consistent units.

19.5 Deductions for Circumference Tape Rises

19.5.1 In the event that the tape is prevented from being in contact with the tank shell at all points along its path by projections from the tank shell, such as butt straps or lap joints, the amount of increase in circumference due to tape rises at such projections should be determined. Circumferences as measured on a given ring should be corrected by deducting the sum of the increases in circumference at each tape rise location.

19.5.2 Deduction for tape rise may be computed from the tape rise correction Equations (3) and (5) in 19.5.3 and 19.5.4, or measured with a caliper where practical to do so. Due to the very small correction for tape rise at a low projection, such as a lap joint or butt strap, it is impractical to measure accurately the correction with a caliper; therefore, the tape rise correction method is preferred for such projections.

19.5.3 The tape rise correction equation for butt straps or similar projections is as follows:

$$Deduction\,(inches) = \frac{2Ntw}{d} + \frac{8Nt}{3}\sqrt{t/d} \tag{3}$$

where

N is number of butt straps or projections per ring;

t is amount of rise (thickness of straps or projections), in inches;

w is width of straps or projections, in inches;

N is nominal diameter of tank, in inches.

19.5.4 The tape rise correction equation for lap joints is as follows.

a) Application of Equation (3) in modified form to tape rise at lap joints is described with reference to Figure 17. In Figure 17, the locations of the plates in the lap joint are shown as positioned by the plates in the rings above and below the lap joint. The position of the plate in the ring if no joint existed is shown by the broken lines in relation to the plates in the lap joint.

b) The circumference as measured over the lap joint should be corrected to the true circumferential path the tape would take if no joint existed. As shown in Figure 17, this requires correction for only one-half of the tape rise. With the width, w, eliminated, the equation becomes:

$$Deduction\,(inches) = \frac{8N}{3} \times \frac{t}{2} \times \sqrt{t/2d} \tag{4}$$

$$= \frac{4Nt}{3} \times \sqrt{t/2d} \tag{5}$$

c) It is also shown in Figure 17 that no deductions for deadwood at lap joints are required, since the deductible and additive volumes at lap joints are equal.

19.6 Expansion and Contraction of Steel Tank Shells due to Liquid Head

19.6.1 Expansion and contraction of steel tank shells due to liquid head shall be taken into consideration. This adjustment need not be made for tanks with a capacity of less than 500 bbl.

19.6.2 The effect of liquid head may be introduced into the capacity table in the following ways.

a) Reduce strapped circumferences to zero stress condition by using Equation (6) (see 19.6.3) and by applying expansion effects of progressively increasing liquid levels at successive course levels.

b) By strapping the tank with maximum liquid level and destressing the tank by courses for decreasing liquid levels.

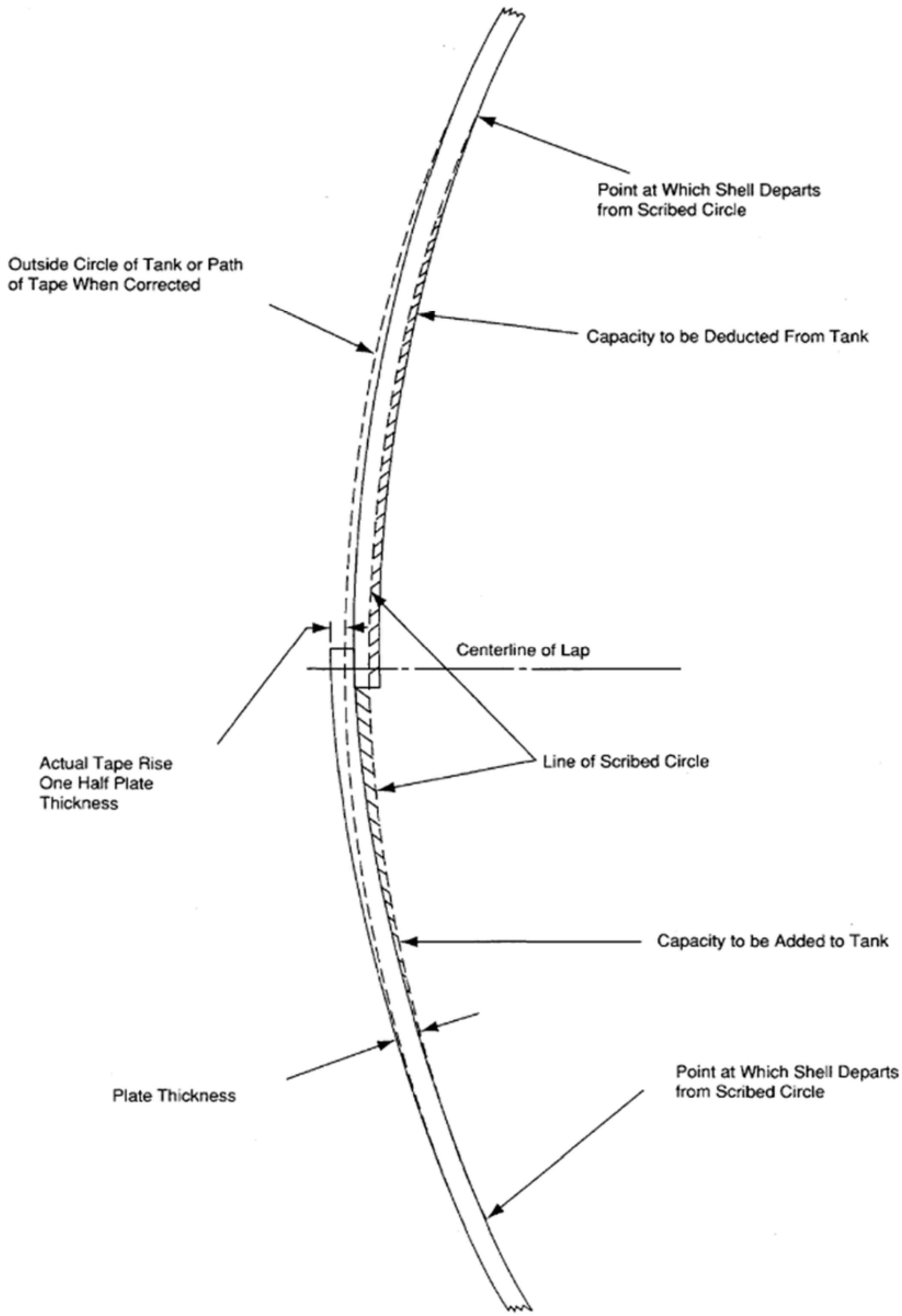


Figure 17—True Circumference vs Tape Path at Axial Lap Joint Away from Circumferential Joint

19.6.3 Field circumference measurements shall be adjusted to "empty tank" or unstressed basis. Then the volume calculations should proceed with volumes adjusted to show progressively increasing capacity, including expansion effects, at successively higher levels by rings. Strapped circumferences should be corrected to zero stress condition by means of the following equation:

$$\Delta C = \frac{-WhC^2}{2\pi Et} \tag{6}$$

where

ΔC is circumference correction to empty tank or unstressed condition;

W is weight of liquid per unit volume;

h is liquid head above strapped elevation;

C is strapped circumference before correction;

E is modulus of elasticity of metal in tank shell;

t is shell thickness at strapped elevation.

NOTE All units shall be consistent. For example, in the customary system, ΔC, C, h, and t may be in inches; W, in pounds per cubic inch; and E in pounds per square inch. The corrected strapped circumference is then stressed to a "ring full" basis by expanding the unstressed circumference for each ring by the height of the liquid above the circumferential elevation necessary to fill each ring.

Volume correction per increment, Δv:

$$\Delta v\,(\text{first or bottom ring}) = 0 \tag{7A}$$

$$\Delta v\,(\text{second ring}) = \frac{\pi Wd^3}{4E}\left(\frac{h_1}{t_1}\right) \tag{7B}$$

$$\Delta v\,(\text{third ring}) = \frac{\pi Wd^3}{4E}\left(\frac{h_1}{t_1} + \frac{h_2}{t_2}\right) \tag{7C}$$

$$\Delta v\,(n\text{th ring}) = \frac{\pi Wd^3}{4E}\left(\frac{h_1}{t_1} + \frac{h_2}{t_2} + \ldots + \frac{h_{n-1}}{t_{n-1}}\right) \tag{7D}$$

where

Δv is additional tank volume resulting from tank shell expansion due to increased head of an increment one unit deep above the ring;

W is weight of liquid per unit volume;

d is nominal tank diameter;

W is modulus of elasticity of metal in tank shell;

h_1, h_2, etc. is height of shell rings;

t_1, t_2, etc. is thickness of shell rings.

NOTE All units shall be consistent. For example, in the customary system, Δv may be in cubic inches; W in pounds per cubic inch; d, h, and t, in inches; and E, in pounds per square inch. The increment corresponding to Δv is 1 in. If the capacity table is made in X-in. increments, Δv shall be divided by 4.

19.7 Expansion and Contraction of Steel Tank Shells due to Temperature

19.7.1 Expansion and contraction of unheated steel tank shells should be calculated. It may be necessary to estimate the service temperature and compute volume corrections for expansion of the tank shell due to the increase in temperature. Such estimates of temperature should be checked after tanks are in service. The correction procedure for computing the volume to be added to the total volume calculated for the tanks from strapping in the unheated conditions is as follows:

Cross-sectional area correction:

$$K = 1 + 12.4 \times 10^{-6}\,\Delta T_s + 4.0 \times 10^{9}\,\Delta^2 T_s \tag{8}$$

where

ΔT_S is tank shell steel temperature minus 60 °F (all tank strapping circumference measurements for steel tanks are at 60 °F).

19.7.1.1 For non-insulated metal tanks, the temperature of the shell may be computed as follows (refer to Annex D):

$$T_s = \left[\left(7 \times T_L\right) + T_a\right] \div 8 \tag{9}$$

where

T_L is liquid temperature;

T_a is ambient temperature.

19.7.1.2 For insulated metal tanks, the temperature of the shell may be taken as closely approximating the adjacent liquid temperature, in which case, $T_S = T_L$.

19.7.2 In applying these principles to upright cylindrical tanks, the horizontal cross-sectional area may be taken as a function of tank calibration. The coefficient determined from Equation (8) (see 19.7.1) is predicated on a thermal expansion for low-carbon steel per degree Fahrenheit.

NOTE The cross-sectional correction [Equation (8)] will have to be modified for stainless steel tanks based upon the coefficient of expansion for the type of stainless steel.

19.7.3 The third dimension, height, needed to generate volume is a function of gauging and should be considered separately. The volumes reflected on tank tables are derived from area times incremental height. Therefore, K-factors for correction of areas have the same ratio as volume corrections and may be applied directly to tank table volumes.

19.7.4 The shell temperature correction factor is to be applied to volumes obtained from capacity tables that are at 60 °F and are unrelated to the corrections designed to account for volume expansion and contraction of the product itself. Depending upon certain requirements, this shell temperature correction factor may be built into the capacity table for a specific operating temperature.

19.7.5 With application of online computers, the temperature correction factor can be continuously updated to reflect varying liquid and ambient conditions. Such an updated factor may then be used to determine the actual volume in the tank (refer to example calculation in D.2 of Annex D).

19.8 Effect of Tilt on Cylindrical Portion of Tank

19.8.1 The amount of tilt in shell height should be measured. For tanks tilted less than 1 part in 70 parts, the error in a vertical capacity table for the cylindrical portion will be less than 0.01 % by volume and the effect may be disregarded. If the amount of tilt is 1 in 70 or more, the vertical capacity table should be adjusted to a zero-tilt basis. The following equation may be used to determine the percentage volume correction due to tilt:

$$\text{Volume Correction, percent} = 100\left(\sqrt{1+m^2}-1\right) \tag{10}$$

where

m is the amount of tilt per foot of shell height, in feet (or decimal part thereof).

19.8.2 The following tabulation shows the volume correction in percent for various amounts of tilt:

Tilt, Feet Per 100 Feet	Volume Correction percent
1.4	+0.0098
1.6	+0.0128
1.8	+0.0162
2.0	+0.0200
2.2	+0.0242
2.4	+0.0288
2.6	+0.0338

19.9 Floating Roofs

19.9.1 General

The capacity table should be prepared on the basis of gauging from the striking point upward to the liquid level in the gauge hatch. The preparation of the gauge table is related to the method used for obtaining field data in the zone of partial displacement, that is, whether liquid calibrated or linear measured (see Section 17).

19.9.2 Liquid Calibration for Floating Roof Displacement

19.9.2.1 The displacement of a floating roof through the critical zone, A to B (see Figure 15), is most accurately determined by liquid calibration, as presented in API 2555. Following this procedure will result in a gauge table with the floating roof treated as deadwood. This type of gauge table is more fully described in 19.8.2.

19.9.2.2 Above Position B (see Figure 15), capacities should be corrected to account for the change in roof displacement resulting from the difference between the density of the calibration liquid and that of the liquid being gauged. It is convenient to correct the table to an assumed particular API Gravity near that of the average liquid that will be handled in the tank. This correction should be computed as follows:

$$\text{Correction (gallons)} = W\left(\frac{1}{p_c}-\frac{1}{p_a}\right) \tag{11}$$

where

W is floating weight of roof in pounds;

p_c is pounds per gallon of the calibration liquid;

p_a is pounds per gallon of a liquid having the assumed particular API Gravity on which the table is based.

19.9.2.3 After correction to an assumed API Gravity, the table is accurate only if at time of gauging the API Gravity at the tank liquid temperature is the same as the API Gravity for which the table is prepared. Usually the API Gravity is different, and it is therefore necessary to correct a volume taken from the table. This correction is described in 19.9.5.

19.9.3 Measurement Procedure for Floating Roof Displacement

19.9.3.1 *Liquid Level Below Position A in Figure 15*—This range can be accurately calibrated by measurements as described in Sections 8 through 14.2. All deadwood shall be deducted.

19.9.3.2 *Liquid Level Between Positions A and B in Figure 15*—This range cannot be accurately calibrated by measurements described in Sections 8 through 14.2. The upper and lower limits should be clearly indicated on the gauge table with a note stating that this range should be avoided for critical measurements.

19.9.3.2.1 In calibrating this range by the measurement procedure (see Annex B), all deadwood, including the geometric shape of the roof, should be deducted. This should be carried up to Position B, the location of which shall be determined by the calculator.

19.9.3.2.2 Since the shape of the roof changes between Position A and Position B, it is necessary to take an arbitrary distribution of roof displacement to make the roof displacement at Position B equivalent to the floating weight.

19.9.3.2.3 Since the displaced volume of liquid is contingent upon an assumed specific gravity of liquid to be handled in the tank, and since the shape of the roof and tank bottom may change with time, it is advisable to allow 2 in. (or 50 mm) of depth below Position A and above Position B in establishing the critical zone. This allowance does not influence any calculation but only the upper and lower limits of the critical zone indicated on the gauge table.

NOTE An accuracy problem often encountered when a roof position is measured is that the roof will be in the high position for maintenance. Often, when the tank is returned to service, the roof legs are adjusted to the low position. This action will create errors in the capacity table if it is computed and issued with the roof in the high position. The quantities from the start of the low position to the end of the high position of the roof critical zone will be in error. To ensure the accuracy of the floating roof capacity table, it is necessary to confirm the operational roof position with the tank operator or owner before development of the capacity table.

19.9.4 Liquid Level Above Position B

The liquid level above Position B (see Figure 15) range can be accurately calibrated by subtracting a volume of liquid equal in weight to the floating weight. The floating weight should include the roof plus any appurtenances that are carried up and down in the tank with the roof. The floating weight is calculated by the builder and given on the drawings and on the roof nameplate. The floating weight should include half of the ladder weight, half of the weight of the hinged or flexible supported parts of the drain, all of the swing line float, and half of the swing pipe. Above Position B, deadwood that is now included as part of the floating weight should be added back in to the gross or open tank capacity and thereafter accounted for by the floating weight deduction. Deadwood not included in the floating weight is retained in the gross capacity.

19.9.5 Capacity Table with Floating Roof Treated as Deadwood

19.9.5.1 In this type of gauge table, the weight of the floating roof should be taken into account by reducing the gross capacity by the volume displaced by the roof based on an assumed API Gravity near that of the average liquid that will be handled in the tank.

19.9.5.2 For liquid levels below Position B, Figure 15, all deadwood should be deducted as it becomes immersed. This deadwood should include the floating roof, itself, based on its geometric shape.

19.9.5.3 For values above Position B, Figure 15, the gross volume should be reduced by a volume equal to the floating weight divided by the weight per unit volume of a liquid having an assumed API Gravity. These net values are given directly in the gauge table. They are correct only if at the time of gauging the API Gravity at tank liquid temperature is the same as the assumed API Gravity for which the table is prepared.

19.9.5.4 Usually, the API Gravity at tank liquid temperature is different from the assumed API Gravity on which the table is` based. It is, therefore, necessary to include a supplementary correction to the capacity table. This correction is equal to the following:

$$\frac{W}{50}\left(\frac{1}{p_{60}}-\frac{1}{p_{10}}\right) \tag{12}$$

where

W is floating weight of roof, in pounds;

P_{60} is pounds per gallon of a liquid having a 60° API Gravity;

P_{10} is pounds per gallon of a liquid having a 10° API Gravity.

19.9.5.5 The API Gravity correction should be handled by a note on the capacity table requiring the deduction or addition of a constant volume for each degree API Gravity difference from the assumed API Gravity for which the basic capacity table was prepared. This note should contain the following information:

> NOTE A total of __ bbl has been deducted from this table between __ ft __ in. and __ ft __ in. for roof displacement based on a floating weight of __ lb and an observed liquid gravity of __ ° API as observed under conditions of the liquid in which the roof is floating. [This may be at any observed temperature.] Gauged levels above __ ft __ in. reflect this deduction but should be corrected for actually observed gravity of the liquid at prevailing temperatures as follows:
>
> For __ ° API observed, no correction.
>
> For each degree below __ ° API observed, add __ bbl.
>
> For each degree above __ ° API observed, subtract __ bbl.

19.9.6 Capacity Table of Gross or Open-tank Capacity

19.9.6.1 This type of capacity table is prepared by deducting only the deadwood not included as part of the floating weight. A supplementary table accounting for all deadwood may be prepared and included as a supplement to the capacity table for all positions up to Position B, Figure 15.

19.9.6.2 For use above Position B, Figure 15, the floating weight should be given on the capacity table. In using the capacity table, the gross or open tank volume is reduced by a volume equal to the floating weight divided by the weight per unit volume of the liquid. The weight per unit volume should be based on a density at 60 °F (or 15 °C) consistent with the liquid in the tank. Also, the weight per unit volume shall be based on the same temperature as the gross volume from which the roof displacement will be subtracted.

19.9.6.3 When using the capacity table, it is convenient to first convert the gross volume to a standard temperature, usually 60 °F (or 15 °C). Then, the floating weight is divided by the weight per unit volume at 60 °F (or 15 °C) before subtracting from the gross volume. When this is to be done, a supplementary table may be prepared giving values of the displacement for a range of values of the API Gravity over which the tank is intended to be used.

19.9.6.4 When applicable, the following notation shall be included on all gauge tables that are prepared for the open or shell capacity of floating roof tanks:

> "The quantities listed on this capacity table do not include adjustments to compensate for floating roof displacement."

19.9.6.5 All capacity tables for floating roof tanks should have the limits of the zone of partial displacement clearly marked thereon. A note on the capacity table should state whether this zone was calibrated by liquid calibration or by the measurement method.

19.10 Summary Data on the Capacity Table

The final capacity table should contain the following information.

a) Tank ID.

b) Product name and gravity at 60 °F (or 15 °C).

c) Type of tank (floating roof, cone, insulated, etc.).

d) Floating roof deadweight.

e) Whether recomputed/recalibrated.

f) If recomputed, basis for recomputing.

g) Reference gauge height, maximum fill height, and maximum safe height.

h) Description/location of reference gauge point.

i) Cone up/cone down/flat bottom.

j) It should be noted on the capacity table that the volume below the striking point, whether determined by linear or liquid calibration, is included in the first increment.

k) Temperature at which the capacity table is computed if integral to the table. It is recommended the capacity table be computed at 60 °F (or 15 °C) and temperature correction factors be applied externally.

l) Contractor company's name.

m) Date of calibration/recalibration/recomputation.

n) Standard on which calibration is based.

19.11 Recalibration Requirements

19.11.1 Storage tanks may require recalibration/recomputation periodically. The factors impacting the frequency of recalibration and/or recomputation are described in Annex A.

19.11.2 However, vertical or upright tanks should in any case be remeasured and calibrated under the following conditions.

a) When restored to service after being disconnected or abandoned.

b) When disassembled and re-erected or when "moved bodily."

c) When deadwood is changed, when concrete or other material is placed on the tank bottom or on the shell of the tank, or when the tank is changed in any manner that would affect the incremental or total volume.

19.12 Certification of Capacity Tables

19.12.1 Certification of a capacity table ensures that all measurements and computations are performed in accordance with this standard. It is recommended that this certification be performed by recognized contractors in the specialized field of calibration or by person or persons who can demonstrate their compliance with this standard.

19.12.2 In the process of certification, it is the responsibility of the contractor and/or individual and tank owners to clearly document and specify any deviations from the standard. Any deviations from the standard that result in nonconformity with the standard renders the capacity table unsuitable for custody transfer usage.

Annex A
(normative)

Tank Calibration Frequency and Recomputation of Calibration Tables

A.1 Terms and Definitions

For the purposes of this document, the following definitions apply.

A.1.1
Class A tanks
Tanks with a capacity greater than 1000 bbl that are used for custody transfer measurement or as the primary backup measurement to another custody transfer measurement system.

A.1.2
Class B tanks
Tanks used for custody transfer or for primary backup measurement that do not meet the criteria for Class A tanks and those tanks used for inventory reporting purposes only.

A.1.3
complete tank calibration
Tank calibration that is based on external and internal measurements taken at the time of calibration.

A.1.4
external tank calibration
Tank calibration that is based on external measurements taken at time of calibration and previously obtained internal measurements.

A.1.5
recomputation
The process of developing a revised capacity table, based on previously established tank calibration measurements.

A.1.6
uniform zone
The vertical section of the tank, above the bottom and floating roof critical zones, where the incremental volumes have stabilized.

A.2 Tank Calibration Frequency Determination for Upright Cylindrical Tanks

A.2.1 General

The date for the next calibration should be determined routinely from a calculation based on the current (new) calibration and the previous calibration.

The interval to the next calibration shall be determined for all Class A tanks, and should be determined for all Class B tanks, based on the difference in volume for the uniform zone from the current (new or latest) capacity table and the volume for the same uniform zone from the previous capacity table. For non-insulated tanks, the maximum interval that can be applied based on this analysis is 25 years. The minimum interval that can be required is 5 years.

For Class A tanks, the initial calibration shall be a complete calibration. Complete tank calibration shall also be performed each time the tank is emptied and cleaned for an internal API 653 inspection, repair, or modification. Repair/modifications of a tank may include changes in tank deadwood, reference gauge height, tank structure (both internal and external including floating roof), and repairs to tank and tank bottom (bottom replacement).

For Class B tanks, the initial calibration should be a complete calibration. Complete tank calibration should also be performed each time the tank is emptied and cleaned for an internal API 653 inspection, repair, or modification.

If a tank calibration is being performed for the sole purpose of meeting the recalibration frequency interval determined from the prior calibration, either a complete or external tank calibration may be performed to satisfy that interval.

A.2.2 Tank Calibration Frequency for Class "A" NON-INSULATED Tanks

A.2.2.1 Tank Calibration Frequency for Tanks Placed Into Service on or After January 1, 2020

— A calibration for a tank placed into service on or after January 1, 2020 shall be completed upon any of the following conditions:

  — prior to its initial commissioning;

  — between 1 and 5 years following its initial commissioning;

  — whenever the tank is opened for API 653 inspection, repair, or modification;

  — as determined by tank calibration frequency calculation if sooner than the next API 653 inspection, repair, or modification.

— If the tank calibration frequency calculation indicates the calibration interval to be 5 years, the tank owner/operator should investigate the cause for the change.

A.2.2.2 Tank Calibration Frequency for Tanks Placed Into Service Prior to January 1, 2020

— For each existing tank that was in service prior to January 1, 2020, the next calibration, for purposes of implementing the tank calibration frequency program, shall be performed at the next API 653 inspection, repair, or modification or, if no API 653 inspection, repair, or modification is scheduled, the later of the interval determined by the tank calibration frequency calculation or January 1, 2035.

— Recalibrations thereafter shall be completed at the earlier of the next API 653 inspection; when the tank has been repaired or modified; or in accordance to the tank calibration frequency calculation.

— If the tank calibration frequency calculation indicates the calibration interval to be 5 years, the tank owner/operator should investigate the cause for the change.

A.2.3 Tank Calibration Frequency for Class "A" INSULATED Tanks

— An insulated tank shall undergo a complete calibration following an internal API 653 inspection or internal repair or modification.

— Insulated tanks should be recalibrated in accordance with the tank calibration frequency calculation.

— If the tank calibration frequency calculation indicates the calibration interval to be less than the next scheduled internal inspection, the difference shall be investigated and documented if the frequency calculation is not followed.

A.2.4 Tank Calibration Frequency for Class "B" Tanks

— Class "B" tanks should be recalibrated:

a) when the tank is emptied and cleaned;

b) when relocated; or

c) in accordance with the tank calibration frequency calculation.

— If the tank calibration frequency calculation indicates the calibration interval to be 5 years or less, the tank owner/operator should investigate the cause for the change.

A.2.5 Volume Shift Calculation Procedure (Between Two Consecutive Calibrations)

1) The previous and new tank capacity tables shall be corrected to the same reference temperature using CTSh (tank shell temperature correction) calculations as referenced in this standard.

2) The uniform zones of the tank should be determined from the incremental factor sheets for both the previous and new tank capacity tables (see Figure A.1).

3) From the two tank capacity tables, generated by the previous (immediately prior) and current calibrations, select the same lower and upper gauged level in the uniform zone of the tank that meet the below listed criteria.

   a) For the low gauge—Select a specific level that is 12 in. above the bottom of the uniform zone.

   b) For the high gauge—Select a specific level that is 12 in. below the top of the uniform zone.

4) Calculate the volume shift percent by:

$$\text{Volume Shift Percent} = \left|\frac{(V_{H2} - V_{L2}) - (V_{H1} - V_{L1})}{(V_{H1} - V_{L1})}\right| \times 100$$

where

V_{H2} is volume at high gauge on new table;

V_{L2} is volume at low gauge on new table;

V_{H1} is volume at high gauge on previous table;

V_{L1} is volume at low gauge on previous table.

EXAMPLE

V_{H2} = 65,063.22 bbl

V_{L2} = 4,395.00 bbl

V_{H1} = 65,089.96 bbl

V_{L1} = 4,429.75 bbl

$$\text{Volume Shift Percent} = \left|\frac{(65{,}063.22 - 4{,}395.00) - (65{,}089.96 - 4{,}429.75)}{(65{,}089.96 - 4{,}429.75)}\right| \times 100$$

Volume Shift Percent = 0.013

5) Use the tank calibration interval calculation to determine the next interval based on the calculated volume shift percentage.

	LINE NO	Gauge From	Gauge To	Number of Increments	Incremental Factor per incr.	Total Volume
	0	----	00-01	1	11.1950340	11.1950
	1	00-01	00-02	1	27.9304806	39.1255
	2	00-02	00-03	1	46.8776582	86.0032
	3	00-03	00-04	1	71.8044428	157.8076
	4	00-04	00-06	2	109.2196885	376.2470
	5	00-06	00-07	1	141.1043809	517.3514
	6	00-07	00-08	1	169.8221143	687.1735
	7	00-08	00-09	1	198.0691384	885.2426
	8	00-09	00-10	1	228.4267896	1,113.6694
	9	00-10	00-11	1	258.1795495	1,371.8490
	10	00-11	01-02	3	290.9255756	2,244.6257
	11	01-02	01-03	1	317.0379736	2,561.6637
	12	01-03	01-04	1	339.8142888	2,901.4780
	13	01-04	01-05	1	363.3394531	3,264.8174
	14	01-05	01-09	4	384.3059454	4,802.0412
	15	01-09	01-10	1	408.0992613	5,210.1405
	16	01-10	01-11	1	425.7292118	5,635.8697
	17	01-11	02-00	1	441.5720370	6,077.4417
	18	02-00	02-01	1	455.3199733	6,532.7617
	19	02-01	02-06	5	461.3735181	8,839.6293
	20	02-06	02-07	1	463.4660536	9,303.0953
	21	02-07	02-08	1	463.4407240	9,766.5360
	22	02-08	02-09	1	463.3342866	10,229.8703
	23	02-09	02-11	2	463.3837817	11,156.6379
	24	02-11	03-00	1	463.6121230	11,620.2500
	25	03-00	03-01	1	463.6522242	12,083.9022
	26	03-01	03-02	1	463.7048605	12,547.6071
	27	03-02	03-03	1	463.7692345	13,011.3763
	28	03-03	03-06	3	463.8479049	14,402.9200
	29	03-06	03-07	1	463.9493059	14,866.8694
	30	03-07	03-08	1	464.0682470	15,330.9376
	31	03-08	03-09	1	464.2078121	15,795.1454
	32	03-09	03-10	1	464.3760415	16,259.5215
	33	03-10	04-02	4	464.5545715	18,117.7397
	34	04-02	04-11	9	466.0329323	22,312.0361
	35	04-11	05-00	1	7.2112851	22,319.2474
	36	05-00	05-01	1	7.2105659	22,326.4580
	37	05-01	05-02	1	7.2086891	22,333.6667
	38	05-02	05-03	1	7.2055235	22,340.8722
	39	05-03	05-04	1	7.1756076	22,348.0478
	40	05-04	05-05	1	329.6346921	22,677.6825
	41	**05-05**	**09-04**	**47**	**465.9793532**	**44,578.7121**
	42	**09-04**	**09-05**	**1**	**465.9709615**	**45,044.6831**
	43	**09-05**	**17-03**	**94**	**465.9644948**	**88,845.3456**
	44	**17-03**	**17-04**	**1**	**465.9616649**	**89,311.3072**
	45	**17-04**	**33-02**	**190**	**465.9581194**	**177,843.3499**
	46	**33-02**	**33-03**	**1**	**465.9537497**	**178,309.3037**
Uniform zone	**47**	**33-03**	**41-02**	**95**	**465.9483838**	**222,574.4001**
	48	**41-02**	**41-03**	**1**	**465.9417239**	**223,040.3419**
	49	**41-03**	**49-01**	**94**	**465.9331528**	**266,838.0582**
	50	**49-01**	**49-02**	**1**	**465.9346528**	**267,303.9929**
	51	**49-02**	**57-00**	**94**	**465.9371528**	**311,102.0852**
	52	**57-00**	**57-01**	**1**	**465.9401528**	**311,568.0254**
	53	**57-01**	**65-00**	**95**	**465.9436528**	**355,832.6724**
	54	**65-00**	**65-01**	**1**	**465.9476528**	**356,298.6201**
	55	**65-01**	**73-04**	**99**	**465.9521528**	**402,427.8832**

Figure A.1—Uniform Zone As Identified on an Increment Table

A.2.6 Tank Next Calibration Interval Calculation

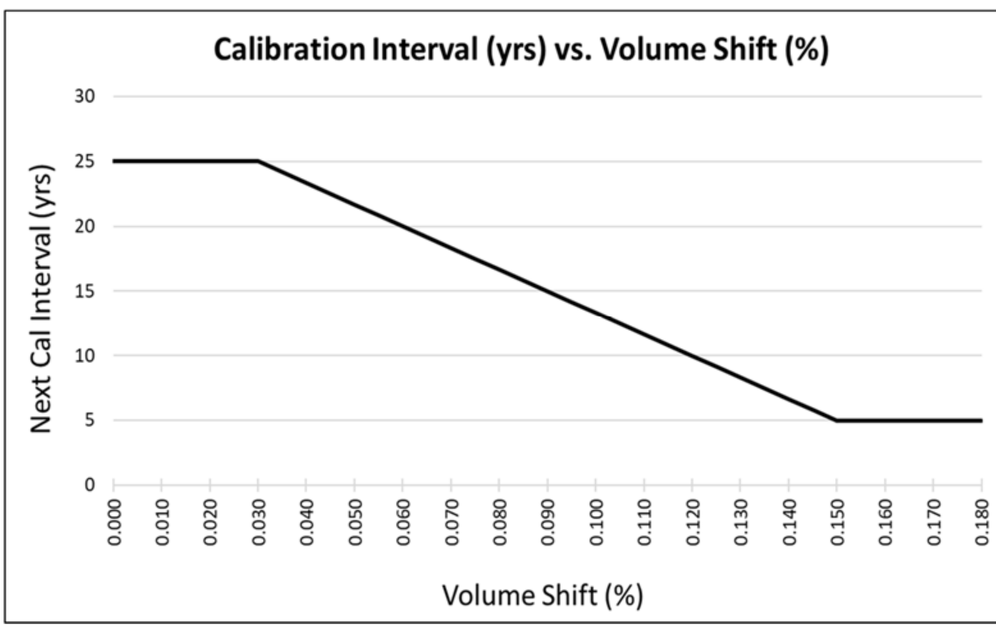
Calculate the next calibration interval in years as shown in Table A.1. Example calculation results are shown in Table A.2. A summary of the relationship between tank volumetric shift and calibration intervals is shown in Figure A.2. The calibration interval shall be no less than 5 years and no greater than 25 years. for volume shifts between 0.030 % and 0.150 %, the calculated next calibration interval shall be rounded to the nearest whole year.

Table A.1—Next Calibration Interval Calculation

Volume Shift Range	Next Calibration Interval (years)
≤0.030 %	Next Calibration Interval = 25
0.030–0.150 %	Next Calibration Interval = 30 − 16,666.7 × Volume Shift Percent
≥0.150 %	Next Calibration Interval = 5

Table A.2—Examples of Tank Calibration Interval Calculation Results

Volume Low (V_{L1})	Volume High (V_{H1})	Volume Low (V_{L2})	Volume High (V_{H2})	Volume Shift (%)	Calculation Result (years)	Next Calibration Interval (years)
4,429.75	65,089.96	4,395.00	65,063.22	0.013 %	27.83	25
14,382.68	187,931.69	15,098.44	188,807.28	0.092 %	14.67	15
2,015.86	18,644.54	2,019.04	18,664.37	0.100 %	13.33	13
4,887.65	28,104.39	4,876.09	28,130.99	0.164 %	2.67	5



Volume Shift (%)	Next Cal Interval (yrs)
≤ 0.030	25
0.036	24
0.042	23
0.048	22
0.054	21
0.060	20
0.066	19
0.072	18
0.078	17
0.084	16
0.090	15
0.096	14
0.102	13
0.108	12
0.114	11
0.120	10
0.126	9
0.132	8
0.138	7
0.144	6
≥ 0.150	5

Figure A.2—Summary of Tank Volume Shift (%) Relationship to Tank Calibration Interval (years)

A.3 Guidelines for Recomputation of Calibration Tables

A.3.1 General

This guideline is intended to provide a general framework and a technical basis to enable terminal operators and tank owners to make sound decisions relating to the recomputation of capacity tables.

A.3.2 Factors Impacting Recomputation

Recomputation should be considered when operating variables of the storage tank change. These variables are product temperature, specific gravity of product contained within the tank, and modification of the reference gauge height.

A.3.3 Acceptable Overall Volume Variability and Criteria Tables

In order to establish acceptance limits of variation on measurement and operating variables, a determination must be made as to what is the overall variability in tank volume that could be considered significant. Such a determination may be made using criteria tables.

Changes in the gravity of the product stored within the tank and reference gauge height variation may affect table accuracy. Under these circumstances, a recomputation of the capacity table should be considered.

Table A.3 provides an illustration of specific gravity variations on capacity table volume. Using Table A.3, depending on the allowable volume variation, a user can determine specific gravity variation to consider for recomputation. Recomputation can be performed as new density measurements are made available.

If the reference gauge height has changed due to external modification, a recomputation and/or reissuance should be performed.

If the tank capacity table is recomputed, the previous calibration date shall remain in effect and annotated on that tank capacity table along with the reissuance date for the recomputation.

Recomputations shall not be used as the basis for tank calibration frequency interval determinations.

If the deadweight of the floating roof has changed, a recomputation of the tank capacity table should be considered.

Table A.3—Product Specific Gravity Impact to Volume (Illustrative)

Variation in Specific Gravity %	Approximate Variation in Volume % [a]
10	0.008–0.015
20	0.015–0.030
30	0.030–0.040
40	0.040–0.050
50	0.050–0.065

[a] Actual variation in hydrostatic head correction volume could be higher than specified, depending on tank plate thickness.

A.3.4 Development of Capacity Table

It is suggested that the tank capacity table be developed in distinct parts.

— Part 1: Basic capacity table considering the tank steel reference temperature, e.g. 60 °F, the tank reference density impacting hydrostatic head correction, and deadwood corrections.

— Part 2: Floating roof corrections, if included in the capacity table, should be applied after the basic table is developed.

Annex B
(informative)

Example Calculations for Upright Cylindrical Steel Tank—Aboveground

B.1 Circumference Corrections

B.1.1 Correction of Circumferences—Working Tape vs Master Tape

See Figure B.2.

Master tape at 10 lb tension = 100.0026 ft per 100.0 ft measured

$$\frac{100.0026}{100.00\ \text{feet}} \approx \frac{X}{210.68\ \text{feet}}$$

$X = 210.6855\ \textit{feet}$
Corrected Master Tape Measurement at 68 °F

B.1.2 Temperature Correction from 68 °F to 60 °F

See Figure B.2.

$(68° - 60°) = 8°\text{F difference} \times 0.00000645\ \text{coefficient of expansion}$

$1.0 - (8 \times .00000645) = 0.9999484$

$0.9999484 \times 210.6855 = 210.6746$ ft. Corrected Master Tape Measurement at 60°F

210.6900 ft.	Working Tape Circumference
–210.6746 ft.	Master Tape Circumference
0.0154 ft.	Correction made to each working tape circumference

B.1.3 Deduction for Circumference Tape Rise

See Table B.2.

Tape rise correction for circumference *A* and *B* due to measurement taken over butt straps, in feet:

$$\left[\frac{2NtW}{d} + \frac{8Nt}{3}\sqrt{\frac{t}{d}}\right] \div 12$$

where

N is number of butt straps per ring;

t is amount of rise (thickness of straps), in inches;

W is width of straps, in inches;

d is nominal diameter of tank, in inches.

$$\text{Correction}_A = \left[\frac{2 \times 14 \times 1 \times 13}{d} + \frac{8 \times 14 \times 1}{3} \sqrt{\frac{1}{804}} \right] \div 12 = 0.1474 \text{ feet}$$

$$\text{Correction}_B = \left[\frac{2 \times 14 \times 0.75 \times 10}{804} + \frac{8 \times 14 \times 0.75}{3} \sqrt{\frac{0.75}{804}} \right] \div 12 = 0.0930 \text{ feet}$$

Tape rise correction for circumference C through F due to measurement taken over lap joint:

$$\left[\frac{4Nt}{3} \times \sqrt{\frac{t}{2d}} \right] \div 12$$

$$\text{Correction}_C = \left[\frac{4 \times 14 \times 0.3125}{3} \sqrt{\frac{0.3125}{2 \times 804}} \right] \div 12 = 0.0068 \text{ feet}$$

$$\text{Correction}_D = \left[\frac{4 \times 14 \times 0.25}{3} \sqrt{\frac{0.25}{2 \times 804}} \right] \div 12 = 0.0048 \text{ feet}$$

$$\text{Correction}_E = \text{Correction}_D \quad \text{–same–} \quad = 0.0048 \text{ feet}$$

$$\text{Correction}_F = \text{Correction}_D \quad \text{–same–} \quad = 0.0048 \text{ feet}$$

B.1.4 Correction of Measured Circumferences to Empty Tank Basis

See Table B.2 and Figure B.1.

$$\text{Correction for circumferences} = -\frac{WhC^2}{2\pi Et}$$

where

W is weight of liquid, in pounds per cubic foot;

h is height of liquid, in feet;

C is measured circumference, in feet;

E is modulus of elasticity of steel (29,000,000 psi);

t is thickness of steel, in inches.

Or more conveniently expressed as:

$$-K\frac{GhC^2}{t}$$

where

$$K=\frac{62.3}{24\pi E}=0.00000002849239$$

G is observed specific gravity of liquid in tank (1.0 in this example).

Correction_A = no correction. On riveted tanks, the circumference at the bottom of the first ring does not expand or contract in a magnitude equal to that reflected by the formula. It is recommended that the formula not be applied to this circumference.

$$\text{Correction}_B = K\left(\frac{1\times 31.2917\times(210.6496)^2}{0.4375}\right)=0.0904\ \text{feet}$$

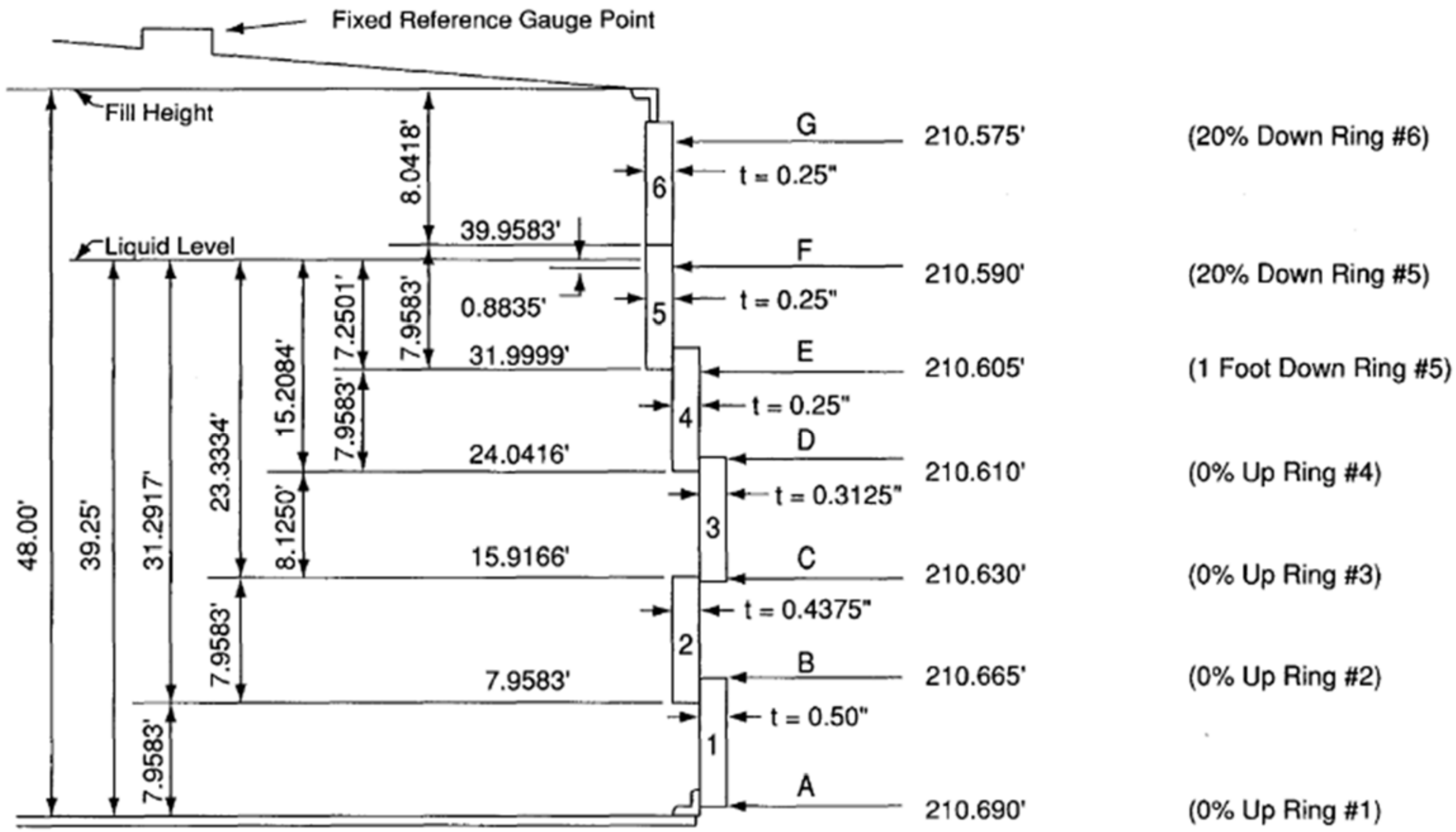
$$\text{Correction}_C = K\left(\frac{1\times 23.3334\times(210.6146)^2}{0.3125}\right)=0.0944\ \text{feet}$$

$$\text{Correction}_D = K\left(\frac{1\times 15.2084\times(210.5946)^2}{0.25}\right)=0.0769\ \text{feet}$$

$$\text{Correction}_E = K\left(\frac{1\times 7.2501\times(210.5896)^2}{0.25}\right)=0.0366\ \text{feet}$$

$$\text{Correction}_F = K\left(\frac{1\times 0.8835\times(210.5746)^2}{0.25}\right)=0.0045\ \text{feet}$$

Correction_G = No correction



Composite Construction to Illustrate:

Riveted In-and-Out Arrangement.
Riveted Shingled Arrangement.
Butt-Welded Arrangement.

Note: The tank shell illustrated above may not be encountered in actual service. This example is used only to illustrate the different aspects to computations which are contained in the example calculations.

Figure B.1—Upright Cylindrical Tank, Composite Construction

United States Department of Commerce
National Institute of Standards and Technology
Gaithersburg, Maryland 20899

REPORT OF CALIBRATION

For: 100 Foot Lufkin Steel Tape NIST No. 15557

Submitted by:

This tape was calibrated under applied tension while supported on a horizontal flat surface. The distances between the terminal points of the indicated intervals have the following lengths at 20 degrees Celsius (68 degrees Fahrenheit):

TENSION (pounds)	INTERVAL (feet)	LENGTH (feet)	UNCERTAINTY (feet)
10	0 to 50	50.0019	0.0005
10	0 to 100	100.0026	0.0010
30	0 to 100	100.0210	0.0010

The uncertainty is based on the limits imposed by the standards used for the calibration, the length of the interval, the character of the terminal points, and the behavior of the tape.

The terminal points of the indicated intervals are the centers of the graduations near the tape edge where the shortest graduations appear.

The average AE value for this tape is 109091 pounds. (AE=Average Elasticity)

The average weight per foot of this tape is 0.01296 pound.

The assumed thermal expansion of this tape is 0.00000645 FT/FT/DEG F.

The exact relationship between the international system of units and the U.S. customary units of length is one foot equals 0.3048 meter.

Tables of computed lengths and tensions for various temperatures and suspensions are attached. The tables are computed from the catenary tape equation and the tape physical constants. All support points are equally spaced along a horizontal line and the tension is horizontally applied.

Measurements were made by ________________________________.

For the Director,

Order No. GD-024
Test No. 821/250176-92
Date: May 12, 1992

Dr. Dennis A. Swyt, Chief
Precision Engineering Division
Center for Manufacturing Engineering

Figure B.2—Typical NIST Report of Calibration

Table B.1—Typical Measurement Record of an Upright Cylindrical Steel Tank for Example Calculations

Date: 5/19/92
Strapped by: WS SL

Tank No.: 117
(Old Tank No.): N/A
Owner's Name: S.R. Co.
Plant or Property name: Corley Terminal
Location: Corley, Illinois
Manufactured by: Braker Plate Co.
Erected by: Braker Plate Co.
Prepare 3 copies, 1 -inch Increments in gallon Fractions to none
Table Form or Size Desired: S.R. Co. Form 746, 11 by 17½ inches

A. Total Shell Height: 48'-0"
B. Shell to Gauge Point: 0'-6½"
C. Total A Plus B: 48'-6½"
D. Total Gauge Height: 48'-6¼"

Horizontal Distance of Gauge Point to Tank Shell: 2'-0"
Describe Gauge Point: Top lip of 8' diameter hatch, opposite hinge
Location of Overflow from Top of Shell: 2'-6"
Safe Fill Height (meas.) 45'-5¾" By Customer: N/A

Type of Roof: Cone (¾ inch, 12-inch slope) Weight of Floating Roof: 4900 pounds (See Deadwood)
Tank Contents—Name: Water Avg. Liquid Temp., °F: 72
Gauge: 39'-3"; Tank Service Gasoline API Gravity: 60.0 at 60°F

Master tape measurement 210.680' at 10 lbs. Tension NIST No. 15557
Working Tape circumference 210.690' at 20 lbs. Tension
Diff -0.01'

Shell Circumferences:

A 210.690'	D 210.610'	G 210.575'
B 210.665'	E 210.605'	H
C 210.630'	F 210.590'	J

Descriptions of Shell Plates and Joints

Bottom Ring							
Ring No.	Thickness (in.)	Type of Vertical Joint	Set, In or Out	Width of Lap or Strap (in.)	Thickness, Butt Strap (in.)	No. of Sections	Inside Ring Height
1	$^1/_2$	Butt rivet	Out	13	1.00	14	7'-11$^1/_2$"
2	$^7/_{16}$	Butt rivet	In	10	.75	14	7'-11$^1/_2$"
3	$^5/_{16}$	Lap rivet	Out	2$^1/_4$	—	14	8'-1$^1/_2$"
4	$^1/_4$	Lap rivet	In	2	—	14	7'-11$^1/_2$"
5	$^1/_4$	Lap weld	In	1$^7/_8$	—	14	7'-11$^1/_2$"
6	$^1/_4$	Butt weld	—	—	—	14	8'-0$^1/_2$"
7	—	—	—	—	—	—	—

Deadwood Measurements (continued from Table B.1)

Description	No.	Size	Elevation	
			From	To
Bottom angle	1	6 × 5 × 1/2” at 16.2 lb × 210.6’	0’-0”	0’-6”
Column bases	1	8” channel at 11.5 lb × 7.5’	0’-3 1/2”	0’-11 1/2”
Column	1	12” channel at 20.7 lb	0’-11 1/2”	48’-0”
Column	1	9” channel at 13.4 lb	0’-11 1/2”	48’-0”
Inside butt straps	14	17” × 1/2” at 28.9 lb	0’-6”	7’-11 1/2”
Inside butt straps	14	15” × 3/8” at 19.13 lb	7’-11 1/2”	15’-11”
Manways	2	20” diameter × 7”	1’-6”	3’-6”
Sump	1	24” diameter × 10”	Below 0’-0”	
Rafters	35	6” channel at 8.2 lb	47’-6”	48’-0”

NOTE Type of bottom 3.5” crown up at center. Roof type: 8” diameter aluminum pontoon floating roof, operating elevation at gauge point 3’-6” to underside of pontoon. ’ = feet; No. = Number; ” = inch(es); Meas. = Measurements; lb = pounds; Diff. = Difference; Avg. Liquid Temp. = Average Liquid Temperature.

Table B.2—Summary of Circumference Corrections

Circumference	Measured Circumference (ft)	Less Master Tape Correction	Less Tape Rise	Less Liquid Head	Less Plate Thickness	Corrected Internal Circumference
A	210.690 ft	0.0154	0.1474	0	0.2618	210.2654
B	210.665 ft	0.0154	0.0930	0.0904	0.2291	210.2371
C	210.630 ft	0.0154	0.0068	0.0944	0.1636	210.3498
D	210.610 ft	0.0154	0.0048	0.0769	0.1309	210.3820
E	210.605 ft	0.0154	0.0048	0.0366	0.1309	210.4173
F	210.590 ft	0.0154	0.0048	0.0045	0.1309	210.4344
G	210.575 ft	0.0154	None	None	0.1309	210.4287

NOTE ft = feet.

B.1.5 Correction of Outside to Inside Circumference

Circumference deduction for plate thickness = $\frac{\pi t}{6}$

where

t is plate thickness in inches.

Ring No.	Thickness (in.)	Correction (ft)
1	0.5	0.2618
2	0.4375	0.2291
3	0.3125	0.1636
4	0.25	0.1309
5	0.25	0.1309
6	0.25	0.1309

B.1.6 Additional of Liquid Head Stress to Internal Circumferences

The same formula used in B.1.4 can be used to calculate the expansion of the tank shell. This computation expands the tank shell based upon the density of product to be stored in the tank. This correction is used to determine an average stressed inside diameter of the tank. By using the stressed inside diameter of the tank, the expansion and contraction of the tank shell due to liquid head is more representative for volume computations.

$$\text{Correction} = K\frac{GhC^2}{t}$$

where

G is specific gravity at 60 °F of the liquid to be stored in the tank (0.7389 in the example).

$$\text{Correction}_A = \text{No correction.}$$

$$\text{Correction}_B = K\left(\frac{0.7389 \times 7.9583(210.2371)^2}{0.4375}\right) = 0.0169 \text{ feet}$$

$$\text{Correction}_C = K\left(\frac{0.7389 \times 8.125(210.3498)^2}{0.3125}\right) = 0.0242 \text{ feet}$$

$$\text{Correction}_D = K\left(\frac{0.7389 \times 7.9583(210.3820)^2}{0.25}\right) = 0.0297 \text{ feet}$$

$$\text{Correction}_E = K\left(\frac{0.7389 \times 1.0 \times (210.4173)^2}{0.25}\right) = 0.0037 \text{ feet}$$

$$\text{Correction}_F = K\left(\frac{0.7389 \times 1.5917 \times (210.4344)^2}{0.25}\right) = 0.0059 \text{ feet}$$

$$\text{Correction}_G = K\left(\frac{0.7389 \times 1.6084 \times (210.4287)^2}{0.25}\right) = 0.0060 \text{ feet}$$

Internal Circumference *B*, ring full stressed = 210.2371 + 0.0169 = 210.2540 ft

Internal Circumference *C*, ring full stressed = 210.3498 + 0.0242 = 210.3740 ft

Internal Circumference *D*, ring full stressed = 210.3820 + 0.0297 = 210.4117 ft

Internal Circumference *E*, ring full stressed = 10.4173 + 0.0037 = 10.4210 ft

Internal Circumference *F*, ring full stressed = 210.4344 + 0.0059 = 210.4405 ft

Internal Circumference *G*, ring full stressed = 210.4287 + 0.0060 = 210.4347 ft

B.1.7 Incremental Volume Calculation

The following calculations determine the inch incremental volume for each ring when it is just full of oil, in this case, 60.0 API Gravity, 0.7389 specific gravity (see Figure B.1).

Ring No. 1

Internal Circumference *A*:	210.2654
Internal Circumference *B* plus 0.2291 plate thickness:	210.4662
	420.7316

$$\text{Full stressed circumference} = \frac{420.7316}{2} = 210.3658 \text{ ft}$$

$$\text{Internal radius} = \frac{210.3658}{2\pi} \bullet 12 = 401.7691 \text{ in.}$$

$$\text{Incremental volume} = \pi\left(401.7691\right)^2 \div 9702 = 52.2687 \text{ bbl/in.}$$

Ring No. 2

Internal Circumference *B*, ring full stressed:	210.2540
Internal Circumference *C* minus 0.2291 plate thickness:	210.1207
	420.3747

$$\text{Full stressed circumference} = \frac{420.3747}{2} = 210.1874 \text{ ft}$$

$$\text{Internal radius} = \frac{210.1874}{2\pi} \bullet 12 = 401.4284 \text{ in.}$$

$$\text{Incremental volume} = \pi\left(401.4284\right)^2 \div 9702 = 52.1801 \text{ bbl/in.}$$

Ring No. 3

Internal Circumference *C*, ring full stressed:	210.3740
Internal Circumference *D* plus 0.1309 plate thickness:	<u>210.5426</u>
	420.9166

Full stressed circumference = $\frac{420.9166}{2} = 210.4583$ ft

Internal radius = $\frac{210.4583}{2\pi} \bullet 12 = 401.9457$ in.

Incremental volume = $\pi\left(401.9457\right)^2 \div 9702 = 52.3147$ bbl/in.

Ring No. 4

Internal Circumference *D*, ring full stressed:	210.4117
Internal Circumference *E*, ring full stressed:	<u>210.4210</u>
	420.8327

Full stressed circumference = $\frac{420.8327}{2} = 210.4164$ ft

Internal radius = $\frac{210.4164}{2\pi} \bullet 12 = 401.8657$ in.

Incremental volume = $\pi\left(401.8657\right)^2 \div 9702 = 52.2938$ bbl/in.

Ring No. 5

Internal Circumference *F*, ring full stressed: 210.4405 ft

Internal radius = $\frac{210.4405}{2\pi} \bullet 12 = 401.9117$ in.

Incremental volume = $\pi\left(401.9117\right)^2 \div 9702 = 52.3058$ bbl/in.

Ring No. 6

Internal Circumference *G*, ring full stressed: 210.4347 ft

Internal radius = $\frac{210.4347}{2\pi} \bullet 12 = 401.9007$ in.

Incremental volume = $\pi\left(401.9007\right)^2 \div 9702 = 52.3029$ bbl/in.

B.1.8 Volumetric Increase for Each Ring for Each Inch of Liquid Head Above the Ring

$$\text{Volumetric Increase } (\Delta V) = \frac{\pi W G d^3 h}{4Et}$$

where

W is 62.3 lb/ft^3;

G is 0.7389 specific gravity, at 60 °F, of liquid to be stored in the tank;

d is 66.9673 ft average inside diameter (from ring full stressed circumference);

h is ring height in inches;

t is plate thickness in inches;

E is modulus of elasticity of steel (29,000,000 psi).

Let $K = \frac{\pi W G d^3}{4E}$; then $K = 0.3744156$ and $\Delta V = K\frac{h}{t}$

Ring No. 1: $\Delta V = \frac{95.5}{0.50} \times \frac{0.3744156}{9702} = +0.0074 \text{ barrels per inch}$

Ring No. 2: $\Delta V = \frac{95.5}{0.4375} \times \frac{0.3744156}{9702} = +0.0084 \text{ barrels per inch}$

Ring No. 3: $\Delta V = \frac{97.5}{0.3125} \times \frac{0.3744156}{9702} = +0.0120 \text{ barrels per inch}$

Ring No. 4: $\Delta V = \frac{95.5}{0.25} \times \frac{0.3744156}{9702} = +0.0147 \text{ barrels per inch}$

Ring No. 5: $\Delta V = \frac{95.5}{0.25} \times \frac{0.3744156}{9702} = +0.0147 \text{ barrels per inch}$

Ring No. 6: $\Delta V = \text{None}$

Incremental Correction:

Ring No. 1: None

Ring No. 2: 0.0074 = 0.0074 bbl/in.

Ring No. 3: 0.0074 + 0.0084 = 0.0158 bbl/in.

Ring No. 4: 0.0074 + 0.0084 + 0.0120 = 0.0278 bbl/in.

Ring No. 5: 0.0074 + 0.0084 + 0.0120 + 0.0147 = 0.0425 bbl/in.

Ring No. 6: 0.0074 + 0.0084 + 0.0120 + 0.0147 + 0.0147 = 0.0572 bbl/in.

B.2 Computation of Capacity Table Height

a) Shell height: 48’-0”

b) Shell to gauge point: 0’-6 1/2”

c) Item a) plus Item b): 48’-6 1/2”

d) Reference gauge height: 48’-6 1/4”
Difference: 1/4” up at strike point

Shell height: 48’-0”
Less difference: 0’-0 1/4”
Less overflow distance: 2’-6”
Effective capacity table height: 45’-5 3/4”

B.3 Deadwood Computations

B.3.1 Structural Deadwood

From	To	Description	Computations	Deduction in Barrels per Inch
0’-0”	0’-6”	Bottom angle	210.6 × 12 × 4.75 ÷ 9702 ÷ 6	−0.2062
0’-0”	0’-11 1/2”	Column base	7.5 × 12 × 3.36 ÷ 9702 ÷ 8	−0.0039
0’-0”	46’-0”	Center column	(6.03 + 3.89) ÷ 9702	−0.0010
0’-0”	7’-11 1/2”	Butt straps	14 × 17 × 0.5 ÷ 9702	−0.0123
0’-0”	15’-11”	Butt straps	14 × 15 × 0.375 ÷ 9702	−0.0081
0’-0”	3’-6”	Manways	20^2 × 0.7854 × 7 × 2 ÷ 9702 ÷ 20	−0.0227
Below	0’-0”	Sump	24^2 × 0.7854 × 10 ÷ 9702	+0.4663
0’-0”	48’-0”	Rafters	None due to overflow	—
NOTE ” = inch(es); ’ = foot/feet.				

B.3.2 Bottom Computations (3 1/2 in. Crownup Bottom)

Bottom ring, bbl/in. = 52.2683

NOTE 1/4 in. up at strike point. Difference to be considered in capacity table heights.

52.2683 × 3.5/3 = 60.9797 bbl ÷ $(3.5)^3$ = 1.4222671 spread factor

Tank Heights		(Difference in Spread Heights) Multipliers	Spread Factor × Multiplier Barrels per Increment
From	To		
0'-0"	0'-0 1/4"	$3.5^3 - 3.25^3 = 8.546875$	−12.1559
0'-0 1/4"	0'-1 1/4"	$3.25^3 - 2.25^3 = 22.9375$	−32.6233
0'-1 1/4"	0'-2 1/4"	$2.25^3 - 1.25^3 = 9.4375$	−13.4226
0'-2 1/4"	0'-3 1/4"	$1.25^3 - .25^3 = 1.9375$	−2.7556
0'-3 1/4"	0'-3 1/2"	$.25^3 = 0.015625$	–0.0223
			60.9797 bbl
NOTE ' = foot/feet; " = inch(es).			

B.3.3 Roof Computation

Data = 8 in. diameter pontoon; aluminum internal floating roof weight = 4900 lb; compute at 60.0 API; pounds per gallon = 6.151

Due to the roof design, the roof shall float in one-half (1/2) of the pontoon diameter

Displacement: 4900 lb ÷ 6.151 lb/gal ÷ 42 = 18.9671 bbl

Spread: 18.9671 bbl ÷ $(4)^2$ = 1.1854438 spread factor

Tank Heights		(Difference in Spread Heights) Multipliers	Spread Factor × Multiplier Barrels per Increment
From	To		
3'-6 1/4"	3'-7 1/4"	$1^2 = 1$	−1.1854
3'-7 1/4"	3'-8 1/4"	$2^2 - 1^2 = 3$	−3.5563
3'-8 1/4"	3'-9 1/4"	$3^2 - 2^2 = 5$	−5.9272
3'-9 1/4"	3'-10 1/4"	$4^2 - 3^2 = 7$	−8.2982
			18.9671 bbl
NOTE ' = foot/feet; " = inch(es).			

B.3.4 Deadwood Recapitulation

Note that the following heights are computed to allow for the difference in elevation at the strike point in the tank vs the intersection of the tank shell and bottom.

Table Height		Structural Deadwood	Bottom (bbl/in.)	Roof (bbl/in.)	Total Deadwood (bbl/in.)
From	To				
	0’-0”	+0.4147	−12.1559	—	−11.7412
0’-0”	0’-1”	−0.2062	−32.6233	—	−32.8295
0’-1”	0’-2”	−0.2062	−13.4226	—	−13.6288
0’-2”	0’-3”	−0.2066	−2.7556	—	−2.9622
0’-3”	0’-4”	−0.2087	−0.0223	—	−0.2310
0’-4”	0’-5”	−0.2101	—	—	−0.2101
0’-5”	0’-6”	−0.1616	—	—	−0.1616
0’-6”	0’-10”	−0.0162	—	—	−0.0162
0’-10”	0’-11”	−0.0158	—	—	−0.0158
0’-11”	1’-0”	−0.0144	—	—	−0.0144
1’-0”	1’-5”	−0.0133	—	—	−0.0133
1’-5”	1’-6”	−0.0076	—	—	−0.0076
1’-6”	3’-5”	+0.0094	—	—	+0.0094
3’-5”	3’-6”	+0.0037	—	—	+0.0037
3’-6”	3’-7”	−0.0133	—	−1.1854	−1.1987
3’-7”	3’-8”	−0.0133	—	−3.5563	−3.5696
3’-8”	3’-9”	−0.0133	—	−5.9272	−5.9405
3’-9”	3’-10”	−0.0133	—	−8.2982	−8.3115
3’-10”	7’-10”	−0.0133	—	—	−0.0133
7’-10”	7’-11”	−0.0128	—	—	−0.0128
7’-11”	8’-0”	−0.0107	—	—	−0.0107
8’-0”	15’-10”	−0.0091	—	—	−0.0091
15’-10”	15’-11”	−0.0070	—	—	−0.0070
15’-11”	24’-0”	−0.0010	—	—	−0.0010
24’-0”	24’-1”	−0.0010	—	—	−0.0010
24’-1”	31’-11”	−0.0010	—	—	−0.0010
31’-11”	32’-0”	−0.0010	—	—	−0.0010
32’-0”	39’-11”	−0.0010	—	—	−0.0010
39’-0”	40’-0”	−0.0010	—	—	−0.0010
40’-0”	45’-5”	−0.0010	—	—	−0.0010
45’-5”	45’-5 3/4”	−0.0008	—	—	−0.0008

NOTE ’ = foot/feet; ” = inch(es); bbl = barrels.

Table B.3A—Tank Table Run Sheet

From	**To**	**No. of Increments**	**Incremental** (bbl/in.)	**Liquid Head Correction** (bbl/in.)	**Deadwood Deduction**	**Net** (bbl/in.)	**Accumulated Barrels**
—	0’-0”	—	13.0672	0	−11.7412	1.3260	1.3260
0’-0”	0’-1”	1	52.2687	0	−32.8295	19.4392	20.7652
0’-1”	0’-2”	1	—	0	−13.6288	38.6399	59.4051
0’-2”	0’-3”	1	—	0	−2.9622	49.3065	108.7116
0’-3”	0’-4”	1	—	0	−0.2310	52.0377	160.7493
0’-4”	0’-5”	1	—	0	−0.2101	52.0586	212.8079
0’-5”	0’-6”	1	—	0	−0.1616	52.1071	264.9150
0’-6”	0’-10”	4	—	0	−0.0162	52.2525	473.9250
0’-10”	0’-11”	1	—	0	−0.0158	52.2529	526.1779
0’-11”	1’-0”	1	—	0	−0.0144	52.2543	578.4322
1’-0”	1’-5”	5	—	0	−0.0133	52.2554	839.7092
1’-5”	1’-6”	1	—	0	−0.0076	52.2611	891.9703
1’-6”	3’-5”	23	—	0	+0.0094	52.2781	2,094.3666
3’-5”	3’-6”	1	—	0	+0.0037	51.2724	2,146.6390
3’-6”	3’-7”	1	—	0	−1.1987	51.0700	2,196.7090
3’-7”	3’-8”	1	—	0	−3.5696	48.6991	2,246.4081
3’-8”	3’-9”	1	—	0	−5.9405	46.3282	2,292.7363
3’-9”	3’-10”	1	—	0	−8.3115	43.9572	2,336.6935
3’-10”	7’-10”	48	—	0	−0.0133	52.2554	4,844.9527
7’-10”	7’-11”	1	—	0	−0.0128	52.2559	4,897.2086
7’-11”	8’-0”	1	52.2023	0.0056	−0.0107	52.1972	4,949.4058
8’-0”	15’-10”	94	52.1801	0.0074	−0.0091	52.1784	9,854.1754
15’-10”	15’-11”	1	52.2811	0.0137	−0.0070	52.2878	9,906.4632
15’-11”	24’-0”	97	52.3147	0.0158	−0.0010	52.3295	14,982.4247
24’-0”	24’-1”	1	52.2990	0.0248	−0.0010	52.3228	15,034.7475
24’-1”	31’-11”	94	52.2938	0.0278	−0.0010	52.3206	19,952.8839
31’-11”	32’-0”	1	52.3028	0.0388	−0.0010	52.3406	20,005.2245
32’-0”	39’-11”	95	52.3058	0.0425	−0.0010	52.3473	24,978.2180
39’-11”	40’-0”	1	52.3036	0.0535	−0.0010	52.3561	25,030.5741
40’-0”	45’-5”	65	52.3029	0.0572	−0.0010	52.3591	28,433.9156
45’-5”	45’-5 3/4”	1	39.2272	0.0429	−0.0008	39.2693	28,473.1849

NOTE bbl = barrels; ” = inch(es); ’ = foot/feet.

Table B.3B—Run Sheet for Soft Conversion to Metric

The following run sheet is a soft conversion of the previous example run sheet. The previous volumes have been multiplied by a factor that converts barrels at 60 °F to cubic meters at 15 °F.

The factor is as follows:

Volume conversion: $$\frac{\text{9702 cubic inches per barrel}}{\text{61023.744095 cubic inches per cubic meter}} = 0.158973$$

Temperature conversion: 15 °C = 59 °F (refer to Annex D)

$$K = 1 + \left[\left(12.4 \times 10^{-6} \times \Delta Ts\right) + \left(4.0 \times 10^{-9} \times \Delta Ts^{2}\right)\right]$$

$$\Delta Ts = \text{steel temperature minus } 60\,°\text{F}$$

$$\Delta Ts = 59 - 60 = \text{-}1$$

$$K = 1 + \left[\left(.0000124 \times \text{-}1\right) + \left(.000000004 \times \left(\text{-}1 \times \text{-}1\right)\right)\right]$$

$$K = 0.9999876$$

Both factors multiplied together: $= 0.1589873 \times 0.9999876$

$= 0.1589853$

The following example shows how run sheets are normally presented.

Line No.	Gauge	No.	Cubic Meters Factor	Total
0	00-00-$^{0}/_{0}$	—	—	0.210815
1	00-1-$^{0}/_{0}$	1	3.090547	3.301362
2	00-2-$^{0}/_{0}$	1	6.143177	9.444539
3	00-3-$^{0}/_{0}$	1	7.839010	17.283549
4	00-4-$^{0}/_{0}$	1	8.273230	25.556779
5	00-5-$^{0}/_{0}$	1	8.276554	33.833333
6	00-6-$^{0}/_{0}$	1	8.284264	42.117597
7	00-10-$^{0}/_{0}$	4	8.307381	75.347121
8	00-11-$^{0}/_{0}$	1	8.307442	83.654563
9	1-0-$^{0}/_{0}$	1	8.307667	91.962230
10	1-5-$^{0}/_{0}$	5	8.307842	133.501440
11	1-6-$^{0}/_{0}$	1	8.308746	141.810186
12	3-5-$^{0}/_{0}$	23	8.311451	332.973559
13	3-6-$^{0}/_{0}$	1	8.310536	341.284095
14	3-7-$^{0}/_{0}$	1	8.119380	349.403475
15	3-8-$^{0}/_{0}$	1	7.742442	357.145917
16	3-9-$^{0}/_{0}$	1	7.365504	364.511421
17	3-10-$^{0}/_{0}$	1	6.988550	371.499971
18	7-10-$^{0}/_{0}$	48	8.307842	770.276387
19	7-11-$^{0}/_{0}$	1	8.307904	778.584291
20	8-0-$^{0}/_{0}$	1	8.298589	786.882880
21	15-10-$^{0}/_{0}$	94	8.295600	1566.669280
22	15-11-$^{0}/_{0}$	1	8.312972	1574.982252
23	24-0-$^{0}/_{0}$	97	8.319622	2381.985586
24	24-1-$^{0}/_{0}$	1	8.318601	2390.304187
25	31-11-$^{0}/_{0}$	94	8.318207	3172.215645
26	32-0-$^{0}/_{0}$	1	8.321433	3180.537078
27	39-11-$^{0}/_{0}$	95	8.322452	3971.170018
28	40-0-$^{0}/_{0}$	1	8.323889	3979.493907
29	45-5-$^{0}/_{0}$	65	8.324328	4520.575227
30	45-5-$^{3}/_{4}$	1	6.243270	4526.818497

NOTE No. = Number.

Annex C
(informative)

Guidelines for Computer Input

C.1 Introduction

Throughout the industry, many companies are installing tank capacity tables into their computer systems. Inventory programs and many other systems require the input of capacity tables in order to determine quantities in their facilities. In order to precisely duplicate the existing capacity tables into computer systems, the increment factors shall be utilized to ensure accurate quantities at measured liquid levels.

Exact replication of capacity tables in computer systems is required for custody transfer transactions. *Increment factors* are data used to exactly generate the capacity tables in a condensed form. Increment factors are commonly referred to as *run sheets*, *critical points*, or *skeleton table.* (Refer to Annex B, Tables B.3A and B.3B.)

The increment factors on floppy disk should be requested from the contractor at the time of tank calibration. These data are normally available in an ASCII format utilizing an MS DOS operating system.

C.2 Criteria

C.2.1 Incremental Volume Considerations

When capacity tables are being prepared, the unit volume and the incremental height shall be taken into consideration. The unit volume is commonly barrels, gallons, cubic meters, liters, and cubic feet. The incremental height is the difference between levels of capacity in the capacity table. The incremental heights can be 1 in., $^{1}/_{4}$ in., $^{1}/_{8}$ in., $^{1}/_{16}$ in., 0.1 ft, 0.01 ft, 1 cm, or 1 mm. The most common volumes and incremental heights expressed in capacity tables are barrels per 1 in. and cubic meters per 1 cm with average fractional values to $^{1}/_{16}$ in. and 1 mm, respectively.

C.2.2 Fractions

Fractional values should not be displayed on capacity tables because the fractional values are an average value. When fractional values are used, the quantities will not match the exact volumes generated by a computer program. By interpolation between incremental volumes, the volumes are more precise, and manual interpolation will match the computer generated volumes.

C.2.3 Incremental Factor Development

Incremental factors basically are two items: cylindrical volumes and deadwood displacement.

Cylindrical volumes are the final corrected volumes per increment of each ring or course of which the tank is constructed. If a tank has six rings, then there are six separate volumes per increment for each level of height. If the tank has six 6 ft (8 ft 0 in.) high rings, then a different volume per increment will be shown from 0 ft to 8 ft, 8 ft to 16 ft, 16 ft to 32 ft, etc. For an example, see Annex B.

Deadwood is defined as any appurtenance that adds or deducts volume by its dimensions. The tank bottom, floating roof, sumps, roof supports, and internal piping affects the total tank capacity. These appurtenances are deducted from the cylindrical volume in relation to the measured elevation above or below the strike point or zero elevation on the incremental factor sheet.

The length of the incremental factor sheet is dependent upon the amount of differing elevations that deadwood is distributed inside the tank. Most deadwood is located in the bottom ring or course of a tank. Incremental factors will have many lines of differing volumes from zero elevation to the top of the bottom ring or course. Above the bottom ring, there will be only the incremental volumes (less deadwood) of the successive rings or courses of the tank.

If fewer data lines of the capacity table's incremental factors are utilized in a computer system, then the replication accuracy of the capacity table is distorted. If random points on a capacity are entered as the incremental factors for a computer system, then levels between these points will not match the capacity table and cannot be used for custody transfer transactions.

C.2.4 Replication Accuracy

Exact replication of capacity tables is required for all custody transfer transactions. Whenever possible, it is recommended that unit volumes on capacity tables be expressed in whole numbers (integer) for ease of replication accuracy.

When volumes are expressed to three decimal places or less (e.g. 2,233.455 m^3 or 14,048.01 bbl), software programming shall take into account the truncation and rounding process. In situations where capacity tables are computed in barrels to two decimals and expressed in 1-in. increments, the replication accuracy will be to within 0.02 bbl at any given level throughout a tank. It is not mathematically possible to generate a more precise replication of volume when the certified capacity table is printed in 1-in. increments with volumes to two decimal places and incremental factors used in the computer system are in ½-inch increments and seven significant digits.

C.2.5 Software Considerations

The development of a computer program for determining precise tank capacities shall be based upon the computations detailed in API *MPMS* Ch. 2.2A. Special attention shall be paid to the following items.

a) Actual incremental factors shall be utilized for generating capacities.

b) Appropriate rounding/truncation procedures shall be utilized.

c) Floating roof at rest elevation and critical zone shall be defined.

d) API Gravity used to compute the capacity table shall be known in order to compute the roof correction factor for differing gravities at observed temperatures.

e) Shell temperature correction factors are important for increased accuracy of inventory (see Annex E).

f) Volume correction factors 5B and 6B are needed for correction of product to 60 °F from observed temperature.

C.3 Verification

For custody transactions, the incremental factor accuracy shall be confirmed. It is recommended that levels on the capacity table and computer system be checked for replication at five to six levels in the lower 8 ft 0 in. of the capacity table and at five to six random levels throughout the balance of the capacity table.

C.4 Conclusion

The guidelines presented herein will enable accurate replication of gauge tables for custody transfer transactions using modem computer systems. These systems provide the means for efficient management of tank capacity tables used in custody transfer transactions and inventory control.

It shall be realized, however, that the use of computer systems by itself will not ensure the integrity of the capacity table but is dependent upon the primary data source. It is important to ensure that the primary data source and tank capacity tables are in accordance with the latest *MPMS* standards to obtain the maximum accuracy possible with a computer inventory system.

Annex D
(informative)

Shell Temperature Correction Factors

D.1 Shell Temperature Determination

API Standard 2550, *Method for Measurement and Calibration of Upright Cylindrical Tanks*, introduced first in 1965, establishes the following equation to determine shell temperature (T_S) for uninsulated tanks:

$$T_s = \frac{K \times T_L \times T_a}{K + 1} \qquad \text{(D.1)}$$ [8]

where

K is 1 (assumes equal weightage for liquid and ambient temperatures);

T_L is liquid temperature of liquid within the tank;

T_a is ambient temperature.

Subsequent investigations have concluded that shell temperature is more dependent on the product temperature and proportionately less influenced by ambient temperature.

The shell temperature may be expressed by the following equation:

$$T_s = \frac{K \times T_L \times T_a}{K + 1}$$

where

$$K = \frac{1}{K_I}$$

$$K_I = \left[\left\{4 \times \left(T_L - 150\right)\right\} + \left\{16.5 \times v \times \mu^{0.5}\right\} + \left\{340 \times \mu^{0.32}\right\} + \left(250 - D\right) \right] \times 10^{-4}$$

μ = viscosity: $1 < \mu < 1000$ cp.

v = wind velocity: $0 < v < 30$ mph

T_L = liquid temperature: $T_L < 150$ °F

T_S = shell temperature: °F

T_a = ambient temperature: °F

Value of K may vary from a minimum of 2.5 to 30 and higher depending on extreme conditions (of viscosity and wind velocity).

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[8] Based on "Correlation Predicts Tank Shell Temperature," by S. Sivaraman et al., *Oil and Gas Journal*, October 3, 1988.

For most observations, the K value lies in between 5 and 10.

Assuming an average value of 7 for K, the shell temperature equation may be simplified as follows:

$$T_S = \frac{(7 \times T_L) + T_a}{7+1}$$

$$T_S = \frac{(7 \times T_L) + T_a}{8} \tag{D.2}$$

This simplified equation gives a weightage of approximately 88 % for liquid temperature and 12 % for ambient temperature.

Assuming a value of K of 7 can, however, introduce a minor bias in the determination of shell temperature for extreme cases. Nevertheless, a value of 7 is still estimated to yield a more realistic shell temperature than the value of one used in Equation (D.1). The data used for the development of simplified new Equation (D.2) are limited but considered accurate.

Additional data would be welcome in the interest of improving accuracy of the equation and its application. It may then be possible to develop better average K-factors for various product groupings.

D.2 Shell Temperature Correction Factors (VCF) for Expansion and Contraction of Upright Cylindrical Steel Tanks Due to Temperature

Tanks undergo expansion or contraction due to variations in ambient and product temperatures. Such expansion or contraction in tank volume may be computed once the tank shell temperature is determined.

For tanks that are insulated, the tank shell temperature (T_S) is assumed to be the same as the temperature of the product (T_L) stored within the tank (i.e. $T_S = T_L$). For tanks that are not insulated, the shell temperature is a weighted average of the ambient and the product temperature based upon Equation (D.3).

Once the shell temperature is determined, the shell temperature correction factor (K_C) is computed using Equation (D.4).

$$T_S = \frac{(7 \times T_L) + T_a}{8} \tag{D.3}$$

$$K_C = 1 + \left(12.4 \times 10^{-6} \Delta T_S\right) + \left(4.0 \times 10^{-9} \Delta^2 T_S\right) \tag{D.4}$$

where

T_L is liquid temperature;

T_a is ambient temperature;

T_S is shell temperature;

ΔT_S is shell temperature minus 60 °F.

D.3 Application of Shell Temperature Correction

Case 1: Capacity Table at Standard Temperature of 60 °F

— Volume at a given level at 60 °F = 100,000 bbl.

— Ambient temperature = 70 °F.

— Product temperature = 300 °F.

— Compute capacity table volume reflecting above conditions.

Solution:

a) Calculate shell temperature T_S at 300 °F product temperature:

$$T_S = \frac{(7 \times T_L) + T_a}{8}$$

$$T_S = \frac{7 \times 300 + 70}{8}$$

$$T_S = \frac{2170}{8} = 271.25 \text{ °F} \tag{D.5}$$

b) Compute the shell temperature correction factor at 271.25 °F:

$$K_C = 1 + \left(12.4 \times 10^{-6}\,\Delta T_S\right) + \left(4.0 \times 10^{-9}\,\Delta T_S^{\,2}\right)$$

$$\Delta T_S = \left(T_S - 60\right)\text{°F}$$

$$\Delta T_S = \left(271.25 - 60\right)\text{°F}$$

$$\Delta T_S = 211.25 \text{ °F}$$

$$K_C = 1 + \left(12.4 \times 10^{-6} \times 211.25\right) + \left(4.0 \times 10^{-9}\,\Delta T_S^{\,2}\right)$$

$$K_C = 1.00279801$$

c) Compute the corrected volume:

$$V = \text{Volume at 60 °F} \times \text{Shell Temperature Correction Factor } (K_C)$$

$$V = 100{,}000 \text{ bbl} \times 1.00279801$$

$$V = 100{,}279.80 \text{ bbl}$$

Case 2: Capacity Table Already Corrected for a Product Temperature of 300 °F

When converting an existing capacity table that reflects expansion of the tank shell due to an operating temperature that differs from the observed temperature, use the following procedure.

— Volume at given level at 300 °F = 100,279.8 bbl.

— Ambient temperature = 70 °F.

— Temperature capacity table computed at 300 °F.

— Compute capacity at a product temperature of 200 °F.

Solution:

a) Compute shell temperature at 300 °F:

$$T_S = \frac{7 \times 300 + 70}{8}$$

$$T_S = 271.25 \text{ °F}$$

b) Compute shell temperature correction factor at K_C 300 °F:

$$K_C = 1 + \left(12.4 \times 10^{-6} \Delta T_S\right) + \left(4.0 \times 10^{-9} \Delta T_S^{\ 2}\right)$$

$$\Delta T_S = \left(271.25 - 60\right) \text{°F} = 211.25 \text{°F}$$

$$K_C = 1 + \left(12.4 \times 10^{-6} \times 211.25\right) + \left(4.0 \times 10^{-9} \times 211.25^2\right)$$

$$K_C = 1.00279801$$

c) Correct tank volume to standard temperature of 60 °F:

$$V_{60\text{F}} = \frac{100,279.80}{1.00279801} = 100,000.00 \text{ bbls}$$

d) Compute new shell temperature correction factor at 200 °F:

$$T_S = \frac{7 \times 200 + 70}{8}$$

$$T_S = 183.75 \text{ °F}$$

$$\Delta T_S = \left(T_S - 60\right) \text{°F} = 183.75 - 60 = 123.75 \text{°F}$$

$$\text{New } K_C = 1 + \left(12.4 \times 10^{-6} \times 123.75\right) + \left(4.0 \times 10^{-9} \times 123.75^2\right)$$

$$\text{New } K_C = 1.00159576 \text{ at } 200 \text{°F}$$

e) Compute new capacity table volume at 200 °F:

$$V\text{ new} = 100{,}000.00\text{ bbl} \times 1.0015976$$

$$V\text{ new} = 100{,}159.58\text{ bbl}$$

NOTE Shell temperature correction shall not be confused with volume correction factor corresponding to product temperature. In the above example one shall still apply the volume correction factor corresponding to the observed product temperature of 100 °F or 300 °F, as the case may be, to compute volume of product contained within the tank at 60 °F.

Annex E
(informative)

Underground Tanks

E.1 Conditions and Procedures for Remeasurement

E.1.1 General

Underground storage tanks may be constructed of steel, concrete, or other materials; they may constitute horizontal or vertical cylinders with flat or dished ends, rectangular or irregularly shaped prisms with flat surfaces, or other solids bounded by a combination of flat or curved surfaces. In large underground tanks, more deadwood may be present than in aboveground tanks of comparable size and shape. It is, therefore, important that deadwood be carefully measured. The following procedures may be used in determining the data necessary for the preparation of capacity tables for vertical underground tanks.

E.1.2 Liquid Calibration

Probably the most satisfactory method of calibrating underground tanks (initially and later) is by liquid calibration, as described in API 2555.

E.1.3 Calibration Based on Outside Measurements

Calibration of underground tanks may be completed by following the procedures for outside measurements specified in this standard for aboveground tanks for the same type if the method of construction makes this possible. It shall be recognized that the placing of earth backfill may result in tank deformations that might appreciably affect the tank capacity.

E.1.4 Calibration Based on Inside Measurements

Calibration of underground tanks may be based on inside measurements. The internal measurement procedure, as applied to cylindrical or rectangular tanks, should be carried out by measuring internal diameters or other dimensions for later preparation of a capacity table. This involves measurement of the following.

a) An adequate number of diameters or other dimensions (see note) with their approximate position in the tank.

b) The volume and location of deadwood, that is, of any fitting or other object that adds to or subtracts from the space available for liquid.

NOTE When drawings for the tank are available, the diameters and other measurements should be compared with those obtained from the drawings, and any measurements that show substantial discrepancies on this comparison should be verified. A similar process of check should be employed in all cases in which reliable information beyond the measurements taken is available.

E.2 Diameter Measurements for Upright Cylindrical Steel Underground Tanks

Diameters should be measured after the tank has been filled at least once with liquid at least as dense as the tank is expected to contain. The usual hydrostatic test, if made, will meet this requirement.

Diameters should be measured with steel tapes that meet the requirements of Section 6. Diameter measurements should be taken, as shown in Figure E.1, between diametrically opposite points so that the measured lines pass through a common center point and at the same elevations at which circumferences are to be measured for aboveground tanks of corresponding type. At each such elevation, the following should be done.

a) A minimum of $D/8$, but not less than four diameters at each elevation, should be measured at approximately equal intervals around the tank, where D is the tank diameter expressed in feet.

b) Diameters should be measured not closer than 12 in. to a vertical joint.

If for any reason it is impractical to take measurements at the positions described, then the diameter should be measured from a point as close to the described position as practicable, but not nearer to the horizontal or vertical joints. The reason for the deviation should be recorded in the field notes.

Measurements should be taken with the end of the steel tape attached to a dynamometer, one operator placing the dynamometer on the predetermined point and the second operator placing a rule end on a point diametrically opposite. The tape should be pulled along the rule until the tension for which the tape has been calibrated is registered on the dynamometer. This tension should be not less than 10 lb.

A firm grip should be maintained on the rule and tape to prevent any alteration in their relative positions; the tension should be released; and a reading should be taken on the tape at that end of the rule that was against the side of the tank. The operation should be repeated at the various positions at which measurements are required throughout the tank. The measurements should be recorded clearly in white chalk on the steel plates in such a manner as to indicate the positions at which they were taken. An alternative procedure is given in E.2.

The check measurements of diameters multiplied by 3.1416 should not differ by more than the values given in Table 4.

Corrections for the effect of sag should be applied to the average diameter for each course using the following formula:

$$\text{Correction, in feet} = \frac{W^2 S^3}{24P^2} \quad \text{(E.1)}$$

where

P is pull on tape, in pounds;

S is span of tape, in feet;

W is weight of tape, in pounds per foot.

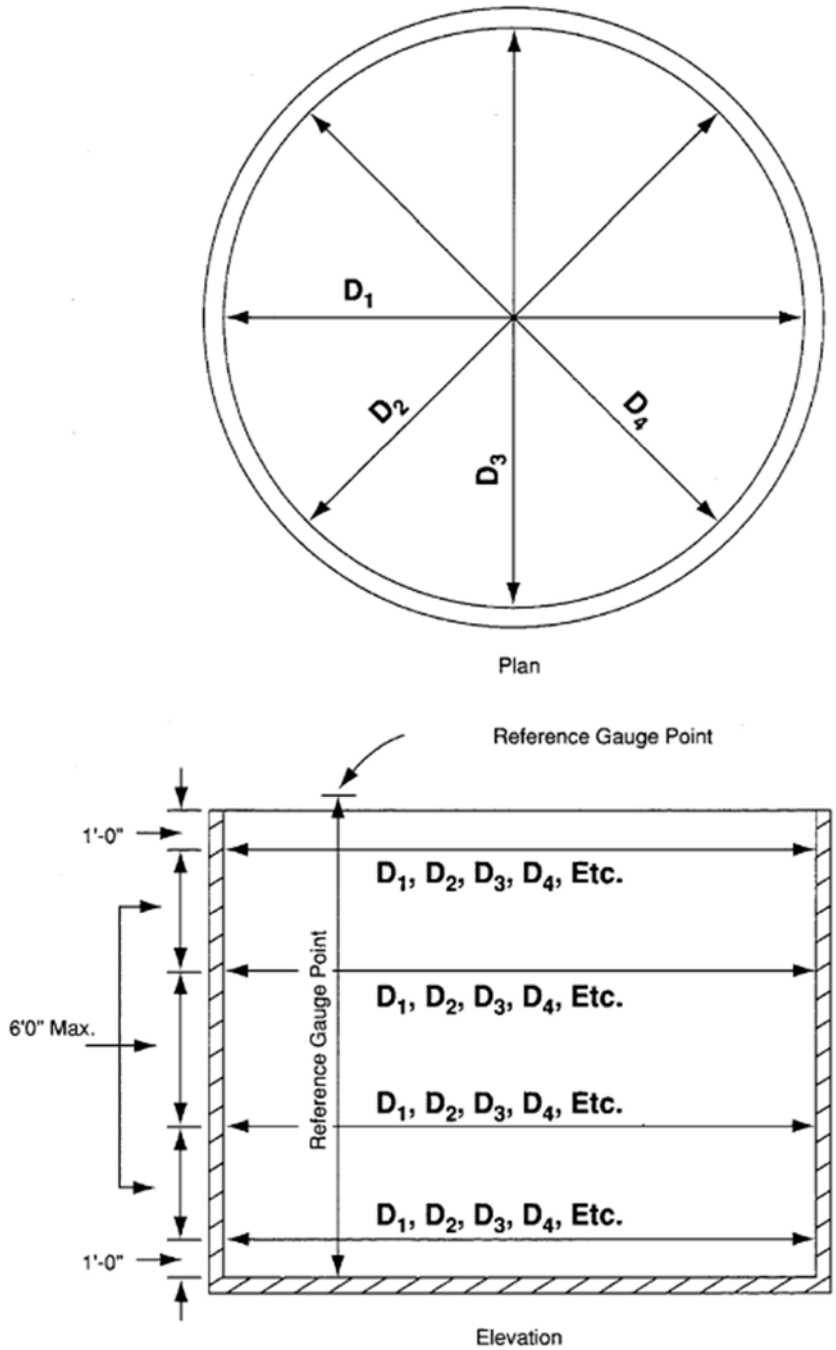

Figure E.1—Locations of Measurements on Upright Cylindrical Concrete Underground Tanks

Corrections for the effect of stretch are unnecessary because the tension applied is that at which the tape was standardized. Corrections for the length of the dynamometer when registering this pull should be made to the average diameter of each course. The dynamometer length at this pull should be measured accurately before it is put into use and subsequently checked before and after the calibration of each tank, the final check being made before leaving the tank site.

As an alternative to the procedure previously outlined, measurements may be made by in the following manner.

a) Establishing plumb lines a few inches distant from the tank wall at the proper locations.

b) Measuring the distance between the plumb lines with the tape resting on the tank floor, thus eliminating the need for a sag correction.

c) Measuring with a rule the distances form the plumb lines to the adjacent tank walls at the required elevations.

d) Adding the two corresponding short-end measurements to the single center floor measurement to determine the required dimension for each elevation.

If a center column makes impractical a direct measurement of the distance between plumb lines, a circular template may be cut and fitted around the base of the column with points on the circumference of this circle marked to correspond with the radial lines on which diameters are to be measured. The total diameter may then be found, equal to the diameter of the template plus the two short-end measurements plus two radial measurements between the circumference of the template and the plumb lines adjacent to the shell.

E.3 Diameter Measurements for Upright Cylindrical Concrete Underground Tanks

a) Diameters should be measured at the following elevations as shown in Figure E.2.

    1) 1 ft above the tank bottom.

    2) 1 ft below the tank roof.

    3) At intermediate elevations not more than 6 ft apart, unless it can be shown that the walls are vertical, in which case measurements at intermediate elevations not more than 12 ft apart are adequate.

    4) At any offsets or abrupt changes in wall dimensions.

b) At each such elevation a minimum of $D/8$, but not less than four diameters, should be measured at approximately equal intervals around the tank, where D is the tank diameter expressed in feet.

c) If for any reason it is impractical to take measurements at the positions described in Items a) and b), then the diameter should be taken as close to the described position as practicable. The reason for deviations should be recorded in the field notes.

d) Diameters should be measured, recorded, and corrected as specified for underground cylindrical steel tanks in E.2.

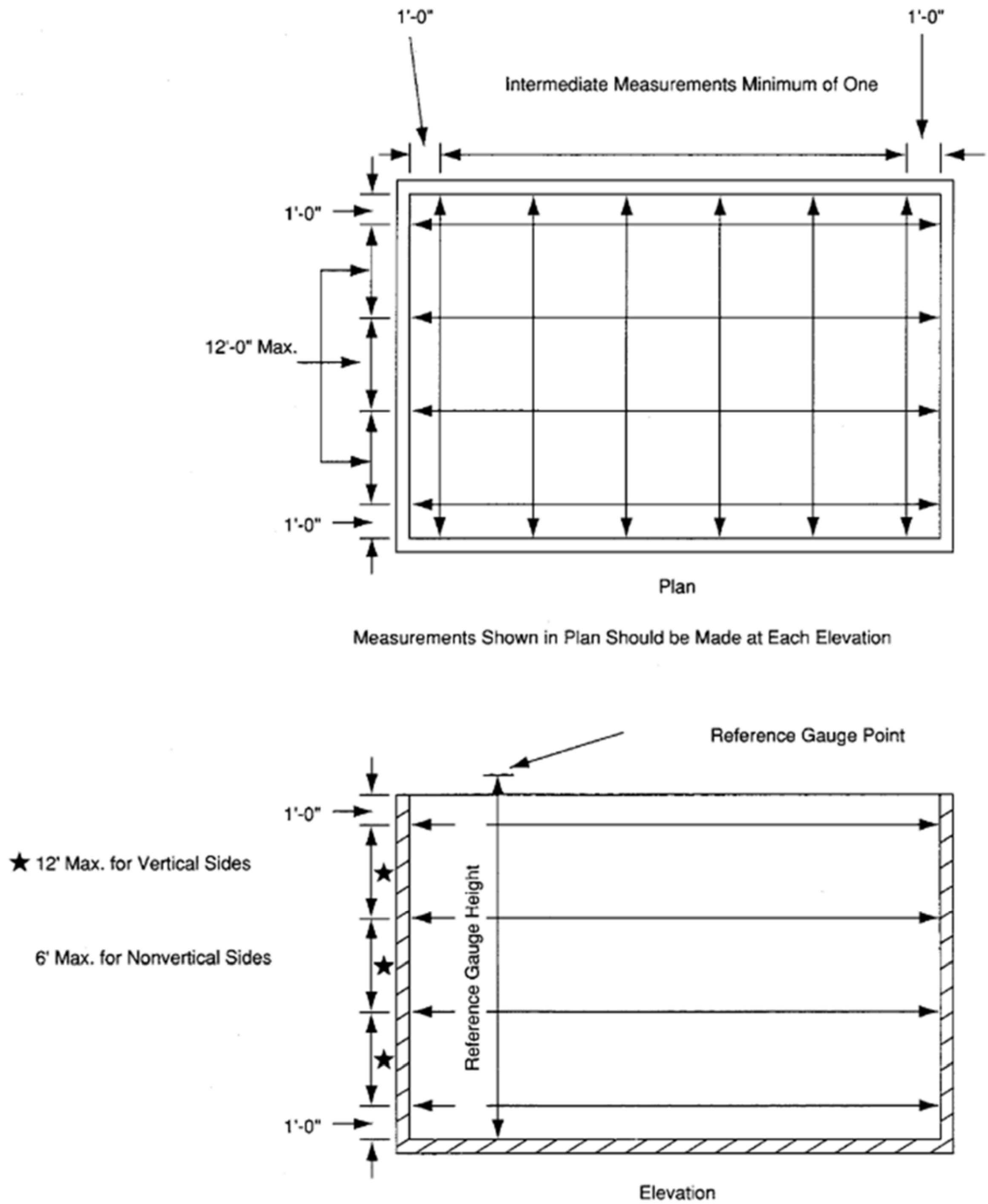

Figure E.2—Locations of Measurements on Rectangular Steel or Concrete Underground Tanks

E.4 Measurements for Rectangular Steel or Concrete Underground Tanks

a) Lengths and widths should be measured at the following elevations, as shown in Figure E.2.

1) 1 ft above the tank bottom.

2) 1 ft below the tank roof.

3) At intermediate elevations not more than 6 ft apart, unless it can be shown that the walls are vertical, in which case measurements at intermediate elevations not more than 12 ft apart are adequate.

4) At any offsets or abrupt changes in wall dimensions.

b) At each such elevation do the following.

1) Two width and two length measurements should be made at points 1 ft inside each of the four walls of the tank.

2) Additional width and length measurements (a minimum of one each) should be made at intermediate points not more than 12 ft apart.

If for any reason it is impractical to take measurements at the positions described in E.3, then the length or width should be taken as close to the described position as practicable. The reason for the deviation should be recorded in the field notes.

Length or width should be measured, recorded, and corrected as specified for underground cylindrical steel tanks in E.2.

Vertical dimensions, plate thicknesses, dimensions of tanks of special shape, measurements of deadwood, and any other special measurements, such as those for unstable bottoms, should be made in accordance with procedures described for aboveground upright cylindrical tanks in Section 13 to Section 16 and as outlined in E.1 to E.4, where applicable.

E.5 Calibration Based on Drawings

In the event that the calibration procedures described in E.4 cannot be used, then liquid calibration or other approved optical methods should be considered. For example, see Figure F.2 and refer to an insulated tank. Capacity tables may be prepared from computations based on the construction drawings and specifications of the tank builder as the least preferred choice.

Annex F
(informative)

Tank Calibration Method Selection [9]

The type of calibration method selected may often be dictated by a number of factors. These factors are broadly grouped into the following.

a) Type of tank—floating or fixed roof.

b) Operational constraints—entry or no entry.

c) Insulation or no insulation.

d) Riveted or welded.

e) Other parameters such as number/size of wind girders.

Selection of any specific method for each of the preceding factors is presented in the form of decision charts (Figures F.1, F.2, and F.3). In the development of these guidelines, it is assumed that the insulation requirements pertain only to the fixed roof tanks.

Also, the term *entry,* as applied to the floating roof tanks, refers to access onto the top of the floating roof with the roof resting on its legs.

The bottom calibration requirements are not considered separately, because they would belong to the same category where entry is required or permitted.

For each category, technology selections are presented in a prioritized order. The priority recommended is based upon the most expedient way of calibration for a given set of conditions, ensuring overall accuracy.

However, the recommended priority is not intended necessarily to optimize the overall cost of calibration. The cost factor associated with any given method is dependent on many factors.

[9] Reproduced in part from *Oil & Gas Journal*, February 5, 1990, Technology Issue. Based on the article “Guidelines Help Select Storage Tank Calibration Method” by S. Sivaraman.

Legend for Figures F.1, F.2, and F3:

LEGEND		
EODR	-	ELECTRO OPTICAL DISTANCE RANGING
MANUAL	-	CONVENTIONAL TAPE STRAPPING
ORLM	-	OPTICAL REFERENCE LINE METHOD
OTM	-	OPTICAL TRIANGULATION METHOD

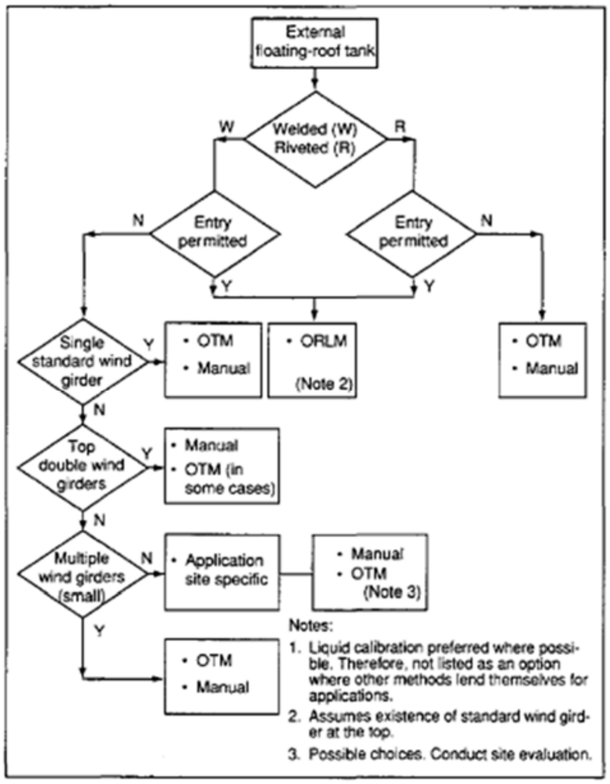

Figure F.1—External Floating Roof Tank Decision Chart

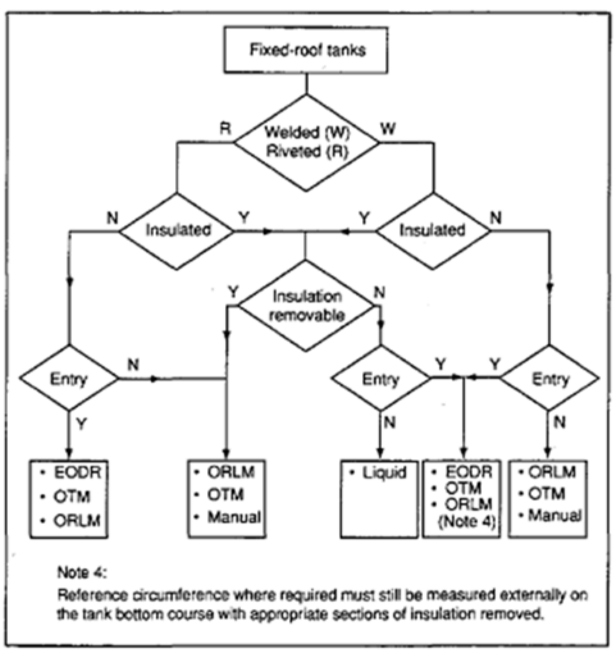

Figure F.2—Fixed Roof Tank Decision Chart

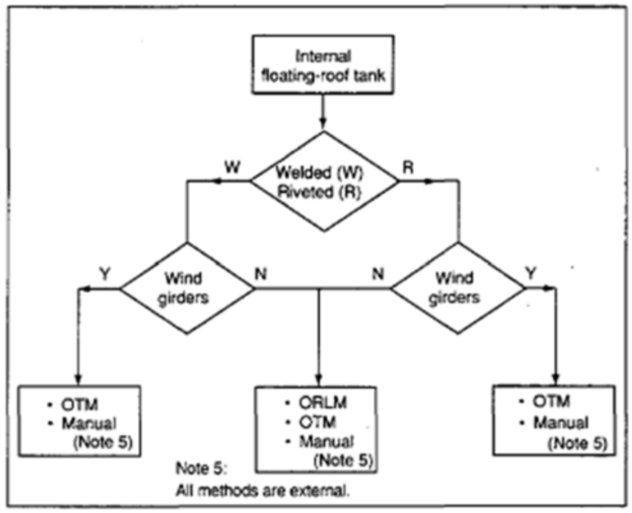

Figure F.3—Chart for Internal Floating Roof Tanks

Bibliography

[1] API *MPMS* Chapter 2.2E, *Manual Methods*

[2] API *MPMS* Chapter 2.2F, *Internal Electro-optical Distance-ranging Method*

[3] API Standard 2552, *Method for Measurement and Calibration of Spheres and Spheroids*

[4] API Standard 2554, *Measurement and Calibration of Tank Cars*

[5] API *MPMS* Chapter 2.7, *Calibration of Barge Tanks*

[6] API *MPMS* Chapter 2.8A, *Calibration of Tanks on Ships and Oceangoing Barges*

[7] ISO 7507-1 [10], *Petroleum and Liquid Petroleum Products—Volumetric Calibration of Vertical Cylindrical Tanks, Part 1: Strapping Method*

[8] ISO 7507-2, *Petroleum and Liquid Petroleum Products—Volumetric Calibration of Vertical Cylindrical Tanks, Part 2: Optical Reference Line Method*

[9] ISO 7507-3, *Petroleum and Liquid Petroleum Products—Volumetric Calibration of Vertical Cylindrical Tanks, Part 3: Optical Triangulation Method*

[10] International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211 Geneva 20, Switzerland, www.iso.org.

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