API Std 2550
October 1965
Price $1.00

MANUAL
OF
PETROLEUM
MEASUREMENT STANDARDS

Chapter 2 ———— Section 1

METHOD FOR MEASUREMENT AND CALIBRATION OF UPRIGHT CYLINDRICAL TANKS

AMERICAN PETROLEUM INSTITUTE	API 2550
AMERICAN SOCIETY FOR TESTING AND MATERIALS	ASTM D 1220
AMERICAN NATIONAL STANDARDS INSTITUTE	ANSI Z11.197

ANSI STANDARD

An ANSI Standard implies a consensus of those substantially concerned with its scope and provisions. An ANSI Standard is intended as a guide to aid the manufacturer, the consumer, and the general public. The existence of an ANSI Standard does not in any respect preclude anyone, whether he has approved the standard or not, from manufacturing, marketing, purchasing, or using products, processes, or procedures not conforming to the standard. ANSI Standards are subject to periodic review and users are cautioned to obtain the latest editions. Producers of goods made in conformity with an ANSI Standard are encouraged to state on their own responsibility in advertising, promotion material, or on tags or labels that the goods are produced in conformity with particular ANSI Standards.

This ANSI Standard is one of nearly 4,000 standards approved as USA Standards by the United States of America Standards Institute. In October 1969, the USASI was reconstituted as the American National Standards Institute. Standards approved as USA Standards are now designated ANSI Standards. There is no change in their index identification or technical content.

NOTE: API Standard 2550-ASTM D 1220 was approved as an ANSI Standard Dec. 30, 1966.

FOREWORD

The standard in this publication is one of a series approved jointly by the American Petroleum Institute and the American Society for Testing and Materials. This standard is the result of a cooperative arrangement established by the two organizations to develop and jointly approve and publish standards dealing with quantitative and qualitative measurements of petroleum products and lubricants.

The American Petroleum Institute and the American Society for Testing and Materials take no position as to whether any method, apparatus, or product mentioned herein is covered by an existing patent, nor as to the validity of any patent alleged to cover any such method, apparatus, or product. Furthermore, the information contained in this standard does not grant the right, by implication or otherwise, for manufacture, sale, or use in connection with any method, apparatus, or product covered by letters patent; nor does it insure anyone against liability for infringement of letters patent.

This standard may be used by anyone desiring to do so, but neither the American Petroleum Institute nor the American Society for Testing and Materials shall be held responsible or liable in any way either for loss or damage resulting therefrom, or for the violation of any federal, state, or municipal regulations with which it may conflict.

Suggested revisions are invited and should be submitted to Industry Affairs, Non-Divisional, American Petroleum Institute, 1801 K Street, N.W., Washington, D.C. 20006.

CONTENTS

Standard Method for

MEASUREMENT AND CALIBRATION OF UPRIGHT CYLINDRICAL TANKS[1]

API Standard: 2550

ASTM Designation: D 1220 - 65

ADOPTED, 1965.[2,3]

This standard of the American Petroleum Institute issued under the fixed designation API 2550 is also a standard of the American Society for Testing and Materials issued under the fixed designation D 1220; the final number indicates the year of original adoption as standard, or, in the case of revision, the year of last revision.

This method was adopted as a joint API-ASTM Standard in 1965.

Scope

1. This standard describes the procedures for calibrating upright cylindrical tanks larger than a barrel or drum. It is presented in two parts: Part I (Sections to 41) outlines procedures for making necessary measurements to determine total and incremental tank volumes; Part II (Sections 42 to 58) presents the recommended procedure for computing volumes.

NOTE 1.—Other calibration standards are:
API Standard 2551—ASTM D 1410: Measurement and Calibration of Horizontal Tanks
API Standard 2552—ASTM D 1408: Measurement and Calibration of Spheres and Spheroids
API Standard 2553—ASTM D 1407: Measurement and Calibration of Barges
API Standard 2554—ASTM D 1409: Measurement and Calibration of Tank Cars
API Standard 2555—ASTM D 1406: Liquid Calibration of Tanks

Definitions

2. (*a*) "Tank strapping" is the term commonly applied to the procedure for the measurement of tanks to provide the dimensions necessary for the computation of gage tables. These tables will show the quantity of oil in a tank at any given depth.

(*b*) Tank strapping includes the following measurements:

(*1*) *Depth.*—Shell height, oil height, ring height, equalizer line height, and gaging height.

(*2*) *Thickness of Tank Walls.*—Stave thickness and metal thickness.

(*3*) *Circumferences of Tank at Specified Locations.*

(*4*) *Deadwood.*—Any object within the tank, including a floating roof, which 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, which increase the capacity of the tank.

Significance

3. Accurate tank measurements are a most important factor in liquid volume determinations, for the reason that an incorrect dimension results in an erroneous gage table, which might be in use over an extended period of time before the error is discovered. In most cases, the person who computes the gage tables is not the one making the actual field measurements and has no direct means of checking such measurements; therefore, this person must depend upon the tank strapper for accurate measurements. Errors in gage tables cause the accounting of tank contents to be inaccurate; therefore, payments are subject to question. Settlements involving such errors are very difficult, and sometimes impossible, to adjust without loss to one of the parties involved. As the procedure for taking measurements and the achievement of accuracy in tank strapping are so important, all such measurements should be witnessed by all parties interested in the subsequent measurement of quantities in the tanks being strapped. It is hoped that the foregoing will provide an adequate idea of the extreme importance of correctness in this particular detail.

---

[1] Under the standardization procedures of the API and the ASTM, this standard is under the jurisdiction of the API Central Committee on Petroleum Measurement and the ASTM Committee D-2 on Petroleum Products and Lubricants.

[2] The API method was adopted as API Standard 2550 in October, 1965.

Prior to their present publication, the API methods of test were issued in December, 1929 as API Code 25. API Code 25 was reissued in 1930, 1931, 1933, 1936, 1940, and 1948. The material was revised and reissued in September, 1955 as API Standard 2501, and the second edition was issued in July, 1961.

[3] Revised and adopted as standard June, 1965 by action of the ASTM at the Annual Meeting and confirming letter ballot.

Prior to adoption as ASTM standard, this method was published as tentative from 1952 to 1959, being revised in 1955, 1956, 1957, 1958, and 1959.

Tank-Measuring Equipment and Its Calibration

4. The equipment to be used for tank measurements is covered in Sections 5 and 6. The measurement of any one tank will not require the use of all the equipment listed. Therefore, the type of tank and the proper calibratiou procedure must be considered carefully before selecting the equipment needed. All equipment shall be in good condition. All tapes shall be in one piece (unmended) and free of kinks.

Measuring Tapes

5. (*a*) *Tapes for Height Measurements.*—For height measurements, a steel tape, Fig. 1(*a*), of convenient length, ⅜ or ½ in. wide and 0.008 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. The working tape shall be calibrated against a "standard" tape in a vertical position, with equal tension (1 to 2 lb) applied to both. Graduations shall be accurate within 1/32 in. or 0.05 ft throughout that portion of the tape length to be used.

(*b*) *Tapes for Circumference Measurements.*—For circumference measurements, a steel tape, Fig. 1(*b*), of convenient length relative to the tank circumference, usually 100, 200, 300, 500, or 600 ft in length, is recommended. The working tape should not be more than ¼ 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 graduated in tenths and hundredths of a foot, or it may be graduated in feet, tenths, and hundredths of a foot throughout its length. The tape shall be calibrated (for required tension) by matching it against the standard tape in the following manner: Choose a convenient tape path on the lower ring and place the standard tape around the tank by the successive tangent method with constant application of tension as near as possible to that at which the standard tape was certified to be accurate, scoring the tank at each 100 ft or fraction thereof. Total the measurements thus obtained and place the working tape around the tank, using the same tape path, by the continuous "wraparound" procedure; slide the working tape to break frictional resistance; and apply tension sufficient to equal the measurement obtained with the standard tape. The amount of tension, in pounds, required to be placed on the working tape to obtain the same measurement as that recorded with the standard 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 standard tape. The amount of correction should not exceed 0.01 ft (approximately 3/32 in.) for each 100 ft of tape in use. In making "critical measurements," this procedure shall be carried out for each tank of different diameter where the circumference differs by more than 20 per cent from the calibrated tape section, and where tank surfaces are different. It should be noted that circumference measurements may be made with working tapes which have been calibrated by a standard tape of length based on 68 F.

If the preceding calibration procedure is not practicable, a suitable flat, horizontal surface, such as a railroad rail, may be substituted for the tank shell surface. In either case, if two or more successive check readings are taken, the supporting surface frictional resistance to movement of the working tape should be broken between such successive readings.

(*c*) *Tape Calibration.*—The standard tape for calibrating tank-measuring (working) tapes shall be identified with a Report of Calibration at 68 F by the National Bureau of Standards attesting to the standard tape accuracy within 0.001 ft (approximately 1/64 in.) per 100 ft of length. The Report of Calibration for a standard tape shall include these factors and/or formulas necessary to correct the tape length for use:

(*1*) At 60 F.

(*2*) Under tension differing from that used in calibration.

(*3*) Under conditions of sag in an unsupported tape.

(*d*) *Reels.*—Tapes shall be equipped with appropriate reels and handles.

(*e*) *Tape Clamps.*—For assurance of positive grip on tape, clamps shall be used.

NOTE 2.—The National Bureau of Standards provides for standard tapes (NBS "reference" tapes) only a Report of Calibration at 68 F when the tape is completely supported in a horizontal position and subject to horizontal tension as prescribed in *National Bureau of Standards Test Fee Schedule 202.404—Steel Tapes.* The additional data indicated in Section 5(*e*), Items (*1*), (*2*), and (*3*), are included in the NBS Report of Calibration only when requested by the applicant and to the extent specifically requested.

Accessory Equipment

6. (*a*) Additional measuring equipment recommended is described in Paragraphs (*b*) to (*m*) and shown in Fig. 1(*c*) to (*h*) and Figs. 2, 3, and 4. Other similar equipment may be used, provided that it will give the same results.

(*b*) *Rope,* ¾-in. Manila hemp, but not less than ½ in., of a length approximately equal to four times the tank height. Block and tackle to be one single block with loose hook and becket and one double block with loose hook. Blocks to have hardwood shells about 8 in. long with sheaves for ½-in. or larger rope.

NOTE 3.—Blocks suitable for larger rope than required will provide an ample factor of safety and take care of swelling of Manila rope due to dampness.

(*c*) *Seat,* of oak or white pine board 1¼ to 2 in. thick, 30 in. long, and 10 in. wide; dressed; and with holes for rope drilled near each corner, top and bottom edges of holes slightly rounded; ½- or ¾-in.-diameter rope passed through holes, ends spliced and wrapped together on each side above the board with short pieces of small rope.

(*d*) *Water Curtain Hook* for fastening block and tackle to the top of the tank, ⅝-in.-diameter steel, and bent to shape; each end welded into an eye suitable for receiving the hook of the double block; and fastened to spray or other fixed point on top of the tank with 1-in. Manila hemp rope.

(*e*) *Special Hook for Open-Top Tanks,* ⅝ by 3 in., flat, bent to shape, and with hole in end suitable for receiving the hook of the double block.

(*f*) *Safety Belts,* two required, heavy canvas webbing with double buckles, leather shoulder straps for fastening, steel ring at crossing of straps in back to which ropes are fastened with a splice. Rope to be ½-in. Manila hemp.

(*g*) *Rope and Ring.*—Two lengths of rope line fitted with snap and ring to be used in raising and lowering circumference measurement tape. Alternatively jointed-type pole guides may be used.

(*h*) *Depth Gage.*—Depth gage of casehardened steel, 6 in. in length, graduated $\frac{1}{64}$ in. This is for determination of thickness of steel plates, wooden tank staves, etc.

(*i*) *Calipers, Step-Overs, and Special Clamps.*—For spanning obstructions in making circumference measurements, the following are recommended:

(*1*) 6 in. maximum expansion calipers for spanning the smaller obstructions, such as vertical flanges, bolt heads, etc.

(*2*) 18 or 24 in. maximum expansion calipers for spanning the larger obstructions, such as butt straps, etc.

(*3*) Special clamps may be substituted for calipers in measuring projecting flanges.

(*4*) Fixed- or adjustable-span steel step-overs may be used instead of calipers or special clamps. See Fig. 1(*f*) for adjustable step-over.

(*5*) To measure the span of a step-over or caliper, apply the instrument 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 (approximately $\frac{1}{64}$ in.).

(*j*) *Straightedges:*

(*1*) Metal, 36 in. long.

(*2*) Engineer's straightedge, 10 ft long, for measuring tank heads.

(*3*) Profile board for measuring knuckles.

(*k*) *Miscellaneous:*

(*1*) A 6-ft ruler for general measurements.

(*2*) A 4-ft crowbar may be useful.

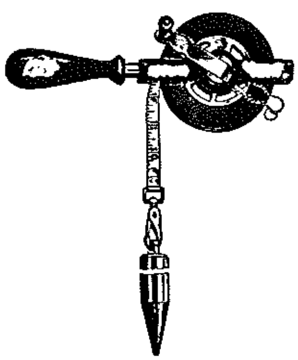
(*3*) Spirit level.

(*4*) Awl and scriber.

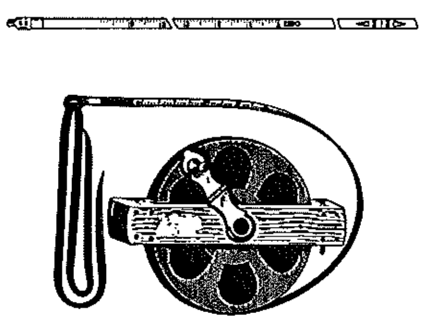
(*5*) Marking crayon.

(*6*) Record paper.

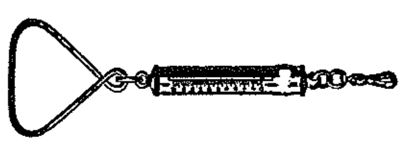
(*7*) Cleaning instruments such as a putty knife and a hard-bristle brush for eliminating dirt, grease, paint scale, rust



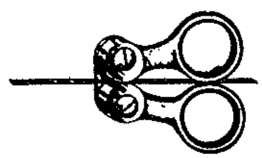
(*a*) Height-measuring tape and bob, usually 50 ft long (including bob) and $\frac{3}{8}$ or $\frac{1}{2}$ in. wide.



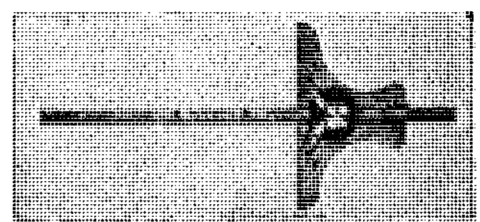
(*b*) Strapping tape for circumference measurement, usually 100, 200, 300, 500, or 600 ft long and not more than $\frac{1}{4}$ in. wide, graduated in feet with extra foot at zero end graduated in tenths and hundredths of a foot.



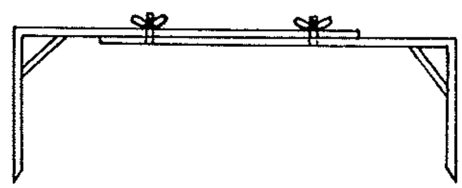
(*c*) Spring tension gage.



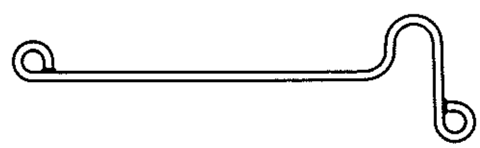
(*d*) Tape clamp.



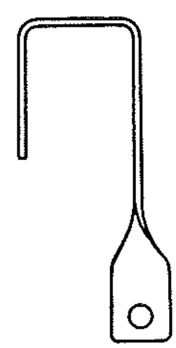
(*e*) Depth gage.



(*f*) Step-over.



(*g*) Special hook for bosun's chair, cone-roof tank.



(*h*) Special hook for bosun's chair, open-top tank.

FIG. 1.—TYPICAL TANK-MEASURING EQUIPMENT.

particles, etc., from the path of circumference measurements.

(*8*) In certain instances, a combined transit and level is required, such as for measurements over floating roofs, tanks that are out of round, inclined tanks, etc.

(*9*) Ladders to facilitate handling of tapes, and removal of paint scale, rust, dirt, etc., from the path of measurement.

(*10*) Plumb line.

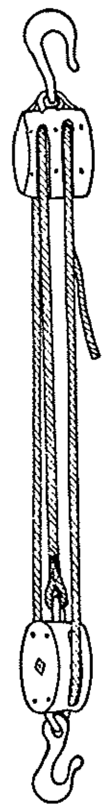
(*11*) Spring tension scale.

(*12*) Dynamometer.

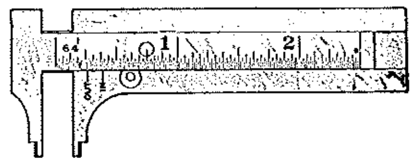
(*l*) *Equipment for Determining Temperature and Gravity:*

(*1*) *Sample Can.*—A clean container of suitable size.

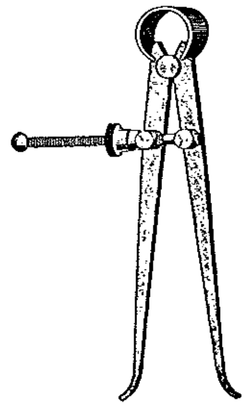
(*2*) *Hydrometer Cylinder.*—Preferably of nonbreakable material, diameter 1 in.



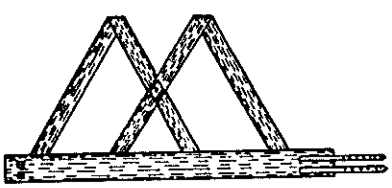
(*a*) Block and tackle.



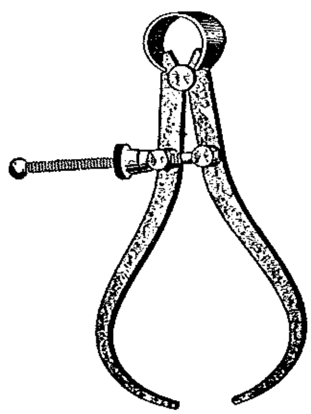
(*d*) Calipers.



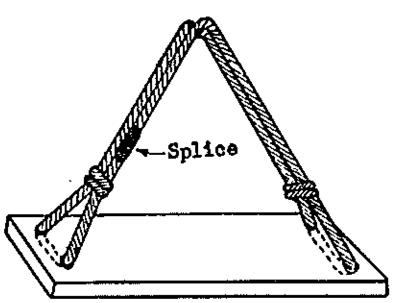
(*e*) Calipers.



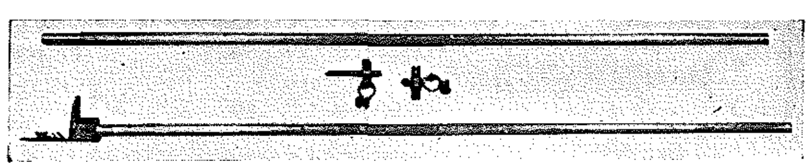
(*b*) Safety belt.



(*f*) Calipers.



(*c*) Seat.



(*g*) Tape positioner—type with attachments marking tape path.

FIG. 2.—TYPICAL TANK-MEASURING EQUIPMENT.

greater than the outside diameter of the hydrometer to be used, height 1 in. greater than the portion of the hydrometer which is immersed beneath the surface of the liquid.

(*3*) *Hydrometer.*—Plain form or combined thermometer and hydrometer known as a thermohydrometer, calibrated in terms of API gravity, the range to be a suitable portion of the interval between 0 and 100° API and graduated in 0.1° API and conforming to Specifications E 100, for ASTM Hydrometers.[4]

(*4*) *Thermometer.*—ASTM Gravity Thermometer, total immersion, having a range of −5 to 215 F and conforming to the requirements for Thermometer 12 F as prescribed in Specifications E 1, for ASTM Thermometers.[4]

NOTE 4.—For making gravity measurements, reference should be made to *API Standard 2544—ASTM D 287: Method of Test for API Gravity of Crude Petroleum and Petroleum Products.*

(*m*) *Liquid Calibration.*—Liquid calibration of the entire or partial volume of tanks is sometimes recommended in lieu of physical measurement of dimensions and calculations of tank volumes. Liquid calibration is especially useful for the following conditions: The critical zone of a floating roof; irregularly shaped portions of tanks, particularly bottoms; unstable bottoms where the deflection of the bottom varies with the liquid-head height in the tank or water-table level of its foundation; tanks that are unevenly tilted, irregular in shape, or inaccessible for measurement. Instructions for liquid calibration for these or any other reasons may be found in API Standard 2555—ASTM D 1406.

General Practices

7. (*a*) Prevailing safety practices should be observed at all times.

(*b*) The number of men required in a strapping crew will depend upon conditions to be encountered, such as the experience of the men, the weather, strapping schedule, rigging available, and the height of tanks. As a general rule, a crew of three may be considered practical, including at least one man who has had previous tank-measuring experience. It would also be decidedly advantageous if the previous experience included some amount of office work in the calculation of gage tables.

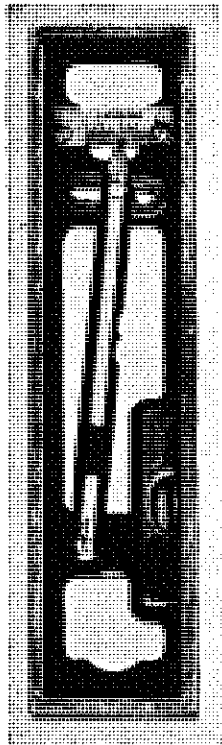


FIG. 3.—COMBINATION PITCH INDICATOR AND LEVEL.

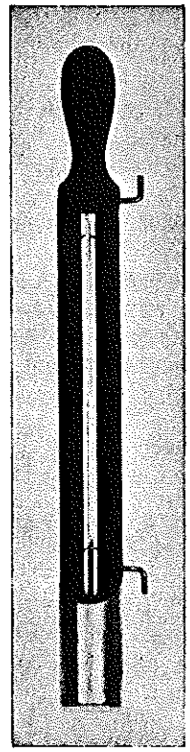


FIG. 4.—CUP-CASE THERMOMETER.

(*c*) Do not use ropes, ladders, or other rigging of questionable strength or condition. This is particularly important in regard to rope that has been stored while wet, saturated with oil or gasoline, or used on an acid tank.

(*d*) If ladders are used, all rungs should be inspected and tested at ground level. Ladders should not be "stretched," for convenience, beyond their normal safe working range. It should be understood that the inherent danger in ladders may be increased considerably by conditions on a tank job, such as possibly soggy footing, relatively smooth upper bearing surface, strong gusts of wind, sudden slack or pull in circumference tape, etc.

(*e*) All measurements and descriptive data taken at the tank site should be checked and legibly recorded immediately, with the recording assigned, preferably, to one man.

(*f*) Take time to do a good job.

PART I. MEASUREMENT PROCEDURES

Conditions for Measurements

8. (*a*) All data, and procedures whereby they are obtained, necessary for the preparation of gage tables should be supported by sound engineering principles.

(*b*) Measurements should be taken only after the tank has been filled at least once at its present location with liquid at least as dense as it is expected to contain. The usual water test, if made, will meet this requirement.

(*c*) The calibration procedures which 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. Internal incrustation or adhesion has the same effect on the tank capacity as deadwood and should be accounted for in the same manner. For additional information for various solutions to this problem, see *API Bulletin on Incrustation* (Supplement No. 1 to API Standard 2500).

[4] 1966 Book of ASTM Standards, Part 18.

(*d*) *Tanks with a Nominal Capacity of 500 Bbl or Less.*—These tanks may be strapped at any condition of fill, provided they have been filled at least once at their present location. Small movements of oil into or out of such tanks are allowed during strapping.

(*e*) *Tanks with a Nominal Capacity of More Than 500 Bbl:*

(*1*) *Bolted Tanks* must have been filled at least once at their present location and must be at least two-thirds full when strapped. Small movements of oil into or out of such tanks are allowed during strapping.

(*2*) *Riveted Tanks and/or Welded Tanks* must 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 Section 53. No movement of oil into or out of such tanks is allowed during the strapping operation.

Disputes

9. In case of controversy, when agreement cannot be reached between the buyer and the seller, a joint strapping should be taken. This joint strapping should be considered final.

Tank Numbers

10. (*a*) *Identification.*—Each tank should be identified clearly and legibly by number or by some other suitable marking, but this identification should not be painted on hoops or tank attachments.

(*b*) *Restrapped Tanks.*—A tank which has been restrapped should be identified completely, either by renumbering or by some other adequate method.

Interrupted Measurements

11. 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 gage and average temperatures of both liquid and outside atmosphere are included as parts of the subsequent strapping operations.

Descriptive Data

12. (*a*) Complete descriptive data should be entered on the Tank Measurements Record Form being used. Suggested record forms are shown in Figs. 6 to 9 and Tables III and IV (see Section 21).

(*b*) Usually the commonly used name for a tank's contents may be a sufficient description. In those cases in which a more accurate description is desired, as for example in critical measurements, the API gravity and the temperature of the tank's contents should be obtained and recorded.

(*c*) Supplemental pencil sketches or notations, each completely identified, dated, and signed, should accompany the strapping. These should be made to indicate typical horizontal and vertical joints; number of plates per ring; location of rings at which thickness of plates change; arrangement and size of angles at top and bottom of shell; location and size of pipes and manways; dents and bulges in shell plates; direction of lean from vertical; procedure used in bypassing a large obstruction, such as a cleanout box or insulation box located in the path of a circumferential measurement; location of tape path different from that shown in Figs. 11 to 19; location and elevation of a possible datum plate; and all other items of interest and value which will be encountered.

(*d*) 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 pencil line and the new data recorded adjacent to it.

UPRIGHT CYLINDRICAL TANK SHELLS—ABOVEGROUND

Classification of Tank Services

13. (*a*) The degree of accuracy desired in the completed gage table for a specific tank will be the governing factor in determining the procedure to be followed. Tanks may be considered to fall within one of two broad classifications:

(*1*) *Operating Control.*—Tanks used in intraplant or intradepartmental service.

(*2*) *Critical Measurements.*—Tanks used in intercompany or interdepartmental service.

NOTE 5.—It should be remembered that the maximum obtainable accuracy in gage tables for all tanks, regardless of service, is of value for inventory.

(*b*) A critical measurements gage table is more precise (Note 6) than an "operating control" gage table (Note 7) because adjustments are included for the effects of the following variables:

(*1*) Differences in requirements for circumferential measurements (see Figs. 10 to 25).

(*2*) Expansion and contraction of steel tank shell due to liquid heads.

(*3*) Expansion and contraction of steel tank shell with temperature.

(*4*) Tilt from a vertical position.

(*5*) Tank bottoms that are irregular in shape, or unstable under varying liquid loads, or both.

NOTE 6.—Tolerances for measurements and calculations included in this procedure apply to the development of both critical measurements and operating control gage tables.

NOTE 7.—Adjustment for effect of such variables may be incorporated in gage tables for operating control tanks. The gage table should indicate the adjustments which have been incorporated.

Expansion and Contraction of Steel Tank Shells Due to Liquid Head and Temperature

14. These effects may be determined in accordance with procedures given in Part II, Sections 53 and 54. In the case of the calculation procedure for expansion and contraction due to liquid head, as mentioned in Section 53(*c*), Item (*1*), a tank may be measured empty or at any condition of fill. When no liquid-head correction is to be made, a tank should be measured only when at least two-thirds full. In either case, the strapping record should include liquid gage, API or specific gravity of liquid, and the average temperature of the liquid and the temperature of the air adjacent to shell at time of circumferential measurements.

Effect of Tilt on Cylindrical Tank Shell

15. 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 [see Section 19(*a*)].

Recalibration of Welded, Riveted, or Bolted Tanks

16. (*a*) In order to obtain a check on the accuracy of existing circumference measurement records, the tank circumferences in question should be remeasured at the same circumference measurement elevations as taken originally. The check measurements should be made in accordance with rules for circumferential measurements as covered in this standard.

(*b*) If the final check measurements taken at a later date—and after further service sufficient to induce maximum stress variations in the shell; permanent "set," if any; etc.—do not check the questioned circumference measurements within the appropriate allowance shown in Table I, a complete recalibration and new gage tables based thereon should be required.

(c) Vertical or upright tanks should be remeasured and recalibrated:

(1) When restored to service after being disconnected or abandoned.

(2) When disassembled and re-erected, or when "moved bodily."

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

NOTE 8.—Experience in checking the circumference measurements of bolted steel tanks indicates that such tanks, in sizes up to a nominal capacity of 1000 bbl, show no significant volumetric change over a period of 10 yr. Tanks having a nominal capacity in excess of 1000 bbl show volumetric changes of a small order of magnitude over a 10-yr period which may be sufficient to warrant recalibration of the tank when considering the type of service and the value of the product involved.

Tolerances

17. (a) Single circumferential measurements should be read and recorded to the nearest 0.005 ft, which is equal to one-half of the distance between two adjacent hundredth-foot division marks on the tape. A segmental circumferential measurement, such as is made in conjunction with the use of a step-over, should be estimated and recorded to the nearest 0.001 ft, which is equal to one-tenth of the distance between two adjacent hundreth-foot division marks on the tape. These interpolations should be made by eye. Therefore, all circumferential measurements should be recorded through the third decimal place.

(b) Vertical tank measurements should be read and recorded to the nearest ⅛ in.

(c) Thermometers should be read to the nearest scale division.

(d) Tank plate thicknesses should be determined to the nearest $\frac{1}{64}$ in.

(e) Deadwood should be determined and located by measurement readings to the nearest ⅛ in.

Shell Plate Thickness

18. (a) Where type of construction leaves the plate edges exposed, a minimum of four thickness measurements should be made on each ring at points approximately equally spaced about the circumference. 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 which should form a part of the measurements record. Care should be taken to avoid plate thickness measurements at locations where edges have been distorted by caulking.

(b) Where plate edges are concealed by the type of construction, the strapping record should be marked "not obtainable at tank." Alternatively, plate thickness measurements may be obtained as described in Paragraph (c).

(c) 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 thicknesses obtained and recorded before or during construction, those shown on the fabricator's drawings may be accepted and so identified in the calculation records. Paint thickness on the various rings should be noted and included with the strapping records.

Vertical Tank Measurements

19. (a) 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 gage hatch. Additional height 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 in plan view.

(b) Gaging height is the vertical distance between the reference point on the gage hatch and the striking point on tank floor or on gage datum plate, and should be measured at the commonly used point on the hatch rim. If a gaging reference point other than the top of the gage hatch rim is known to be commonly used, a description of the reference point should be included in the record.

(c) A comparison should be made immediately of the gaging height with the sum of shell height plus the height (approximate) from the top of the top angle to the level of the gaging point on the hatch rim, in order to investigate the possible existence of a gaging datum plate or false bottom. The result of this field investigation should be recorded by identifying the gaging height as a distance to the floor (Note 9) or to the datum plate. The measurements and calculations involved should be attached to, and become a part of, the measurements record.

NOTE 9.—If a false bottom is known or suspected to be present, the record should be so marked.

(d) Effective inside tank height is a vertical distance along the gaging path. This is of primary concern to the gage table calculator in that it establishes the upper and lower limits of variable gages to be provided for in the gage table. If the effective tank height can be obtained directly on the tank, it should be measured and reported as such. If it cannot be measured directly, the strapper should assure himself that other vertical meas-

TABLE I.—TOLERANCES FOR RECALIBRATION OF WELDED, RIVETED, OR BOLTED STEEL TANKS.

Circumference, ft	Welded		Riveted		Bolted		Other Types
	Tolerance, ft	Avg. per cent by Volume	Tolerance, ft	Avg. per cent by Volume	Tolerance, ft	Avg. per cent by Volume	
Up to 100, incl.	0.010	0.040	0.020	0.080	0.030	0.120	Consider on individual merits, by types of construction and in terms of closest applicable similar tolerance, expressible as a percentage by volume.
101 to 200, incl.	0.015	0.020	0.025	0.033	0.040	0.053	
201 to 300, incl.	0.020	0.016	0.030	0.022	..	..	
301 to 400, incl.	0.025	0.014	0.035	0.020	..	..	
401 to 500, incl.	0.030	0.013	0.040	0.018	..	..	

urements taken and recorded will permit the calculator to develop therefrom the effective inside tank height.

(*e*) 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. The measurement record should include a complete description of such a connection, including size and location, and whether or not a valve, which can be closed and sealed, is included in the line. If such a valve is present, its location should be included in the record. 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 gaging 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 gage table. If the connection can be closed and sealed against overflow, then the effective inside tank height, and the gage table, should extend upward to the top of the top angle. In this latter case, in which the gage table is extended upward beyond the connection, the gage table should include a note, at the elevation of the connection, citing its presence and stipulating the condition under which that portion of the gage table may be used.

(*f*) Liquid in tank at time of strapping should be gaged and its mean temperature and API gravity determined. Checked results should be recorded, including a description of gaging procedure used; i.e., whether innage or outage.

(*g*) Shell plate height of each ring should be measured and recorded.

NOTE 10.—Where rings are lapped horizontally, the lap should be reported so that the inside height of the ring can be developed by the calculator.

Preparations for Circumferential Measurements

20. (*a*) The strapper should first determine where circumferential measurements are to be taken. A summary of elevations for circumference measurements on various types of upright cylindrical tanks is shown in Table II. Circumferential tape paths located at elevations shown in the appropriate illustration in Figs. 10 to 25 should be examined for obstructions and type of upright joints. Projections of dirt and scale should be removed along each path. Occasionally, some feature of construction, such as a manway or insulation box, may make it impracticable to use a circumference elevation prescribed on the appropriate illustration. If the obstruction can be spanned by a step-over, then the circumference should be measured at the prescribed elevation, using a suitable procedure in Section 21. If the obstruction cannot be conveniently spanned by a step-over, then a substitute 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.

(*b*) 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-welded joints, or butt-strap or lap joints at which voids between tape and shell at 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 Section 21(*a*) and (*b*), without the use of a step-over. In the case of butt-strap or lap joints in which voids at joints are not uniform because of interference by rivet heads or other features, then circumferences should be measured in accordance with the procedure described in Section 21(*a*) and (*c*), which incorporates the use of a step-over at each joint. In the case of flanged upright joints, circumference measurements should be made in accordance with the procedure described in Section 21(*a*) and (*f*), which incorporates the use of a step-over or special clamps.

(*c*) The amount of tension, in pounds, to be applied to the measuring tape in all cases should have been determined previously in accordance with the procedure described in Section 5(*a*) or (*b*).

TABLE II.—ELEVATIONS FOR CIRCUMFERENCE MEASUREMENTS ON VARIOUS TYPES OF UPRIGHT CYLINDRICAL TANKS.

Type of Tank Construction	Circumference Measurement Elevations: Operating Control	Circumference Measurement Elevations: Critical Measurements
Welded Steel, One or More Rings	20 per cent down from top of exposed height of each of 3 lower rings, below circumferential weld on outer surface, and 20 per cent down from top of top ring, whether butt or lap joints.	20 per cent of exposed portion of each ring, whether butt or lap joints.[b]
Riveted Steel, Shingled Arrangement	0 per cent (exposed portion) on each of lower 4 rings, and 12 in. below top of top ring.[a]	0 per cent (exposed portion) on each ring and 12 in. below top of top ring.[a]
Riveted Steel, In-and-Out Arrangement	Lowest exposed portion above horizontal rivet rows on each of lower 4 rings and 12 in. below top of top ring.[a]	Lowest exposed portion above horizontal rivet rows on each ring, and 12 in. below top of top ring.[a]
Riveted Steel, Combination Shingled and In-and-Out Arrangement	Lowest exposed portion above horizontal rivet rows on each ring to and including first two shingled, and 12 in. below top of top ring.[a]	Lowest exposed portion above horizontal rivet rows on each ring, and 12 in. below top of top ring.[a]
Steel Tank One Ring High, Riveted Lap Joints	25 and 75 per cent above bottom of shell.	
Bolted Steel, Lapped Vertical Joints	25 and 75 per cent above bottom of each ring.	
Bolted Steel, Flanged Vertical Joints	75 per cent above bottom of each ring.	
Corrugated Steel	50 per cent of each ring, in valley.	
Wooden Stave, Plain Tapered	0 ft 6 in. above inside bottom surface and at 2 ft 0 in. intervals thereafter.	
Wooden Stave, Barrel Shape	0 ft 6 in. above inside bottom surface and at 1 ft 0 in. intervals thereafter.	

[a] When bottom angle is welded, take lowermost circumference 12 in. above bottom of bottom ring. Where tank shells are of composite construction, take measurements in accordance with instructions above for each type of construction.

[b] For one-ring tanks, two circumferential measurements shall be taken at 20 per cent and 80 per cent down from the top of the ring. For tanks of more than one ring, if obstructions block the tape path at the 20 per cent down plane, the measurement may be taken at a point 80 per cent 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.

Circumferential Measurements

21. (*a*) For the measurements described in Paragraphs (*b*), (*c*), (*d*), or (*e*), 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, increments of circumference measurement should be read and recorded to the nearest 0.005 ft. For the measurements described in Paragraph (*f*), where the length of circumferential path to be measured at any one time is limited to the distance between extremities of the spanning instrument in adjacent locations, any approved tape, with either of the two types of graduations described in Section 5(*b*), may be used. In all cases, the tape to be used should be applied to the tank surface, at the prescribed elevations, by the continuous wraparound procedure, as described in Section 5(*b*). All points at which circumferential readings (Note 11) are taken should be located at least 2 ft from an upright joint. After a circumferential measurement reading has been taken, the tension should be reduced sufficiently to permit the tape to be shifted. It should then be returned to position and required tension and another reading taken. This procedure should be repeated until two equal readings have been obtained. The equal readings should be recorded as the circumferential measurement at that location.

Note 11.—The word "reading" is used in this paragraph for convenience and is not intended to indicate a difference in meaning from the word "estimate" used in the procedures described in Paragraphs (*d*) and (*e*).

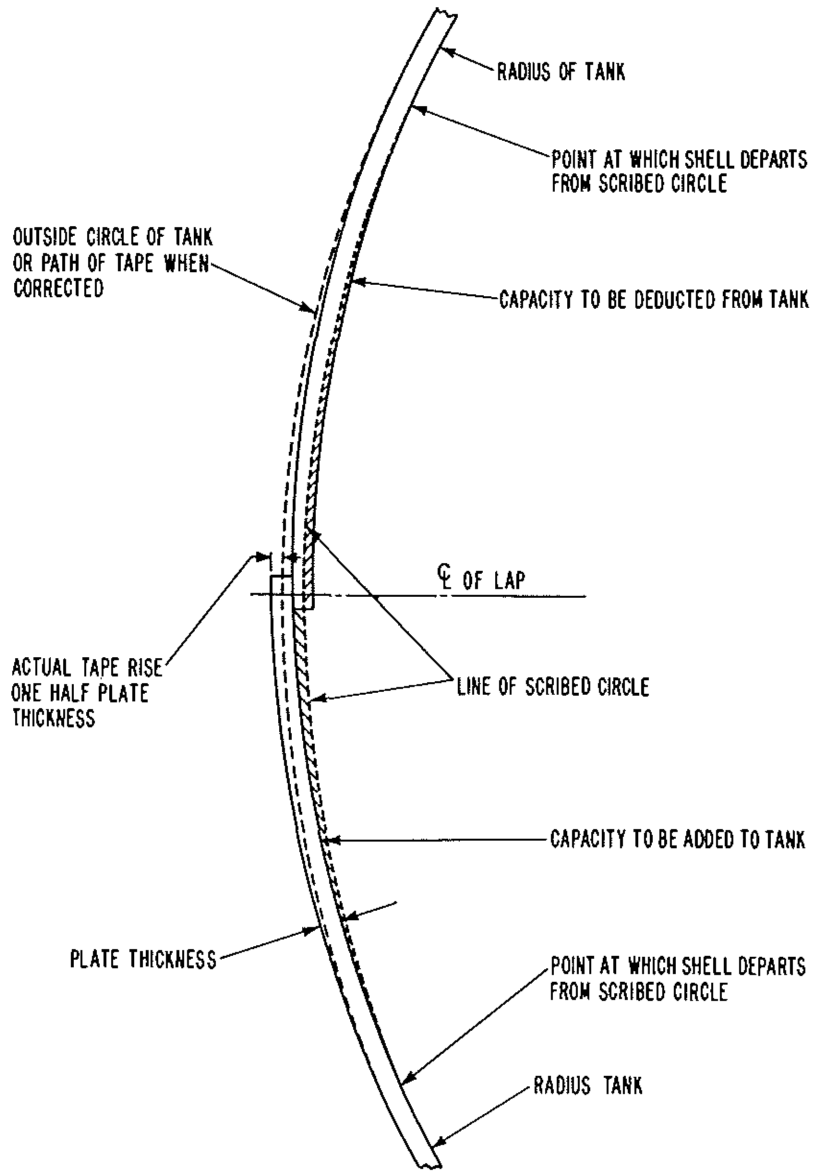


Fig. 5.—True Circumference *versus* Tape Path at Axial Lap Joint Away from Circumferential Joint.

(*b*) Butt-welded joints at which there is no void between tape and tank shell, or butt-strap or lap joints at which void between tape and tank shell is uniform at all joints: When the circumference measuring tape is in contact with the tank surface at all points along its path, circumference measurements should be made and checked in accordance with Paragraph (*a*). The checked measurements should be recorded as final measurements. When butt-strap or lap joints cause uniform voids between tape and tank shell at each joint, circumference measurements should be made in accordance with Paragraph (*a*). Measure and record the width and thickness of butt straps, and record the number of butt straps in each ring. In the case of lapped joints, measure and record the thickness of exposed lapped plate, Fig. 5, at at least three joints 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 Part II, Section 52(*c*) or (*d*).

(*c*) When butt-strap or lap joints, or tank shell, include rivets or other features which exert uneven effects on the resultant void between the tape and tank, from joint to joint, then a step-over will be required. The span of the instrument should be measured prior to use in accordance with Section 6(*i*), Item (*5*). The step-over must be of sturdy construction, either adjustable or fixed in spread, but an adjustable step-over is preferable. The two legs must be separated by a distance sufficient to span each void encountered between tape and shell. The legs must be of sufficient length to prevent contact between the interconnecting member and the tank plate or obstruction. The manner in which the step-over may be used is related to the type of measuring tape used; i.e., whether the tape is graduated in hundredths of a foot throughout its length [see Paragraph (*d*)] or in feet only, with an extra 1-ft length at the zero end graduated in tenths and hundredths of a foot [see Paragraph (*e*)].

TABLE III.—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............................Gaging.....................................
Type of Roof:............................Weight of Floating Roof:.................
Tank Contents—Name:...............Avg. Liquid Temp., °F:........................
Gage:....ft....in.; Innage to: Shelf ☐ Floor ☐ or Outage☐
Hydrometer Reading: .... at ...... °F Sample Temperature
Gaging Reference Point to Top of Top Angle: ...... ft ...... in.; Normal Service:....

Shell Circumferences:[a]

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

Descriptions of Shell Plates and Joints:[b]

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

Shell Connections:[c]

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

Amount of Tank Lean from Vertical:[d] .... 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.)...............
....
....

[a] Length measurements are recorded as values taken with a tape of length based on 68 F calibration. Each value thus recorded shall be mathematically corrected to the equivalent 60 F value for use in computing gage tables.

[b] Show sketches of vertical and horizontal joints on back of this Table.

[c] Show circumferential location on plan view sketched on back of this Table.

[d] Show direction of lean on plan view sketched on back of this Table.

TABLE IV.—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 .... Gaging ....
Type of Roof: .... Weight of Floating Roof:....................
Tank Contents—Name: .... Avg. Liquid Temp., °F:.......................
Gage: .... ft .... in.; Tank Service: .... API Gravity:......................
Hydrometer Reading: .... at .... °F Sample Temperature

Shell Circumferences:[a]

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

Descriptions of Shell Plates and Joints:

	Ring No.	Thick-ness	Type of Vertical Joint	Set, in or out	Width of Lap or Strap	Thick-ness 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):

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

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

[a] Length measurements are recorded as values taken with a tape of length based on 68 F calibration. Each value thus recorded shall be mathematically corrected to the equivalent 60 F value for use in computing gage tables.

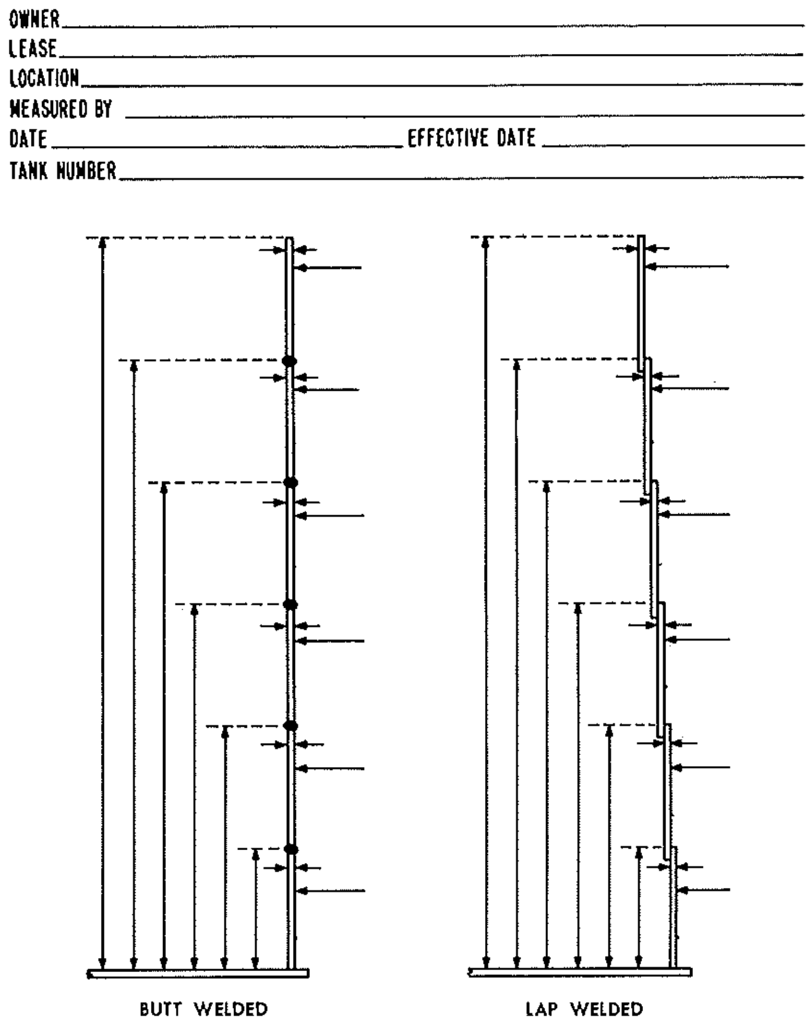


FIG. 6.—EXAMPLE OF RECORD FORM FOR MEASUREMENT OF UPRIGHT TANK SHELL, BUTT- AND LAP-WELDED.

DEADWOOD

TANK NO.

FROM	TO	PIECES	DESCRIPTION

Fig. 7.—Example of Record Form for Deadwood.

OWNER____

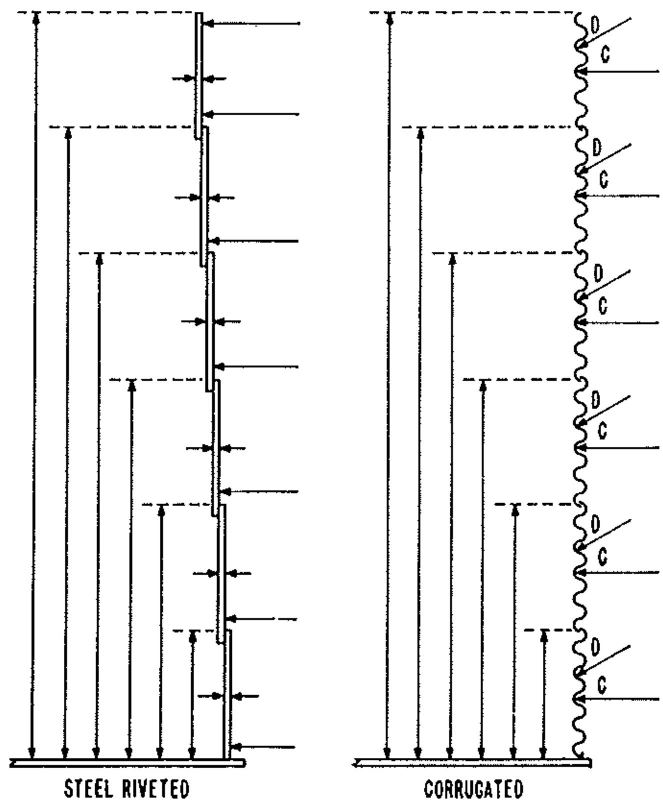
LEASE____

LOCATION______________________________________

MEASURED BY ____________________________________

DATE____________________ __EFFECTIVE DATE____________________

TANK NUMBER____________________________________



D = measured depth of valley.
C = circumference measurement.

FIG. 8.—EXAMPLE OF RECORD FORM FOR MEASUREMENT OF UPRIGHT TANK SHELL, RIVETED AND CORRUGATED.

OWNER ________________________________

LEASE ________________________________

LOCATION ______________________________

MEASURED BY ____________________________

DATE ________________ EFFECTIVE DATE ________________

TANK NUMBER ____________________________

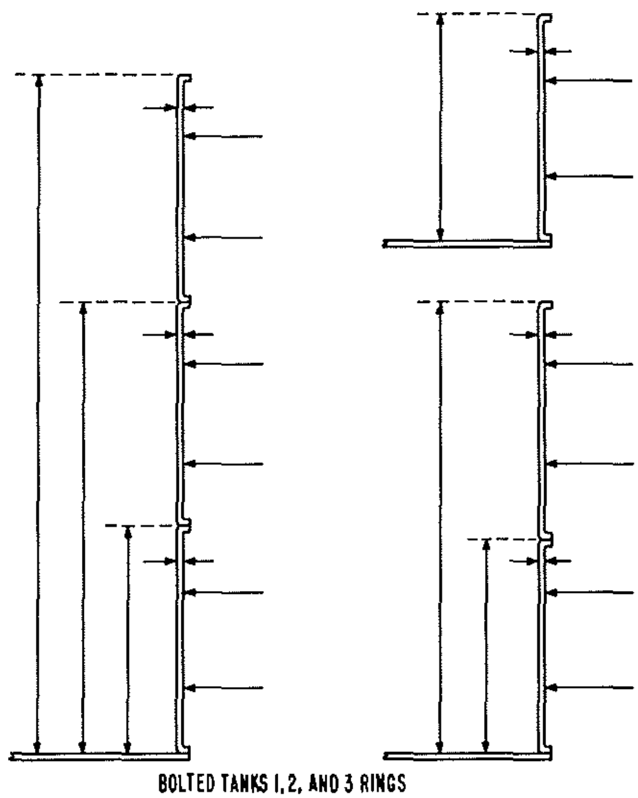


FIG. 9.—EXAMPLE OF RECORD FORM FOR MEASUREMENT OF UPRIGHT TANK SHELL, BOLTED.

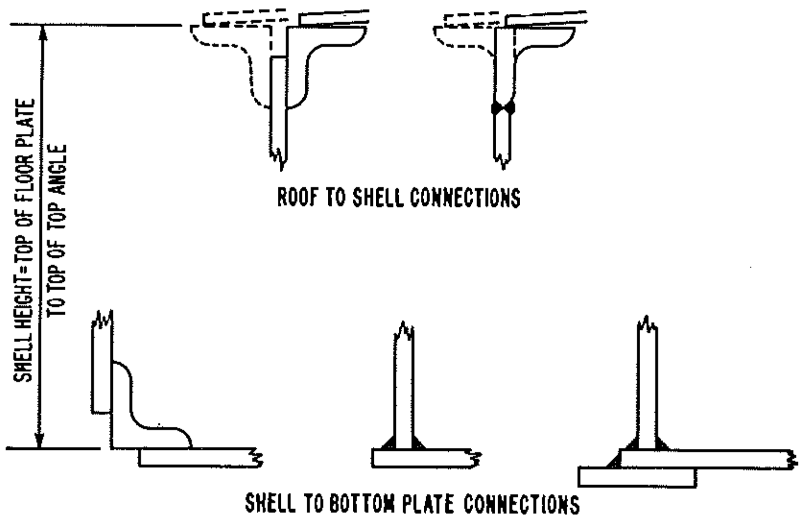
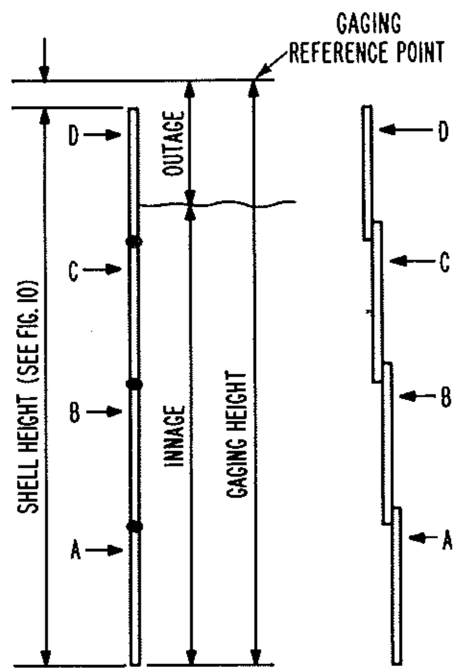


FIG. 10.—TANK ROOF AND BOTTOM CONNECTIONS TO SHELL OF UPRIGHT CYLINDRICAL STEEL TANKS.



For Critical Measurements:

A circumference measurement should be made on each ring at a point located 20 per cent of the exposed ring height below the circumferential weld on the outer surface.

For Operating Control:

Circumference measurements should be made on each of three lower rings at points located 20 per cent of the exposed ring height below circumferential welds on outer surface, and one measurement on top ring at a point located 20 per cent of exposed ring height down from top.

For Either Critical Measurements or Operating Control:

(*a*) If obstructions block the tape path at the 20-per-cent down elevation, the circumference can be taken at an elevation 80 per cent down.

(*b*) If circumferences taken on successive rings indicate unusual variations or distortions, more measurements should be taken to satisfy the judgment of all strappers involved.

FIG. 11.—LOCATIONS OF MEASUREMENTS ON UPRIGHT CYLINDRICAL TANKS WITH WELDED JOINTS, ONE OR MORE RINGS.

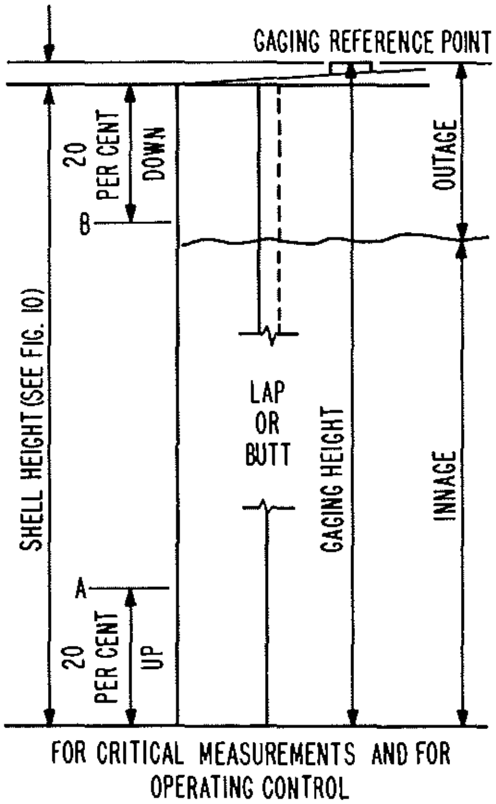
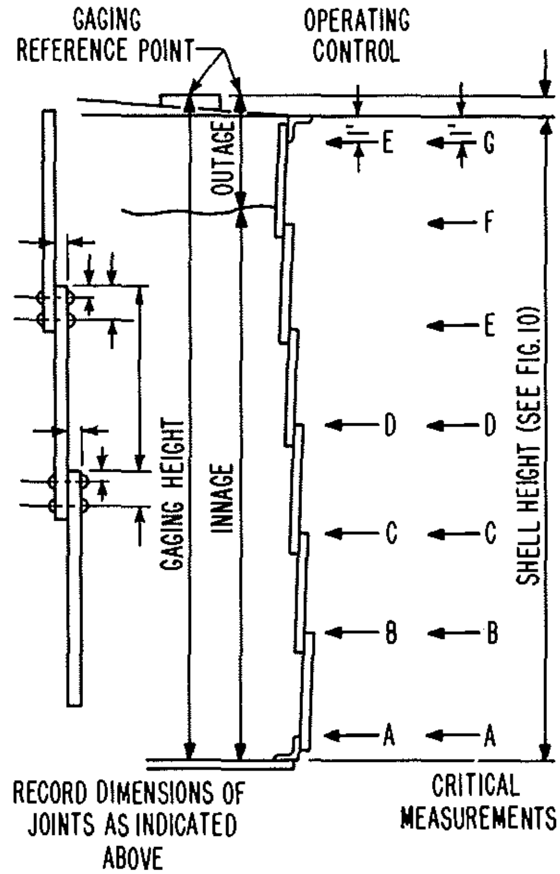


FIG. 12.—LOCATIONS OF MEASUREMENTS ON UPRIGHT CYLINDRICAL TANKS, ONE COURSE HIGH WITH LAP- OR BUTT-WELDED VERTICAL JOINTS.



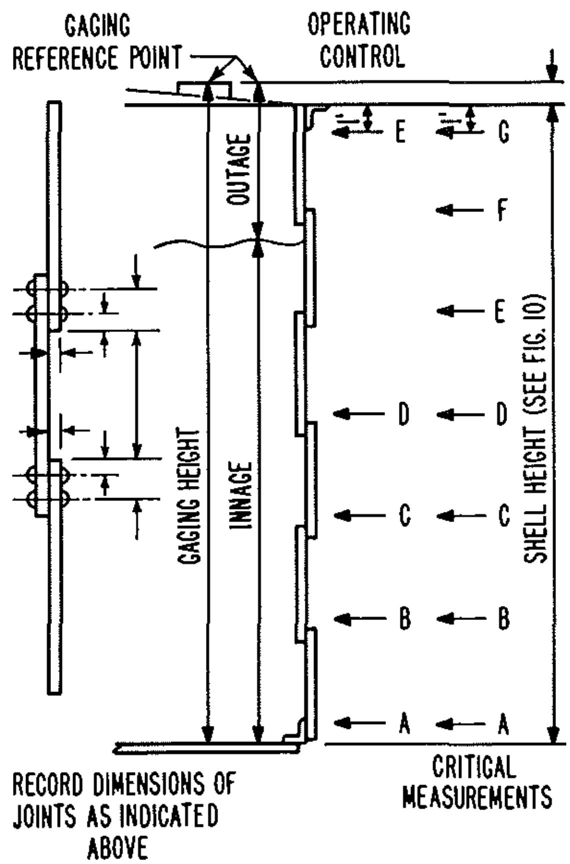
Circumference Measurements:

For Critical Measurements.—At lowest exposed surface on all rings, and 12 in. down from top of top ring.

For Operating Control.—At lowest exposed surface on lower four rings, and 12 in. down from top of top ring.

NOTE.—If bottom ring is welded at bottom angle, circumference measurement at *A* should be 12 in. above bottom of bottom ring.

FIG. 13.—LOCATIONS OF MEASUREMENTS ON UPRIGHT CYLINDRICAL TANKS, SHINGLED ARRANGEMENT OF RIVETED SHELL PLATES.



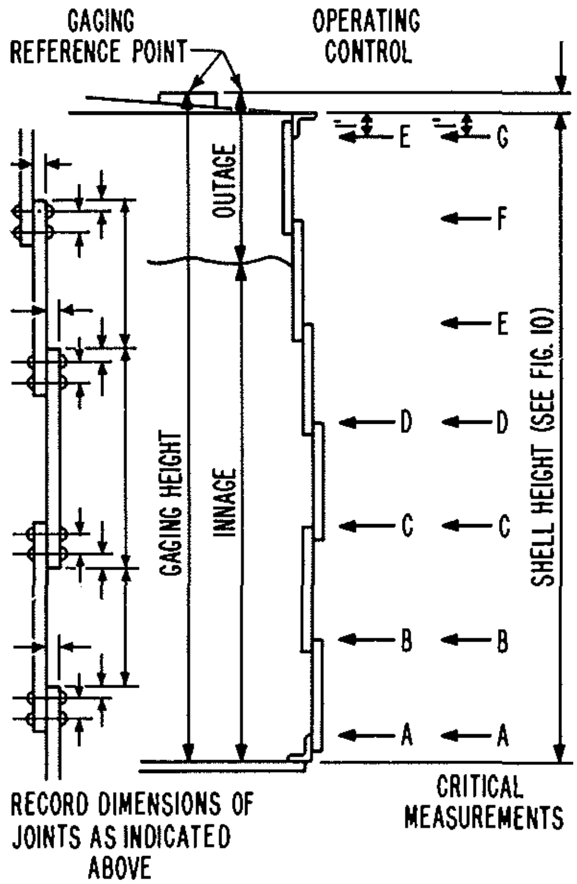
Circumference Measurements:

For Critical Measurements.—At points indicated above on exposed surface of all rings, the uppermost point being 12 in. down from top of top ring.

For Operating Control.—At points indicated above on exposed surface of lower four rings, and 12 in. down from top of top ring.

NOTE.—If bottom ring is welded at bottom angle, circumference measurement at *A* should be 12 in. above bottom of bottom ring.

FIG. 14.—LOCATIONS OF MEASUREMENTS ON UPRIGHT CYLINDRICAL TANKS, IN-AND-OUT ARRANGEMENT OF RIVETED SHELL PLATES.



Circumference Measurements:

For Critical Measurements.—Measure circumferences at points indicated above on exposed surface of all rings, the uppermost point being 12 in. down from top of top ring.

For Operating Control.—Measure circumferences at points indicated above on exposed surface of lower rings, to and including first two adjacent rings (from bottom) of similar arrangement, and 12 in. down from top of top ring.

NOTE.—If bottom ring is welded at bottom angle, circumference measurement at *A* should be 12 in. above bottom of bottom ring.

FIG. 15.—LOCATIONS OF MEASUREMENTS ON UPRIGHT CYLINDRICAL TANKS, COMBINATION IN-AND-OUT AND SHINGLED ARRANGEMENT OF RIVETED SHELL PLATES.

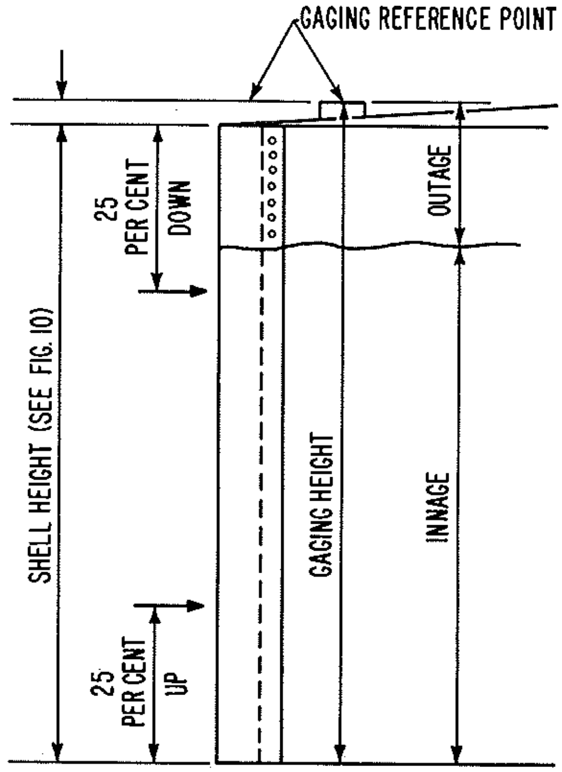
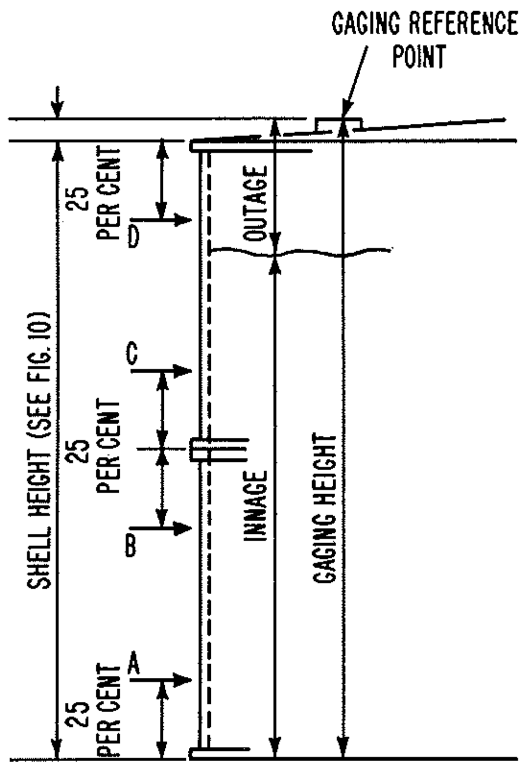


Fig. 16.—Locations of Measurements on Upright Cylindrical Tanks, One Course High with Riveted Vertical Lap Joints.

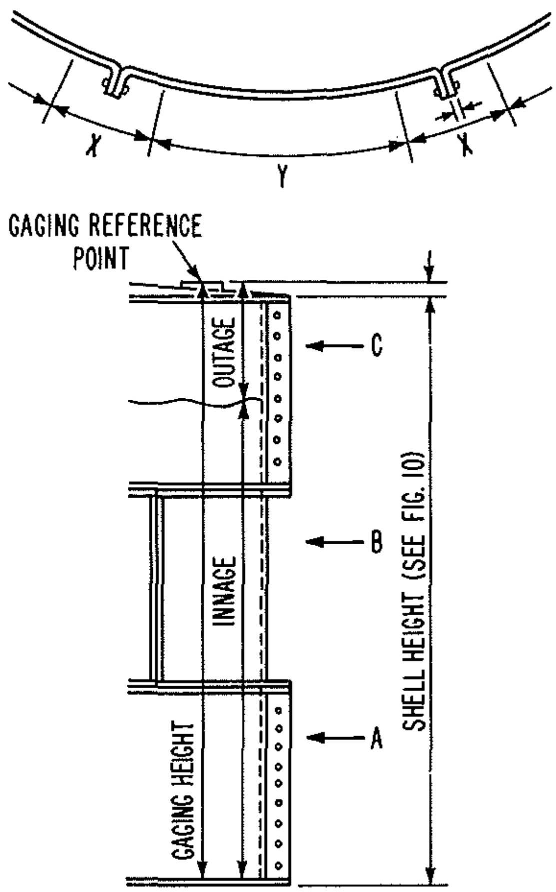


Circumference Measurements:

Circumference measurements at *A* and *C* to be located 25 per cent of plate height up from bottom of plate flange.

Circumference measurements at *B* and *D* to be located 25 per cent of plate height down from top of plate flange.

Fig. 17.—Locations of Measurements on Upright Cylindrical Tanks with Flanged Horizontal Joints and Lapped Vertical Joints.

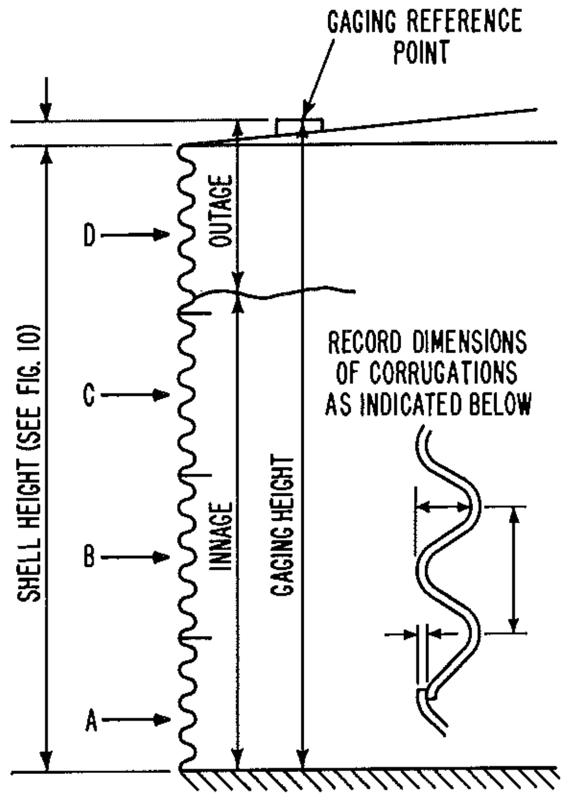


Circumference Measurements:

Circumference measurements at *A*, *B*, and *C* to be located one-fourth height of riug from top of each ring.

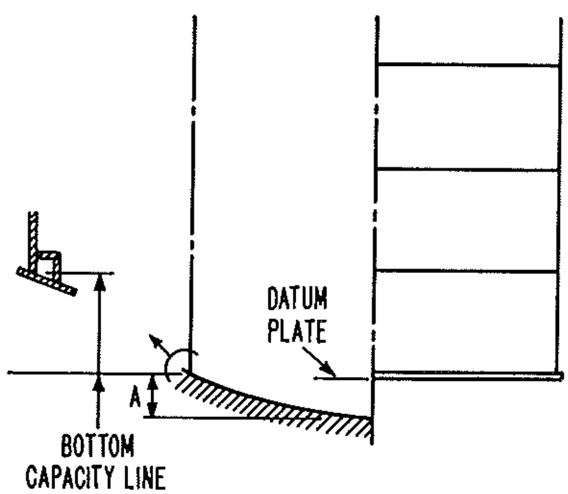
Measurements at *X* to be obtained by calibrated step-over, caliper, or special clamps; those at *Y* by circumference tape.

FIG. 18.—LOCATIONS OF MEASUREMENTS ON UPRIGHT CYLINDRICAL TANKS WITH FLANGED VERTICAL AND HORIZONTAL JOINTS.



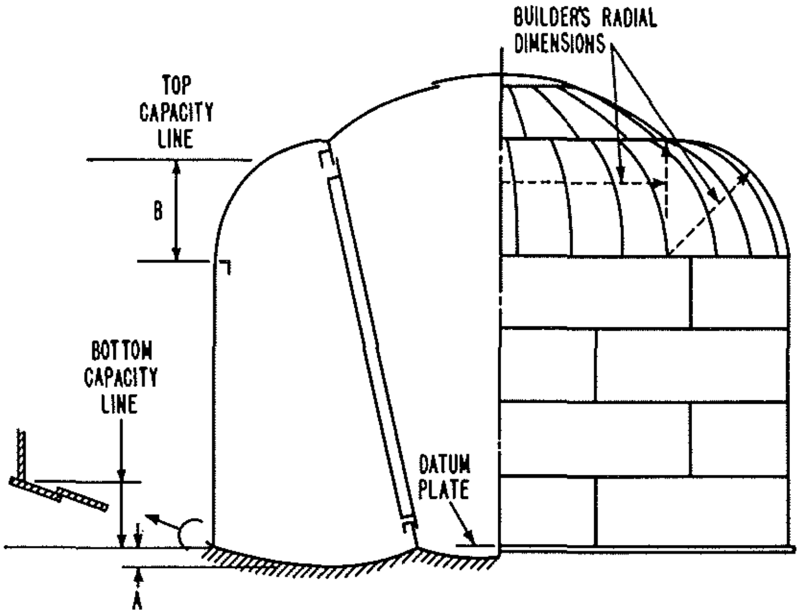
Circumference measurements at *A*, *B*, *C*, and *D* to be located in valley at center of each ring.

FIG. 19.—LOCATIONS OF MEASUREMENTS ON UPRIGHT CYLINDRICAL CORRUGATED STEEL TANKS.



Capacity of tank bottom, *A*, may be determined by calculations based on builder's drawings, or by liquid calibration in accordance with API Standard 2555-ASTM D 1406.

FIG. 20.—STRAIGHT SHELL TANK WITH INACCESSIBLE PRESSURE-TYPE BOTTOM.



Capacity of bottom, *A*, and upper curved portion, *B*, from straight shell to top capacity line, may be determined by calculations based on builder's drawings or by liquid calibration in accordance with API Standard 2555-ASTM D 1406.

Locations of measurements on welded cylindrical shell are the same as for welded upright cylindrical tanks (see Fig. 11).

FIG. 21.—NODED HEMISPHEROIDAL TANK.

(*d*) In a case as described in Paragraph (*c*), if circumference measurements are made with a step-over and a tape graduated in hundredths of a foot throughout its length, stretch the tape over the joints in accordance with Paragraph (*a*), and place the step-over in position at each location of void between tape and shell, completely spanning the void, so that the scribing points contact the shell at an edge of the tape. The length of tape encompassed by the scribing points, with the tape maintained in proper position and tension, should be estimated to the nearest 0.001 ft (approximately 1/64 in.). At each step-over location, therefore, the difference between the length of tape encompassed by the scribing points and the known span of the instrument is the effect of the void, at that point, on the circumference as measured. The sum of such differences in any given path, subtracted from the measured circumference, will give the corrected circumference.

(*e*) In a case as described in Paragraph (*c*), if circumference measurements are made with a step-over and a tape graduated in feet only, with an extra 1-ft length at the zero end graduated in tenths and hundredths of a foot, stretch the tape over the joints as in Paragraph (*a*), place the step-over in position at each location of void between tape and shell, and mark the tank shell at the points of contact of scribing points to shell. Each location so marked should then be measured with the same tape. For each separate measurement, the tape should be reapplied against the tank in proper tension, but so adjusted that a whole-foot marking lies opposite one of the scribed marks, and so chosen that the other scribed mark will lie within the graduated 1-ft extra length at the zero end. The tape length between the scribed marks should be estimated to the nearest 0.001 ft (approximately 1/64 in.). The measured circumference should be corrected as described in Paragraph (*d*) to obtain the corrected circumference. Alternatively, step-over and tape may be used as described in Paragraph (*f*).

(*f*) When obstructions are encountered in the tape path over which it is impracticable to place the tape—for example, the upright flanges on bolted tanks—a spanning instrument, such as a special clamp (used on bolted tank flanges only) or a step-over (used on bolted tank flanges or other obstructions), is used to measure a section of the true circumference at each obstruction. The span of the instrument, in relation to the diameter of the tank being measured, should be determined prior to use. In use, the circumferential sections along the tape path, and between the successive outer limits of reach in each application of the spanning instrument, should be measured with the tape in the usual way, except that the tank shell is not completely encircled. The total circumference, therefore, will be the sum of the tape measurements and the spanning instrument measurements. Care must be taken in placing the instrument in a truly level position at each obstruction to avoid distortions in the circumferential path. In the case of a step-over of relatively long span, the use of a spirit level is recommended as an aid in determining the correct position before scribed marks are struck off on the plates.

Deadwood

22. (*a*) Deadwood should be accurately accounted for, as to size and location, to the nearest 1/8 in., in order to permit:

(*1*) Adequate allowance for the volumes of liquid displaced or admitted by the various parts.

(*2*) Adequate allocation of the effects at various elevations within the tank.

(*b*) Deadwood should be measured, if possible, within the tank. Dimensions shown on the builder's drawings may be accepted if actual measurement is impossible.

(*c*) 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. Measurements should be increments which permit allowance for its varying effect on tank capacity at various elevations.

(*d*) Work sheets on which details of deadwood are sketched, dimensioned, and located should be clearly identified and should become a part of the strapping record.

TANK BOTTOMS

Tank Bottoms—Flat Type

23. (*a*) Tank bottoms which are flat and stable under varying liquid loads will have no effect on tank capacity determined on the basis of geometric principles.

(*b*) For critical measurements, where tank bottom conditions of irregular slope or shape and/or instability exist, as depicted in Figs. 22 through 25, and where correct capacities cannot be determined conveniently from linear measurements, it

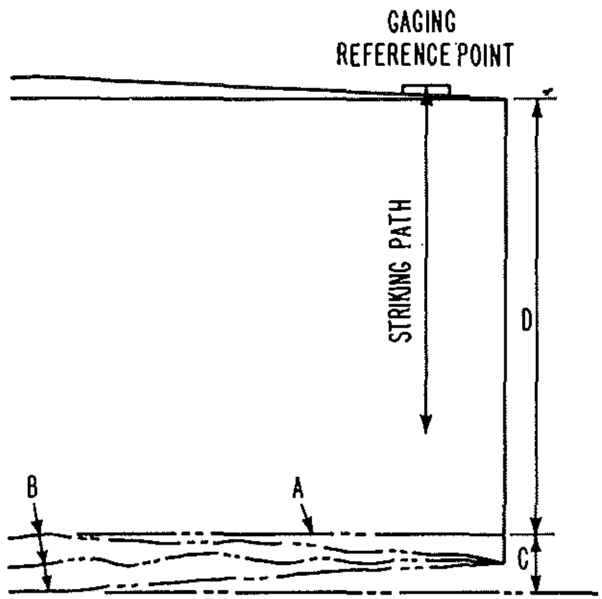
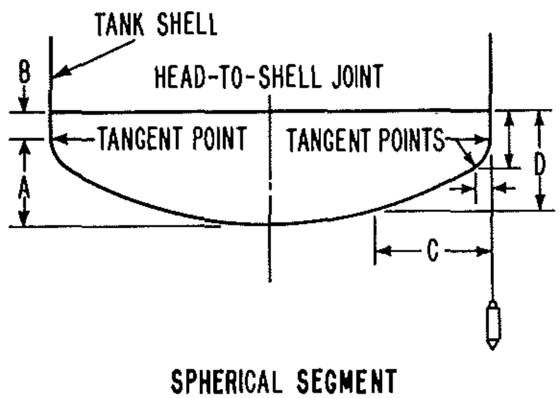


FIG. 22.—TANK BOTTOMS, IRREGULAR, UNSTABLE, OR BOTH, OF UPRIGHT CYLINDRICAL TANKS.

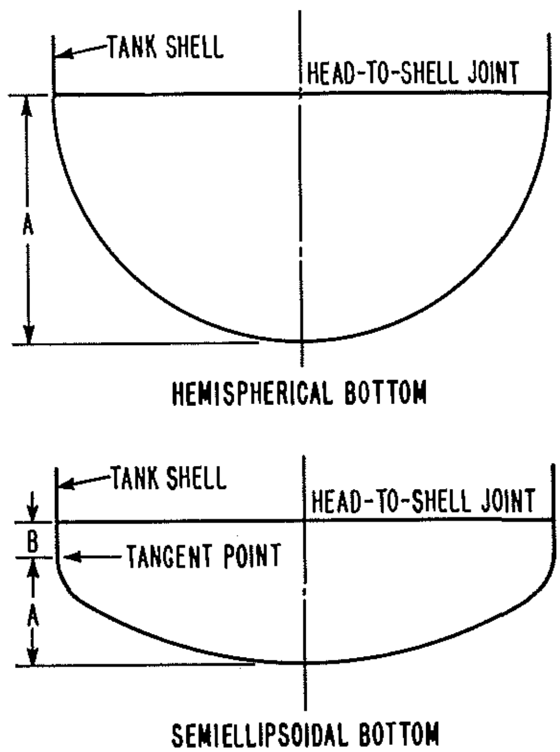


Linear Measurements:

Measurements at *A* and *B*, and offset measurements at *C* and *D* sufficient to describe knuckle and contour of spherical segment.

For convex tank bottoms of indefinite contour or with localized deformations, sufficient offset measurements such as *C* and *D* should be taken and recorded to establish contour of bottoms and extent of deformations. Sketches showing shape of bottoms, deformations, if any, and locations of measurements should be included in the strapping record.

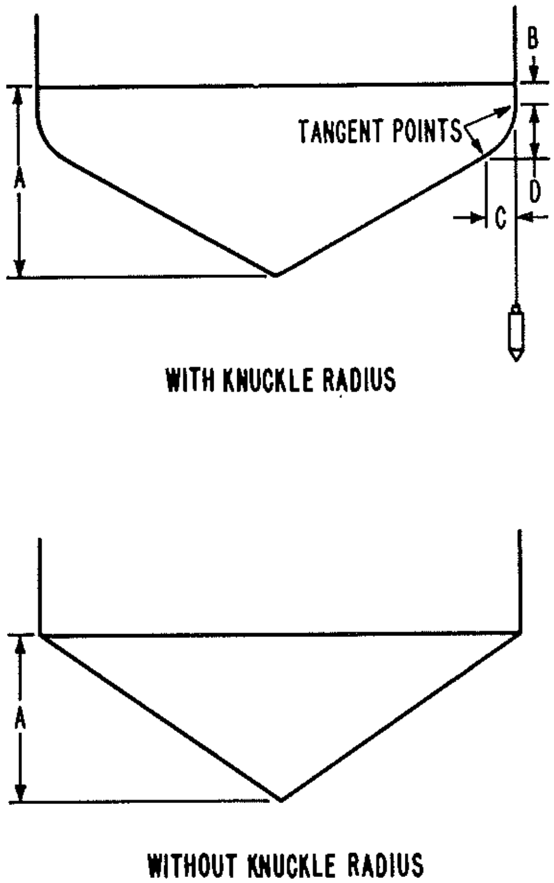
FIG. 23.—SPHERICAL SEGMENT (DISHED) TANK BOTTOMS, CONVEX AND ACCESSIBLE, OF UPRIGHT CYLINDRICAL TANKS.



Linear Measurements:

Measurements at *A*, or at *A* and *B*, for bottoms known to be hemispherical or semiellipsoidal in shape. It is recommended that additional offset measurements, as shown in Fig. 23 for spherical segment (dished) bottoms, be taken and recorded as supporting evidence. Strapping records should include known type name of bottom and sketch or sketches showing locations of measurements.

Fig. 24.—Hemispherical and Semiellipsoidal Tank Bottoms, Convex and Accessible, of Upright Cylindrical Tanks.



Linear Measurements:

Measurements at *A* and *B*, and offset measurements at *C* and *D* sufficient to describe the knuckle and the cone.

FIG. 25.—TANK BOTTOMS, CONED DOWNWARD AND ACCESSIBLE, OF UPRIGHT CYLINDRICAL TANKS.

will be necessary to resort to liquid calibration as described in API Standard 2555—ASTM D 1406.

(*c*) Correction for the effect of bottom characteristics should be made for critical measurements gage tables. 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.

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

(*e*) If liquid calibration is used, it should be continued to a depth in the tank sufficient to overcome all irregular shapes or unstable conditions as described in API Standard 2555—ASTM D 1406.

(*f*) Correction for the effect of bottom characteristics need not be made for operating control gage tables, provided the tank is operated at all times with liquid head sufficient to overcome all tank bottom characteristics, and the gage table is clearly marked to show "unused liquid depth."

(*g*) A tank with sloping or irregular bottom, not covered with water continuously, should be calibrated by the measurement and summation of incremental liquid volumes introduced into the tank, from the lowest point in the bottom to a point above which computations can be made from linear measurements (see API Standard 2555—ASTM D 1406).

Tank Bottoms—Conical, Hemispherical, Semiellipsoidal, and Spherical Segment

24. Tank bottoms conforming to geometric shapes have volumes which may be either computed from linear measurements or measured by liquid calibration by incremental filling, as desired. When volumes are to be computed, measurements should be made at the points shown on the applicable illustration in Figs. 23 to 25. Any detailed differences in shape affecting the volume, not shown on the guide sheets, such as knuckle radii, should be measured and recorded in sufficient detail to permit computation of the true volume.

TANK ROOFS OTHER THAN FIXED ROOFS

(Includes Various Types of Conservation Roofs)

Floating Roofs

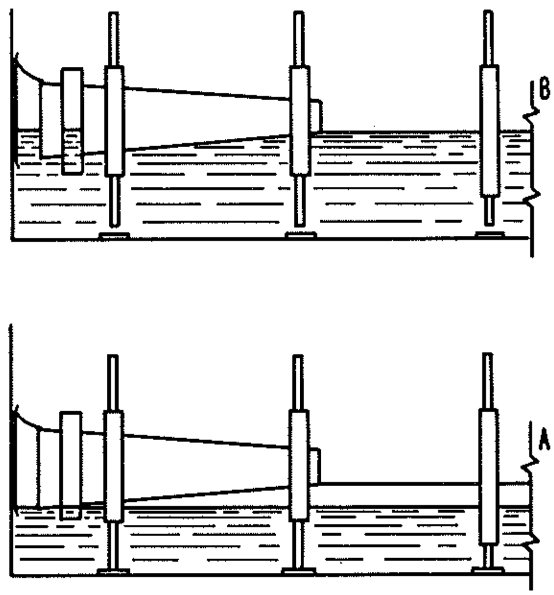
25. (*a*) Floating roofs, illustrated in Figs. 26 to 34, are installed in tanks with upright cylindrical shells. Measurements of the tank shell should be made as described in Sections 8 to 21. Floating-roof displacement, however, gives rise to special deductions for floating weight and deadwood. Position *A*, Fig. 26, 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.

(*b*) For critical measurement tank tables, liquid calibration is recommended for the levels between *A* and *B*, Fig. 26. Refer to API Standard 2555—ASTM D 1406 for liquid calibration procedure. For operating control tables, linear measurements may be used to determine the volumes between *A* and *B*.

Measurement Procedure for Floating-Roof Displacement

26. (*a*) *Floating 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. It is calculated by the builder and given on the drawing and on the roof nameplate and should be reported by the strapper.

(*b*) *Deadwood.*—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, 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



Zone in which floating roof displaces a part of its weight. Zone limits should be clearly marked on the gage table.

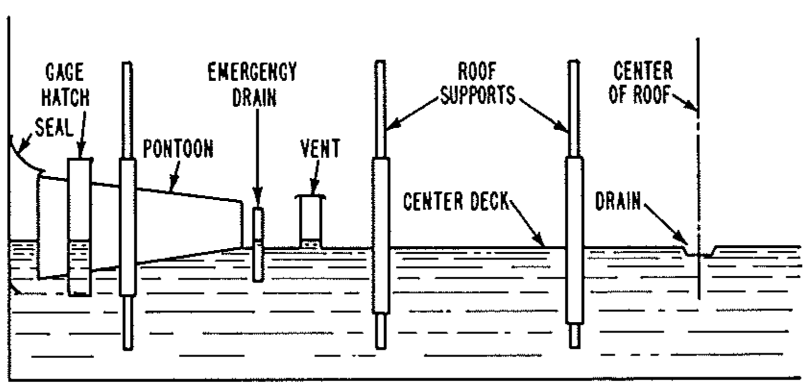
If accuracy in liquid measurements is desired, the need for gages in this zone should be avoided.

For Critical Measurements.—The zone should be calibrated with liquid, using a calibrated tank or meters of known accuracy (see API Standard 2555-ASTM D 1406).

For Operating Control.—The zone may be calibrated by field determination of the geometric shapes between positions *A* and *B*, or by geometric shapes determined from builder's drawings.

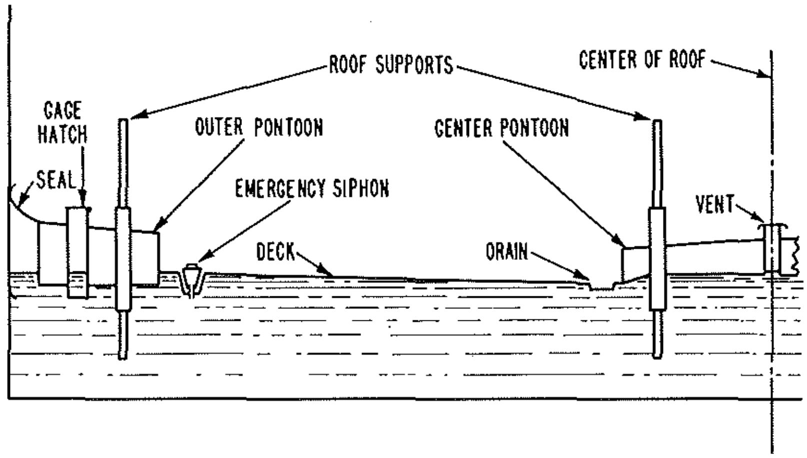
Incremental displacements throughout the zone of partial displacement should be continued up to the total displacement, which is equivalent to the weight of the roof and appurtenances.

FIG. 26.—SCHEMATIC DIAGRAM ILLUSTRATING THE ZONE OF PARTIAL DISPLACEMENT, COMMON TO ALL FLOATING ROOFS.



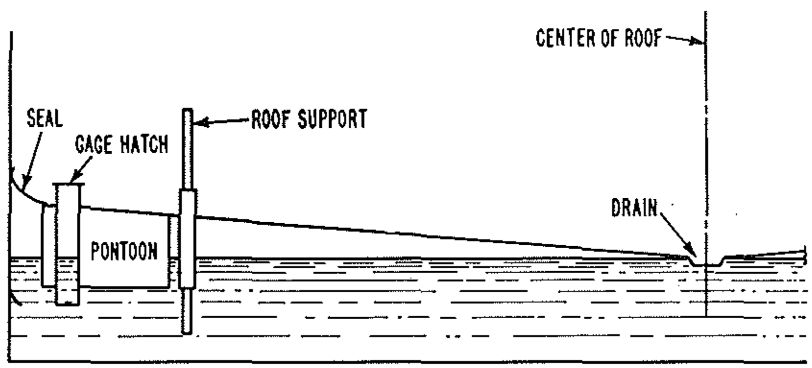
For zone of partial displacement, see Fig. 26.

FIG. 27.—ANNULAR PONTOON FLOATING ROOF WITH SINGLE CENTER DECK.



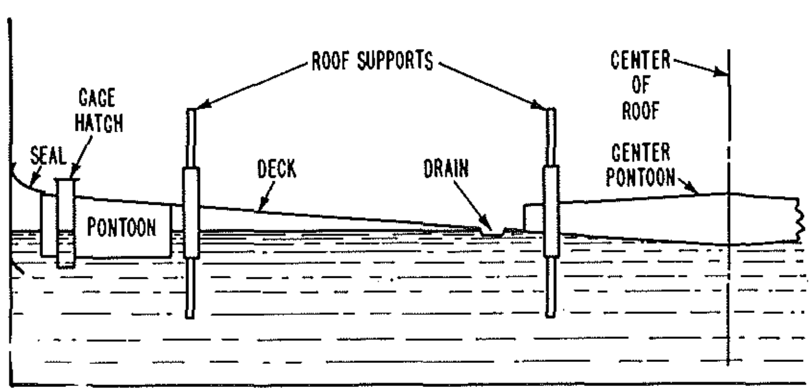
For zone of partial displacement, see Fig. 26.

FIG. 28.—LOW-DECK-TYPE FLOATING ROOF WITH CENTER PONTOON.



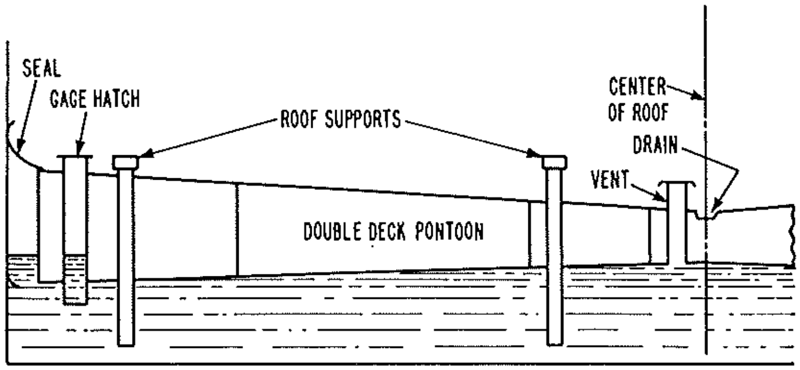
For zone of partial displacement, see Fig. 26.

FIG. 29.—HIGH-DECK-TYPE FLOATING ROOF WITHOUT CENTER PONTOON.



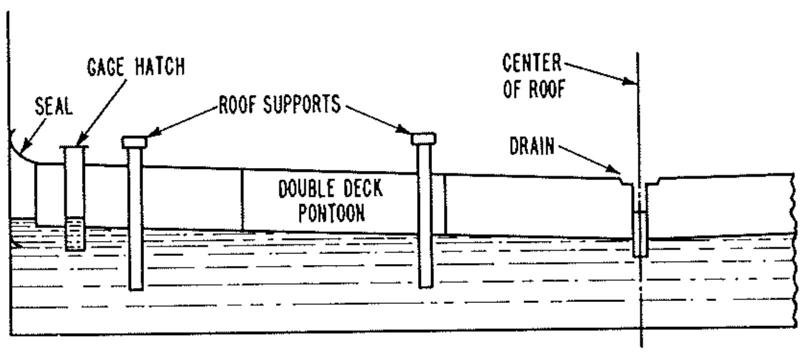
For zone of partial displacement, see Fig. 26.

FIG. 30.—HIGH-DECK-TYPE FLOATING ROOF WITH CENTER PONTOON.



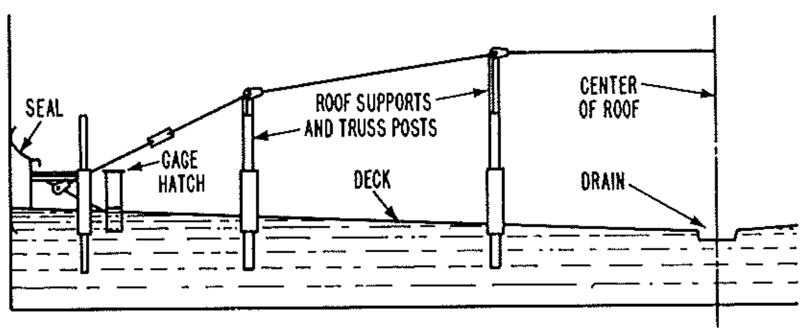
For zone of partial displacement, see Fig. 26.

Fig. 31.—Floating Roof with Converging Double Deck.



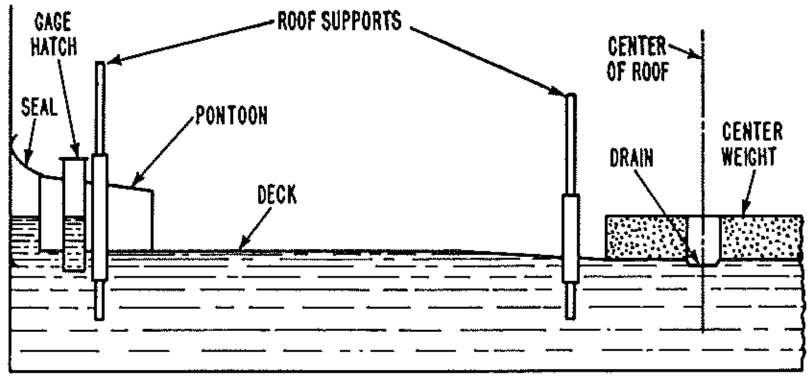
For zone of partial displacement, see Fig. 26.

Fig. 32.—Floating Roof with Parallel Double Deck.



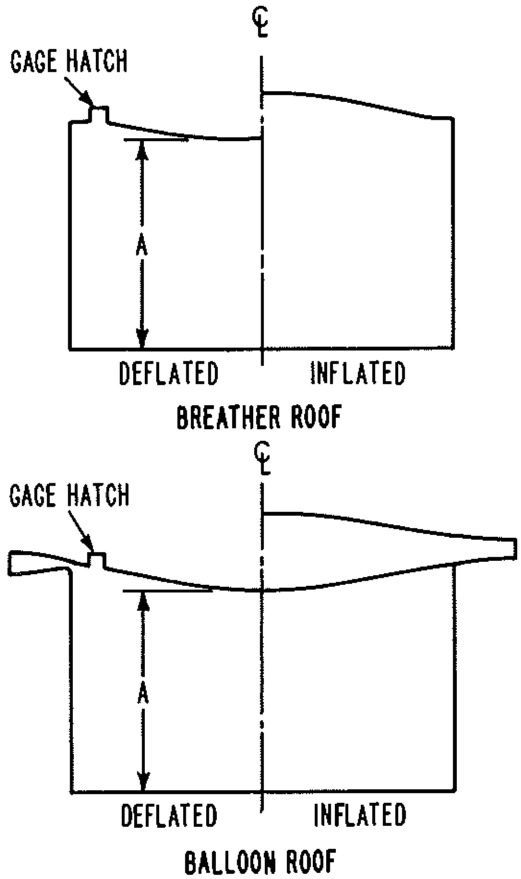
For zone of partial displacement, see Fig. 26.

Fig. 33.—Trussed, Pan-Type Floating Roof.



For zone of partial displacement, see Fig. 26.

FIG. 34.—CENTER WEIGHTED, PONTOON-TYPE FLOATING ROOF.



Height *A* should be noted on the gage table. Above this height, calculated gage tables will not be accurate if the liquid contacts the roof plates.

Roof plates are subject to deflection so that there is no fixed gaging reference point.

FIG. 35.—BREATHER AND BALLOON TYPES OF VARIABLE VOLUME ROOFS.

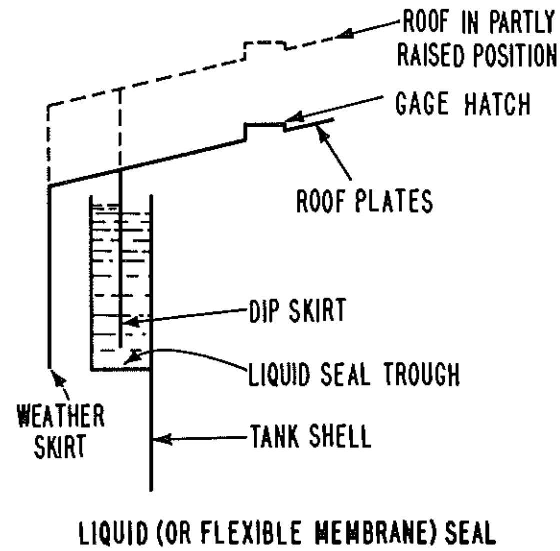


Fig. 36.—Lifter Roof Seal for Variable Volume Roof.

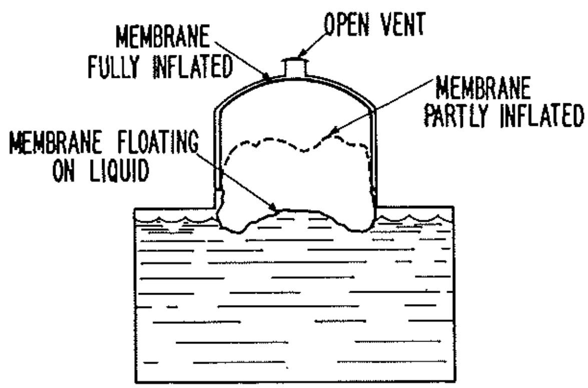


Fig. 37.—Variable Volume Roof with Flexible Membrane in Roof Dome.

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 with the aid of an engineer's level while the roof is resting on its supports.

(c) *Gage Measurements*.—The heights of the liquid levels at positions *A* and *B*, Fig. 26, should be measured and recorded.

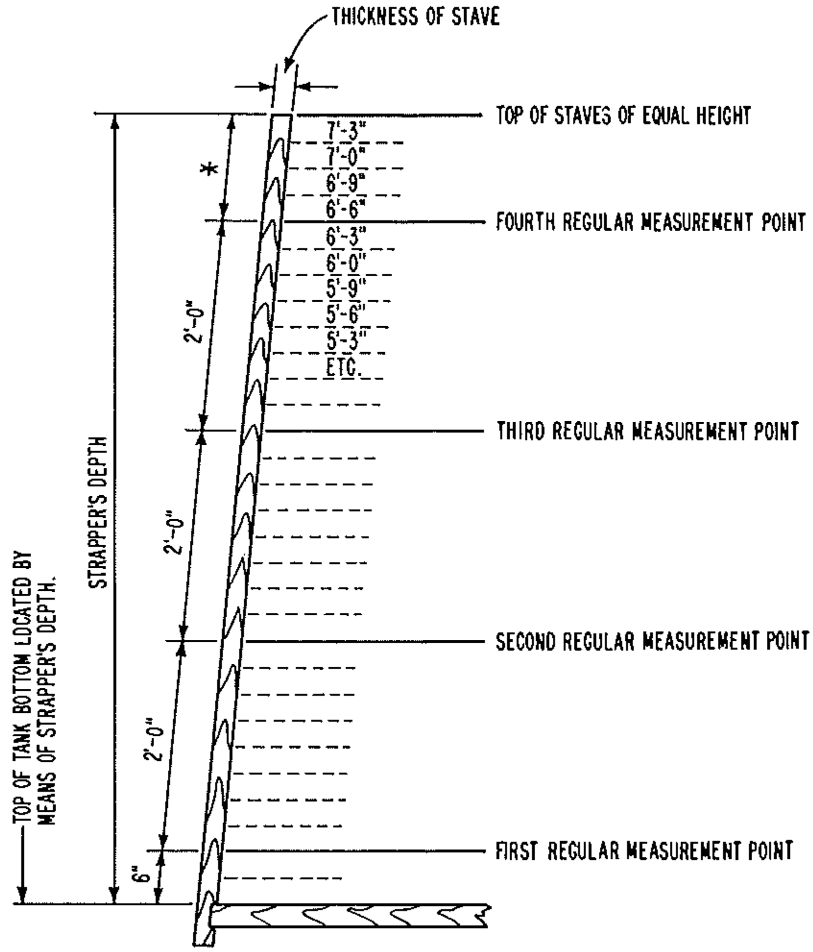
Variable Volume Roofs

27. (a) Variable volume roofs, Figs. 35 to 37, such as breather, balloon, lifter, or flexible membrane, may require special deadwood measurements for roof parts that are sometimes submerged. When these parts, such as columns, are fixed relative to the tank shell, they should be measured as deadwood in the usual way. When these parts move with the roof and hang down into the liquid, they should be deducted as fixed deadwood with the roof in the lowest position. Details may be secured from the builder or measured in the field.

(b) Some variable volume roofs have flexible membranes which may float on the surface when the membrane is deflated and the liquid level is high. The floating weight of the membrane displaces a small volume of liquid. Data on the floating weight should be secured from the builder and supplemented, if necessary, by field observation and measurement.

(c) Some variable volume roofs have liquid seal troughs or other appurtenances which make the upper outside part of the shell inaccessible for outside circumference measurements. Liquid calibration, as described in API Standard 2555—ASTM D 1406, of this portion of the shell may be made, or (*1*) theoretical dimensions may be taken from the builder's drawings, or (*2*) the highest measurable circumferential measurements may be used as a basis for the portion of the tank that cannot be measured. When the procedure in either (*1*) or (*2*) is used, it should be so indicated on the gage table.

WOODEN TANKS



* If the height of the tank, based on the gager's depth, extends to 1 ft 6 in. or more above the uppermost regular measurement point, an additional regular measurement point should be established at a distance of 1 ft 0 in. above the uppermost regular measurement point established by measurements illustrated.

Irregular measurement points, if required, are to be located at 3-in. intervals above or below the regular measurement points.

FIG. 38.—LOCATIONS OF MEASUREMENTS ON REGULAR TYPE OF WOODEN TANK.

General

28. (*a*) Wooden tanks may be measured at any time after they have been filled at least once.

(*b*) Prior to use, measurement tapes should be checked for accuracy and for required tension, against a certified tape in accordance with the procedure described in Section 5.

(*c*) A wooden tank should be completely remeasured when it has been relocated, altered, or modified in any way that might change its capacity.

Terminology

29. (*a*) *Hoop Driven* (*H.D.*).—A tank should be considered to have been hoop driven when there is a break in paint marks across hoops to staves, or in paint marks across threads and nuts on turnbuckles.

(*b*) *Rebuilt* (*R.B.*).—A tank is considered to be rebuilt when it has been wholly or partially dismantled and reassembled on the same or a new location.

(*c*) *Moved Bodily* (*M.B.*).—A tank moved to a new location without being dismantled.

(*d*) *Deadwood Change* (*D.W.C.*).—A change in deadwood which does not affect the tank shell, including:

(*e*) *Concrete in Bottom* (*C.B.*).—The addition of concrete or other material to the tank bottom. The condition requires particular attention at the time of remeasurement because of its effect on stave height and oil height and on locations of tape paths for circumferential measurements.

(*f*) *Strapper's Depth, or Stave Height.*—The perpendicular distance from the top of staves of equal height, used for marking elevations for regular circumferential measurements, to the inside surface of the tank bottom.

(*g*) *Gager's Depth, or Oil Depth.*—The perpendicular distance from the top of the shortest stave to the inside surface of the tank bottom. In the case of a tank with a deck set in (D.S.I.) below the level of the shortest stave, the oil depth is the perpendicular distance from the lowest point on the lower surface of the deck to the inside surface of the tank bottom.

(*h*) *Thickness of Staves.*—A simple average of the thickness of individual staves, up to 10 in number, to the nearest 1/16 in.

(*i*) *Regular-Type Tank.*—Wooden stave construction, in the shape of a frustum of a right-angle cone, with staves encircled by hoops.

(*j*) *Eccentric Slope.*—Irregularity in slope along length of staves.

(*k*) *Regular Slope.*—Constant slope throughout length of staves.

(*l*) *Regular Circumferential Measurements.*—Circumferential measurements taken at 0 ft 6 in. above the inside surface of the tank bottom (neglecting the effect of the slope angle), and at successive 2 ft 0 in. intervals (or 1 ft 0 in. for barrel or other types) upward along the slope of the staves [plus the exception described in Section 32(*b*)].

(*m*) *Irregular Circumferential Measurements.*—Circumferential measurements taken at elevations of 3, 6, 9, or 12 in. above or below the points for regular circumferential measurements, as described in Paragraph (*l*).

Tolerances

30. (*a*) Vertical measurements should be recorded to the nearest 1/4 in.

(*b*) Circumferential measurements should be recorded to the nearest 0.01 ft.

(*c*) Stave thickness should be recorded to the nearest 1/16 in.

(*d*) Circumference measurements taken at different dates, with the same or different tapes, and by the same or different personnel, may be considered to be in agreement if results check to or within 0.03 ft per 100 ft of circumference. For a circumference less than 100 ft, the tolerance of 0.03 ft may be reduced by the ratio of circumference, in feet, to 100 ft.

(*e*) Any evidence of hoop drive or of tightening of bolted hoops, as indicated, for example, by a severance of paint marks at hoop edges or at bolts, should require that a complete restrapping be made.

Previous Data

31. When a tank is to be restrapped, the strapper should make a check with the original strapping report, if readily available, of information such as the following: name of tank owner, lease names, and locations. If discrepancies appear, an explanation should accompany the strapper's report.

Vertical Measurements of Regular-Type Wooden Tanks

32. (*a*) The strapper's depth [Section 29(*f*)] and, for boxed-roofed tanks, the gager's depth [Section 29(*g*)] shall be measured and recorded.

(*b*) Using the strapper's depth, elevations for regular circumferential measurements should be located along the outside surface of staves, lengthwise, at the following elevations above the inside surface of the tank bottom (angle of slope of staves neglected) as shown in Fig. 38:

0 ft 6 in. (first regular point)
2 ft 6 in. (second regular point)
4 ft 6 in. (etc.)
6 ft 6 in.
8 ft 6 in.
10 ft 6 in.
12 ft 6 in.
14 ft 6 in.
etc., except that: If the height of the tank, based on the gager's depth, extends to 1 ft 6 in., or more, above the uppermost regular point, then an additional regular point should be established at a distance of 1 ft 0 in. above the uppermost regular point as determined by the progression shown in this tabulation.

(*c*) Regular measurement points should be marked on the tank wall in at least four places approximately evenly spaced around the tank.

(*d*) Irregular measurement points should be located, as required, due to obstructions in the tape paths at regular points, at distances of 3, 6, 9, or 12 in.

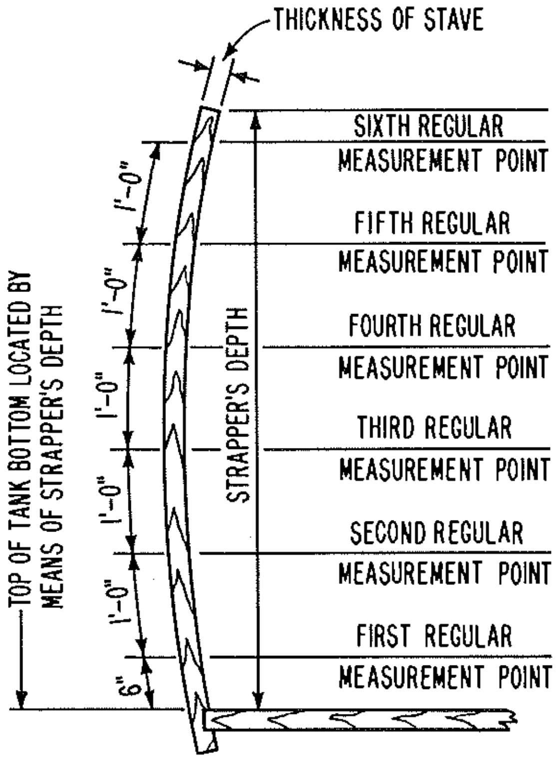


Fig. 39.—Locations of Measurements on Barrel or Other Types of Wooden Tanks.

Circumferential Measurements of Regular-Type Wooden Tanks

33. (*a*) Sequence of measurements may be established to suit existing circumstances.

(*b*) Tape paths should be clean.

(*c*) At each measurement elevation the tape should be positioned at the measurement point, brought to proper tension, and the reading taken and recorded. Each such initial reading at each measurement point should be checked by shifting the tape circumferentially, repositioning, and reapplying the proper tension. A step-over or caliper may be used to span localized obstructions, if convenient. This equipment should be calibrated for the particular tank diameter as described in Section 6(*i*). Check readings should be repeated until agreement has been reached.

(*d*) It is recommended that circumference measurements taken at irregular points be computed to equivalent regular-point basis before leaving the tank site, as an aid in appraisal of circumference variations relative to slope characteristics of the shell.

(*e*) Because irregular measurement points are removed from regular measurements by increments of 3 in., the difference between regular and irregular measurements must be computed in sections of 3 in. each. Thus, 1 ft 9 in. equals seven sections of 3 in. each; 2 ft 0 in. equals eight sections of 3 in. each, etc.

Barrel and Other Types of Wooden Tanks

34. (*a*) Circumference measurements on all types of wooden tanks, other than the regular type, should be taken at 1 ft 0 in. intervals, beginning at a point 0 ft 6 in. above the inside surface of the tank bottom as shown in Fig. 39. If hoops are found to interfere at these locations, measurements should be taken at points equidistant in 3-in. increments above and below the regular points of measurement. The average of these measurements should be taken as the regular measurement. When manholes or other obstructions are encountered at the regular locations, a step-over or caliper of adequate span should be used. When paint lines at hoop edges or at tightening bolts have been severed, circumferences should be remeasured.

(*b*) Thickness of staves should be determined as described in Section 29(*h*).

Deadwood

35. Deadwood in all types of wooden tanks should be determined and located by measurement readings to the nearest ⅛ in.

UNDERGROUND TANKS

Conditions and Procedures for Measurements

36. (*a*) 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 gage tables:

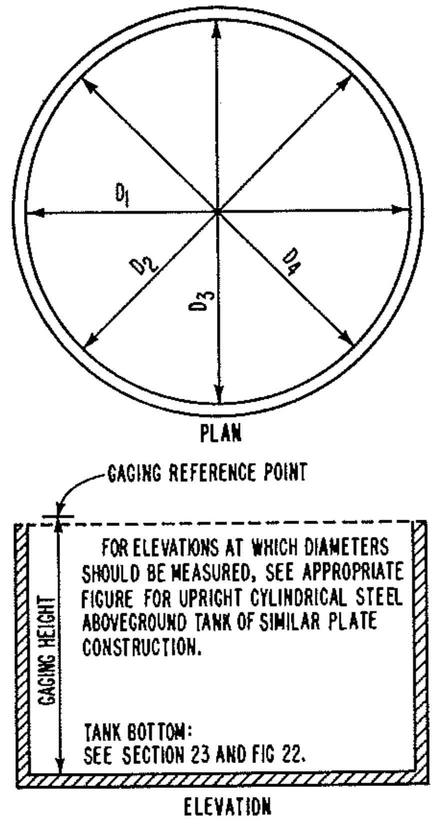
(*b*) *Liquid Calibration.*—Probably the most satisfactory method of calibrating underground tanks (initially and later) is by liquid calibration, as described in API Standard 2555—ASTM D 1406.

(*c*) *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 of the same type, if the method of construction makes this possible. It must be recognized that the placing of earth backfill may result in tank deformations which might appreciably affect the tank capacity.

(*d*) *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 table of tank capacities. This involves measurement of:

(*1*) An adequate number of diameters or other dimensions (Note 12) with their approximate position in the tank.

(*2*) The volume and location of deadwood; i.e., of any fitting or other object which adds to or subtracts from the space available for liquid.



Diameter Measurements:

Minimum number of diameter measurements = $D/8$, but not less than four measurements, where D = nominal tank diameter, in feet.

Half of the diameter measurements should be made with one end of the tape located near the middle of a shell plate; remainder with one end of the tape located near but not closer than 12 in. to a vertical joint.

FIG. 40.—LOCATIONS OF MEASUREMENTS ON UPRIGHT CYLINDRICAL STEEL UNDERGROUND TANKS.

NOTE 12.—When drawings for the tank are available, the diameters and other measurements should be compared with those obtained from the drawings, and any measurements which 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.

Diameter Measurements for Upright Cylindrical Steel Underground Tanks

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

(*b*) Diameters should be measured with steel tapes which meet the requirements of Section 5.

(*c*) Diameter measurements should be taken, as shown in Fig. 40, 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:

(*1*) 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.

(*2*) Half of the diameters should be measured with one end of the tape located near the middle of a shell plate.

(*3*) Half of the diameters should be measured with one end of the tape located near but not closer than 12 in. to a vertical joint.

(*d*) If for any reason it is impractical to take measurements at the positions described in Paragraph (*c*), 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.

(*e*) 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 which 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. [For an alternative procedure, see Paragraphs (*i*) and (*j*).]

(*f*) Each measurement of diameter should be recorded to the nearest 0.005 ft.

(*g*) Check measurements of diameters multiplied by 3.1416 should not differ by more than the values given in Table I [Section 16(*b*)].

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

$$\text{Correction, in feet} = \frac{W^2S^3}{24P^2} = KS^3$$

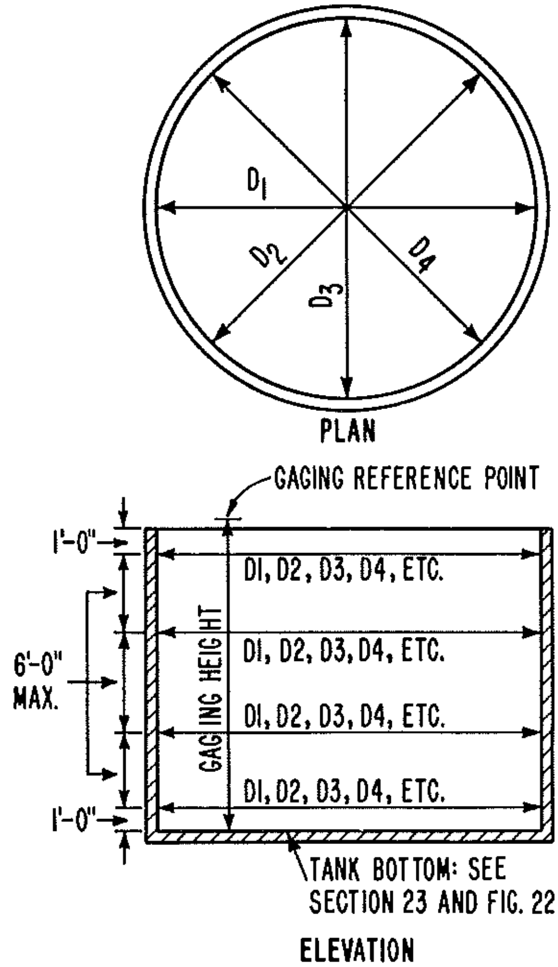
where:

P = pull on tape, in pounds.
S = span of tape, in feet.
W = weight of tape, in pounds per foot.
K = constant for tape $= \frac{W^2}{24P^2}$

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.

(*i*) As an alternative to the procedure outlined in Paragraph (*e*), measurements may be made by: (*1*) establishing plumb lines a few inches distant from the tank wall at the proper locations; (*2*) measuring the distance between the plumb lines with the tape resting on the tank floor, thus eliminating the need for a sag correction; (*3*) measuring with a rule the distances from the plumb lines to the adjacent tank walls at the required elevations; and (*4*) adding the two corresponding short-end measurements to the single center floor measurement to determine the required dimension for each elevation.

(*j*) If a center column makes impractical a direct measurement of the distance between plumb lines [Paragraph (*i*)], 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



Diameter Measurements:

Minimum number of diameter measurements = $D/8$, but not less than four measurements, where D = nominal tank diameter, in feet.

Diameter measurements should also be made at locations of offsets or abrupt changes in tank diameter.

Measurements at all locations illustrated should be reported on strapper's record, along with field sketches of tank.

FIG. 41.—LOCATIONS OF MEASUREMENTS ON UPRIGHT CYLINDRICAL CONCRETE UNDERGROUND TANKS.

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.

Diameter Measurements for Upright Cylindrical Concrete Underground Tanks

38. (*a*) Diameters should be measured at the following elevations, as shown in Fig. 41:

(*1*) 1 ft above the tank bottom.

(*2*) 1 ft below the tank roof.

(*3*) At intermediate elevations not more than 6 ft apart.

(*4*) At any offsets or abrupt changes in wall diameter.

(*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 Paragraphs (*a*) and (*b*), then the diameter should be taken as close to the described position as practicable. The reason for the deviation should be recorded in the field notes.

(*d*) Diameters should be measured, recorded, and corrected as specified for underground cylindrical steel tanks in Section 37.

Measurements for Rectangular Steel or Concrete Underground Tanks

39. (*a*) Lengths and widths should be measured at the following elevations, as shown in Fig. 42:

(*1*) 1 ft above the tank bottom.

(*2*) 1 ft below the tank roof.

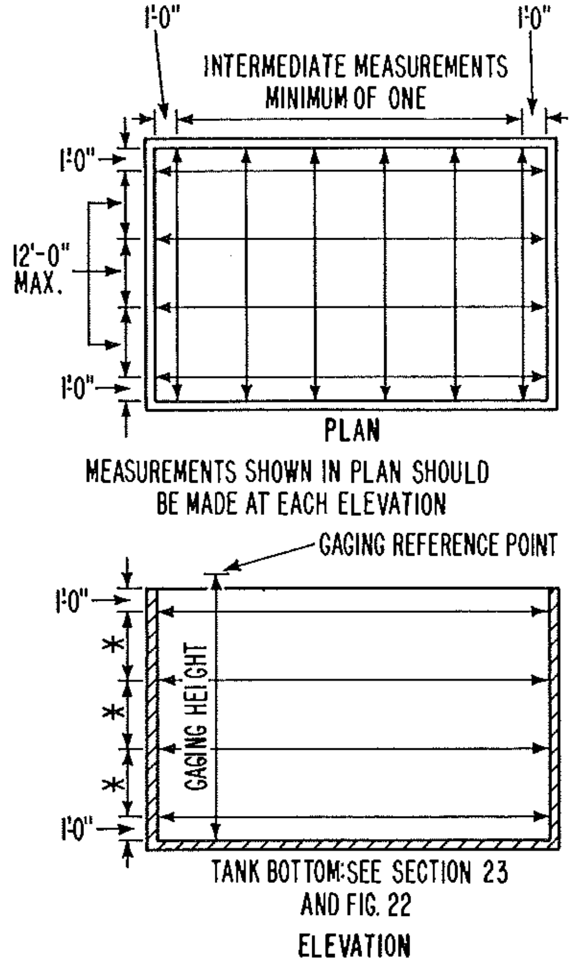
(*3*) At intermediate elevations not more than 6 ft apart, unless it can be shown that the walls are vertical, in which case measurements at intermediate elevations not more than 12 ft apart are adequate.

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

(*b*) At each such elevation:

(*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.



Measurements at Intermediate Elevations:

For vertical sides, * = 12 ft, max.

For nonvertical sides, * = 6 ft, max.

Length and width measurements should be made at elevations of offsets or abrupt changes in wall dimensions.

Measurements at all locations illustrated should be reported on strapper's record, properly identified, along with field sketches of tank.

FIG. 42.—LOCATIONS OF MEASUREMENTS ON RECTANGULAR STEEL OR CONCRETE UNDERGROUND TANKS.

(*c*) If for any reason it is impractical to take measurements at the positions described in Paragraphs (*a*) and (*b*), 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.

(*d*) Length or width should be measured, recorded, and corrected as specified for underground cylindrical steel tanks in Section 37.

(*e*) 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 Sections 8 to 22 and as outlined for underground tanks in Sections 36 to 39, where applicable.

Calibration Based on Drawings

40. In the event that the calibration procedures described in Section 36(*b*), (*c*), and (*d*) cannot be used, gage tables may be prepared from computations

based on the construction drawings and specifications of the tank builder.

OUTSIDE INSULATED TANKS

Conditions and Procedures for Measurements

41. (*a*) Insulation may be applied to any tank so that it becomes impractical to use outside measurements for calibration purposes. The following procedures may be followed in determining the data necessary for the preparation of gage tables:

(*b*) *Liquid Calibration.*—Insulated tanks may be calibrated by the introduction of measured quantities of liquid in accordance with API Standard 2555—ASTM D 1406.

(*c*) *Calibration Based on Outside Measurements.*—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. The addition of insulation should not normally affect the accuracy of this calibration.

(*d*) *Calibration Based on Inside Measurements.*—Calibration of insulated tanks may be based on inside measurements as described for underground tanks in Sections 36 to 39.

(*e*) *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 methods in Paragraphs (*b*), (*c*), or (*d*) can be used.

PART II. TANK CAPACITY CALCULATION PROCEDURES

General

42. Sound engineering and mathematical principles should be used in all calculations. These principles should include those given herein for application to this particular type of work. It should be noted that length measurements may be made by working tapes which may have been calibrated against a standard tape of length based on 68 F. Where this occurs, the calculation of gage tables shall mathematically correct such length values to the equivalent 60 F value prior to use.

Gage Tables

43. (*a*) Tank capacities should be expressed in whole gallons, or barrels and decimal parts of a barrel (see Tables VII and VIII in Appendix I).

(*b*) Attention is directed to the fact that tolerances for measurements and calculations included in this standard are intended to apply to the development of both critical measurements and operating control gage tables (see Section 13). Adjustments for the effect of any of the variables may be incorporated in gage tables for operating control tanks. It is recommended that gage tables be marked to show adjustments which have been incorporated therein.

(*c*) As a matter of principle, it is recommended that all newly prepared gage 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: (*1*) the date a new tank was first used; (*2*) the date an old tank was recalibrated; and (*3*) the date agreed upon for purchase, sale, or exchange of product.

Conversion of Outside to Inside Circumferences

44. Plate thicknesses used in calculations should be those reported on field measurement records. Values for plate thicknesses taken from drawings may be used where necessary.

Inside circumference (in feet)

$$= \text{outside circumference (in feet)} - \frac{\pi t}{6} \quad \ldots\ldots(1)$$

where:

t = steel thickness, in inches.

Significant Figures

45. All incremental or total volume calculations should be carried to seven significant figures. Corrections to incremental or total volume calculations need be carried only to the number of significant figures consistent with the seventh in the quantity corrected.

Interpolations

46. Interpolations for determinations of tank volumes preferably should be made on circumference (or diameter) measurements rather than on capacities for given height increments. In the development of operating control gage tables for welded steel tanks, interpolations should be made between those circumferences (or diameters) measured at locations 20 per cent down from the top of the top ring and 20 per cent down from the top of the third ring.

Extrapolation

47. Extrapolation should be avoided if possible. If required, it should be accomplished by the graphical method or the algebraic method.

Weighted Averages

48. Weighted averages, where applicable, rather than simple averages should be used in circumference weightings. If more than two circumferences have been measured for a given tank ring or height segment, and if the individual measurements are representative of different width increments, a weighted rather than a simple average should be used in circumferential weightings. Thus, if a ring or height segment has been meastred at the top, bottom, and center locations, the top and bottom measurements should each be given a weight of one and the center measurement a weight of two in determining the desired weighted average. Weighting of circumference measurements is necessary only in those cases where one or more measurements are made on a given ring at locations intermediate to those locations illustrated in Figs. 11 to 19, by reason of bulges or other departures from the typical tank shell contour.

Deadwood Deductions

49. 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.

UPRIGHT CYLINDRICAL STEEL TANKS—ABOVEGROUND

Incremental Height Capacity Basis

50. Capacities for incremental heights of upright cylindrical tanks should be based on calculations considering each ring as a vertical cylinder. Use weighted average of measured circumferences where more than two circumferences have been measured per ring or height segment. The lower of the ring circumference measurements on lap-riveted tanks should be used, when properly corrected, as a circumference measurement on the ring directly below; i.e., the circumference measurement on ring No. 2, when properly corrected, should be averaged with the circumference measurement of ring No. 1.

Disregarded Tank Volume

51. The preparation of gage tables for upright tanks is based on a maximum liquid height not greater than the upper rim of the cylindrical shell. The volume within the tank which is above that level shall be disregarded in gage 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.

Deductions for Circumference Tape Rises

52. (*a*) 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 on the ring.

(*b*) Deduction for tape rise may be computed from the tape-rise correction equations, in Paragraphs (*c*) and (*d*), or measured with step-over calipers 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 step-over; therefore, the tape-rise correction method is preferred for such projections.

(*c*) *Tape-Rise Correction Equation for Butt Straps or Similar Projections:*
Deduction, in inches

$$= \frac{2Ntw}{d} + \frac{8Nt}{3}\sqrt{t/d} \quad \ldots (2)$$

where:

- N = number of butt straps or projections per ring.
- t = amount of rise (thickness of straps or projections), in inches.
- w = width of straps or projections, in inches.
- d = nominal diameter of tank, in inches.

(*d*) *Tape-Rise Correction Equation for Lap Joints:*

(*1*) Application of Equation (2), in modified form, to tape rise at lap joints is described with reference to Fig. 5. In Fig. 5 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.

(*2*) 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 Fig. 5, this requires correction for only one-half of the tape rise. With the width, w, eliminated, the equation becomes:

$$\text{Deduction, in inches} = \frac{8N}{3} \times \frac{t}{2}\sqrt{t/2d} = \frac{4Nt}{3}\sqrt{t/2d} \quad \ldots\ldots (3)$$

(*3*) It is also shown in Fig. 5 that no deductions for deadwood at lap joints are required, since the deductible and additive volumes at lap joints are equal.

Expansion and Contraction of Steel Tank Shells Due to Liquid Head

53. (*a*) Expansion and contraction of steel tank shells due to liquid head, though small, is consistent as to direction and should be taken into consideration where maximum accuracy in gage tables is desired. On the basis of practical consideration, this adjustment need not be made for tanks in crude oil service on oil-producing properties; however, tanks with nominal capacity of over 500 bbl should be measured when at least two-thirds full. Smaller tanks in this service may be measured at any condition of fill. All such tanks, regardless of size, should have been filled at least once before being measured. If movement into or out of such crude oil tanks cannot be halted conveniently, measurements may be made on such tanks during transfer operations.

(*b*) This section does not cover the effects of slippage in joints of bolted or riveted tanks.

(*c*) The effect of liquid head may be introduced into critical measurements gage tables in either of two ways:

(*1*) By calculation of expansion effects at progressively increasing liquid levels.

(*2*) By measuring the tank when it is at least two-thirds full.

(*d*) In the case of the calculation procedure in Paragraph (*c*), Item (*1*), field circumference measurements should be adjusted to "empty tank" or unstressed basis, after which 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 by means of the following equation:

$$\Delta C = -\frac{WhC^2}{2\pi Et} \quad \ldots\ldots\ldots (4)$$

where:

- ΔC = circumference correction to empty tank or unstressed condition.
- W = weight of liquid per unit volume.
- h = liquid head above strapped elevation.
- C = strapped circumference before correction.
- E = modulus of elasticity of metal in tank shell.
- t = shell thickness at strapped elevation.

NOTE 13.—All units must be consistent. For example, in the English 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 liquid above the circumferential elevation necessary to fill each ring.

Volume correction per increment, Δv:

Δv (first, or bottom, ring)

$$= 0 \quad \ldots\ldots\ldots\ldots (5)$$

Δv (second ring)

$$= \frac{\pi W d^3}{4E}\left(\frac{h_1}{t_1}\right) \quad \ldots\ldots\ldots\ldots (6)$$

Δv (third ring)

$$= \frac{\pi W d^3}{4E}\left(\frac{h_1}{t_1} + \frac{h_2}{t_2}\right) \quad \ldots\ldots\ldots\ldots (7)$$

Δv (nth ring)

$$= \frac{\pi W d^3}{4E}\left(\frac{h_1}{t_1} + \frac{h_2}{t_2} + \cdots + \frac{h_{n-1}}{t_{n-1}}\right)..(8)$$

where:

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

W = weight of liquid per unit volume.

d = nominal tank diameter.

E = modulus of elasticity of metal in tank shell.

h_1, h_2, etc. = height of shell rings.

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

NOTE 14.—All units must be consistent. For example, in the English 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 gage table is made in ¼-in. increments, Δv must be divided by 4.

(*e*) In the event that it is not desired to produce a gage table which incorporates the expansion effects calculated at differing liquid levels, as mentioned in Paragraph (*c*), Item (*1*), the gage table may be based on field measurements taken when the tank is at least two-thirds full, as stated in Paragraph (*c*), Item (*2*).

(*f*) For operating control, use either of the two procedures noted in Paragraph (*c*), or, alternatively, base the gage table on measurements taken at any condition of fill desired, to conform with tank owner's general practice for tanks in this category, and omit the effect of tank expansion and contraction from the gage table.

Expansion and Contraction of Steel Tank Shells Due to Temperature

54. Expansion and contraction of unheated steel tank shells may be disregarded. Correction for expansion or contraction will not be necessary, except when very accurate measurements are required of the contents of heated tanks. On the basis of practical consideration, this adjustment need not be made for tanks in crude oil service on oil-producing properties. If this adjustment is to be made, then, in the case of strappings made at cold nonservice temperatures of tanks which will be heated in normal service, 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 volume correction procedure for computing the volume to be added to the total volume computed for the tanks from strapping in the unheated condition is as follows:

Cross-sectional area correction,

$$K = 1 + 12.4 \times 10^{-6}\Delta t_s + 4.0 \times 10^{-9}\,\Delta^2 t_s..(9)$$

where:

Δt_s = steel temperature minus 60 F. (All tank strapping circumference measurements for steel tanks are at 60 F.)

(*1*) For noninsulated metal tanks, the temperature of the shell may be taken, in general, as the mean of the adjacent liquid and ambient temperatures on opposite sides at the same location. In which case:

$$t_s = \frac{t_L + t_A}{2}.........(10)$$

where:

t_L = liquid temperature.

t_A = ambient temperature.

(*2*) For insulated metal tanks, the temperature of the shell may be taken as closely approximating the adjacent liquid temperature. In which case, $t_s = t_L$.

In applying these principles to upright cylindrical tanks, the horizontal cross-sectional area may be taken as a function of tank calibration. The third dimension, height, needed to generate volume is a function of gaging 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. The coefficient determined from Equation (9) is predicated on a thermal expansion for low-carbon steel per degree Fahrenheit. For other than low-carbon steel, the coefficient should be corrected by the ratio of the coefficient of low-carbon steel and the actual metal used at actual temperature.

If the tank shell is aluminum at a temperature of 180 F, from the values of α_m in the following tabulation, the ratio of K_a (aluminum) to K_s (steel) would be:

$$K_a = K_s \times \frac{0.0000130}{0.0000065}$$

Tank Shell Temperature, t, °F	Value of α_m per °F
Steel	
−70 to −21	0.0000060
−20 to +28	0.0000061
+29 to 78	0.0000062
79 to 128	0.0000063
129 to 177	0.0000064
178 to 227	0.0000065
228 to 276	0.0000066
277 to 326	0.0000067
327 to 376	0.0000068
377 to 425	0.0000069
Aluminum	
−70 to −11	0.0000122
−10 to +49	0.0000124
+50 to 109	0.0000126
110 to 169	0.0000128
170 to 229	0.0000130
230 to 289	0.0000132
290 to 349	0.0000134
350 to 409	0.0000136

where:

α_m = the mean coefficient of linear expansion between temperatures, t, and 60 F.

Effect of Tilt on Cylindrical Portion of Tank

55. (*a*) The liquid surface in a tilted cylindrical tank is elliptical in shape, rather than circular, and the capacity per unit of gaging height is greater than would be the case if the tank were truly upright. For procedures relative to calibration of tank bottom characteristics, reference should be made to Section 22.

(*b*) For critical measurements, the amount of tilt in shell height should be measured. For tanks tilted less than one part in 70 parts, the error in a "vertical" gage table for the cylindrical portion will be less than 0.01 per cent by volume, and the effect may be disregarded. If the amount of tilt is 1 in 70, or more, the vertical gage table should be adjusted to a zero-tilt basis. The following equation may be used to determine the percentage volume correction due to tilt:

Volume correction, per cent

$$= 100\,(\sqrt{1 + m^2} - 1)..(11)$$

where:

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

The following tabulation shows the volume correction in per cent for various amounts of tilt:

Tilt, ft per 100 ft	Volume Correction, per cent
1.4	+0.0008
1.6	+0.0128
1.8	+0.0162
2.0	+0.0200
2.2	+0.0242
2.4	+0.0288
2.6	+0.0338

(*c*) For operating control, it is recommended that the effect of tilt be provided for in accordance with Paragraph (*b*).

Effect of Out-of-Round Condition

56. The amount of out-of-roundness necessary to cause an error of 0.01 per cent in area is far more than is acceptable in tank construction. This effect may be disregarded.

FLOATING ROOFS AND VARIABLE VOLUME ROOFS

Floating Roofs

57. (*a*) The gage table should be prepared on the basis of gaging from the striking point upward to the liquid level in the gage hatch. The preparation of the gage table is related to the method used for obtaiuing field data in the zone of partial displacement; i.e., whether liquid is calibrated or measured (see Sections 25 and 26).

(*b*) *Liquid Calibration for Floating-Roof Displacement.*—The displacement of a floating roof through the critical zone, *A* to *B* (Fig. 26), is most accurately determined by liquid calibration as presented in API Standard 2555—ASTM D 1406. Following this procedure will result in a gage table with the floating roof treated as deadwood.

This type of gage table is more fully described in Paragraph (*d*). Above position *B*, Fig. 26, capacities should be corrected to account for the change in roof displacement resulting from the difference between the specific gravity of the calibration liquid and that of the liquid being gaged. 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:

Correction, in gallons

$$= W\left(\frac{1}{p_c} - \frac{1}{p_a}\right) \quad (12)$$

where:

W = floating weight of roof, in pounds.

p_c = pounds per gallon of the calibration liquid.

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

After correctiou to an assumed API gravity, the table is accurate only if, at time of gaging, the API gravity at the tank liquid temperature is the same as the API gravity for which the table is prepared. Usually it is different, and it is therefore necessary to correct a voluine taken from the table. This correction is described in Paragraph (*d*).

(*c*) *Measurement Procedure for Floating-Roof Displacement:*

(*1*) *Liquid Level Below Position A, Fig. 26.*—This range can be accurately calibrated by measurements as described in Sections 8 to 21. All deadwood must be deducted.

(*2*) *Liquid Level Between Positions A and B, Fig. 26.*—This range cannot be accurately calibrated by measurements described in Sections 8 to 20. The upper and lower limits should be clearly indicated on the gage table with a note stating that this range should be avoided for critical measurements. In calibrating this range by the measurement procedure (Section 26), all deadwood, including the geometric shape of the roof, should be deducted. This should be carried up to position *B*, the location of which must be determined by the calculator. 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. 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. of depth below position *A* and above position *B* in establishing the critical zone. This does not influence any calculation but only the upper and lower limits of the critical zone indicated on the gage table.

(*3*) *Liquid Level Above Position B, Fig. 26.*—This 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 appnrtenances that are carried up and down in the tank with the roof. It is calculated by th 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 flexibly supported parts of the drain, all of the swing line float, and half of the swing pipe. Above position *B*, deadwood which 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.

(*d*) *Gage Table with Floating Roof Treated as Deadwood:*

(*1*) In this type of gage 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.

(*2*) For liquid levels below position *B*, Fig. 26, all deadwood should be deducted as it becomes immersed. This deadwood should include the floating roof itself based on its geometric shape.

(*3*) For values above position *B*, 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 gage table. They are correct only if, at time of gaging, the API gravity at tank liquid temperature is the same as the assumed API gravity for which the table is prepared.

(*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 on the gage table. This correction is equal to:

Correction, in units of volume per °API

$$= \frac{W}{50}\left(\frac{1}{p_{60}} - \frac{1}{p_{10}}\right) \quad (13)$$

where:

W = floating weight of roof, in pounds.

p_{60} = pounds per gallon of a liquid having a 60° API gravity.

p_{10} = pounds per gallon of a liquid having a 10° API gravity.

(*5*) The API gravity correction should be handled by a note on the gage 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 gage table was prepared. This note should be substantially as follows:

"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.] Gaged 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 as observed, no correction.

For each degree below ..... ° API observed, ... add ..... bbl.

For each degree above ..... ° API observed, ... subtract ..... bbl.

ROOF DISPLACEMENT HAS BEEN DEDUCTED."

(*e*) *Gage Table of Gross or Open-Tank Capacity:*

(*1*) This type of gage table is prepared by deducting only the deadwood not included as part of the floating weight.

(*2*) A supplementary table accounting for all deadwood may be prepared and included as a supplement to the gage table for all positions up to position *B*, Fig. 26.

(*3*) For use above position *B*, the floating weight should be given on the gage table. In using the gage 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 consistent with the liquid in the tank. Also, the weight per unit volume must be based on the same temperature as the gross volume from which the roof displacement will be subtracted.

(*4*) When using the gage table, it is convenient to first convert the gross volume to a standard temperature, usually 60 F. Then, the floating weight is divided by the weight per unit volume at 60 F 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.

NOTE 15.—When applicable, the following notation shall be included on all gage tables which are prepared for the open or shell capacity of floating-roof tanks: THE QUANTITIES LISTED ON THIS GAGE TABLE DO *NOT* INCLUDE ADJUSTMENTS TO COMPENSATE FOR FLOATING-ROOF DISPLACEMENT.

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

(*g*) In using a gage table for critical measurement, the gravity sample used for calculating or correcting the floating-roof displacement may normally be a composite sample as described in *API Standard 2546—ASTM D 270: Sampling Petroleum and Petroleum Products.* Likewise, the temperature of the liquid in the tank may normally be an average temperature for the tank contents as determined in accordance with *API Standard 2543—ASTM D 1086: Measuring the Temperature of Petroleum and Petroleum Products.* If the tank contains product with abnormal gravity or temperature stratification, the gravity sample and the temperature used for calculating or correcting the floating-roof displacement should be taken 6 in. below the bottom edge of the gage hatch tube. Abnormal stratification may occur in blending tanks before complete mixing has been achieved.

(*h*) For operating control, the procedure outlined in Paragraph (*g*) should be used, or any gravity or temperature correction as it affects floating-roof displacement may be disregarded entirely.

Variable Volume Roofs

58. (*a*) Fixed deadwood should be calculated in the usual manner.

(*b*) The movable parts of lifter roofs that hang down into the liquid should be deducted as fixed deadwood, assuming that the roof is in its lowest position.

(*c*) For variable volume roofs having a flexible membrane, the only approach available is as follows: Compute the area of membrane contacting the liquid surface for various liquid levels. The membrane weight within this area displaces an equal weight of liquid when the membrane is deflated. This weight should be converted to volume of liquid, assuming an average gravity of liquid to be stored. Prepare a separate table giving the volume to be subtracted from the regular gage table for convenient increments of liquid height. This table should carry notes as follows:

"NOTE.—When the seal is partly or completely inflated, do not deduct."

"NOTE.—When a vapor pressure less than atmospheric exists above the liquid level and beneath a portion of the membrane, that portion of the membrane in contact with the liquid will be increased and thereby cause additional displacement. This condition should be relieved before gaging to eliminate this effect."

(*d*) The correction described in Paragraph (*c*) may be ignored for operating control but should be included for critical measurements.

APPENDIX I

EXAMPLE OF CALCULATIONS FOR UPRIGHT CYLINDRICAL STEEL TANK—ABOVEGROUND

TABLE V.—TYPICAL MEASUREMENT RECORD OF AN UPRIGHT CYLINDRICAL STEEL TANK FOR EXAMPLE CALCULATIONS.

Report No.: 117-2-78
Date: Aug. 15, 1953

Tank No.: 117
(Old Tank No.):
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-in. Increments in gal: Fractions to 1/16 in.
Table Form or Size Desired: S. R. Co. Form 746, 11 by 17½ in.
Height: Shell 36 ft 11 in. Gaging 37 ft 5¾ in.
Type of Roof: Cone (¾ in., 12-in. slope) Weight of Floating Roof:
Tank Contents—Name: Water Avg. Liquid Temp., °F: 72
Gage: 28 ft 9 in.; Tank Service: No. 2 Fuel Oil API Grav.: 34.9 at 60 F
Hydrometer Reading: _____ at _____ °F Sample Temperature

Shell Circumferences:

A 367.630 ft	D 367.105 ft	G 366.745 ft
B 367.240 ft	E 367.024 ft	H
C 367.555 ft	F 366.795 ft	J

Descriptions of Shell Plates and Joints:

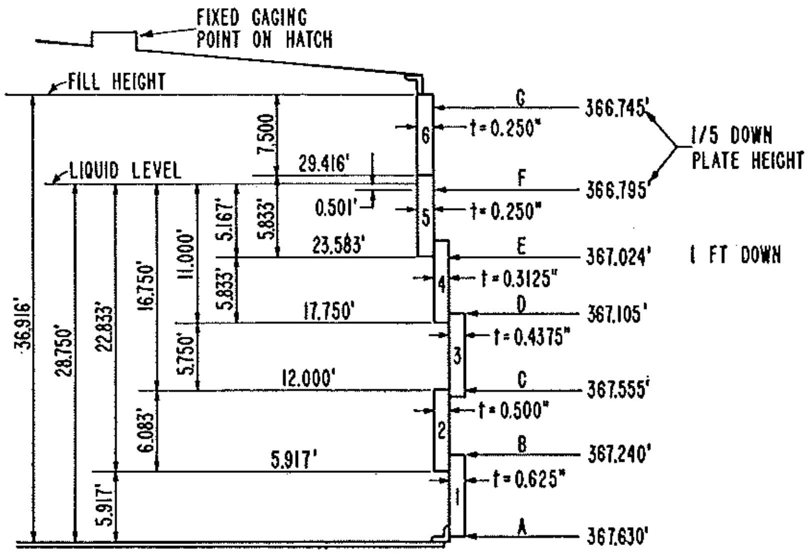
Ring No.	Thickness, in.	Type of Vertical Joint	Set, in or out	Width of Lap or Strap, in.	Thickness, Butt Strap, in.	No. of Sections	Inside Ring, Height
7	..	...	..	..	..	..	..
6	¼	Butt Weld	..	..	..	20	7 ft 6 in.
5	¼	Lap Weld	in	1⅞	..	20	5 ft 10 in.
4	5/16	Lap Rivet	in	2	..	20	5 ft 10 in.
3	7/16	Lap Rivet	out	2¼	..	20	5 ft 9 in.
2	½	Butt Rivet	in	10	7/16	20	6 ft 1 in.
(Btm. Ring) 1	⅝	Butt Rivet	out	12	9/16	20	5 ft 11 in.

Deadwood and Remarks (use reverse side if necessary):

Description	No.	Size	Elevation From	Elevation To
Bottom Angle	1	6 by 4 by ½ in. at 16.2 lb by 367 ft 6 in.	0 ft 0 in.	0 ft 6 in.
Column Bases	16	8-in. Channel at 11.5 lb by 7 ft 5 in.	0 ft 0 in.	0 ft 8 in.
Column	1	12-in. Channel at 20.7 lb	0 ft 1 in.	36 ft 11 in.
Column	15	10-in. Channel at 15.3 lb	0 ft 1 in.	36 ft 11 in.
Column	1	9-in. Channel at 13.4 lb	0 ft 8 in.	36 ft 11 in.
Column	15	8-in. Channel at 11.5 lb	0 ft 8 in.	36 ft 11 in.
Inside Butt Straps	20	17 by ½ in. at 28.9 lb	0 ft 6 in.	5 ft 11 in.
Inside Butt Straps	20	15 by ⅜ in. at 19.13 lb	5 ft 11 in.	12 ft 0 in.
Manhead	1	24 in. Diam by 0 ft 6 in.	1 ft 6 in.	3 ft 6 in.
Rafters	80	6-in. Channel at 8.2 lb	36 ft 5 in.	36 ft 11 in.

Type of Bottom: Flat Height of Crown:
Witness: A. B. Doe Measurements by: J. R. Roe

NOTE.—For field sketch applicable to this report, see Fig. 43.



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. It is used only to illustrate the different aspects to computations which are contained in the example calculations.

FIG. 43.—UPRIGHT CYLINDRICAL TANK, COMPOSITE CONSTRUCTION.

Correction of Measured Circumferences to Empty Tank Basis $= -\dfrac{WhC^2}{2\pi Et}$

where:
W = weight of liquid, in pounds per cubic foot.
h = height of liquid, in feet.
C = measured circumference, in feet.
E = modulus of elasticity of steel (29,000,000 psi).
t = thickness of steel, in inches.

This can be more conveniently expressed as: $-K\dfrac{GhC^2}{t}$

where:

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

G = observed specific gravity of liquid in tank.

NOTE 16.—This same formula may be used to calculate the expansion of the tank shell. In such cases, G should be the specific gravity at 60 F of the liquid to be stored in the tank.

Circumference 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.

$$\text{Circumference } B = K\frac{1 \times 22.83333 \times 367.240^2}{0.500} = 0.175 \text{ ft}$$

$$\text{Circumference } C = K\frac{1 \times 16.750 \times 367.555^2}{0.4375} = 0.147 \text{ ft}$$

$$\text{Circumference } D = K\frac{1 \times 11.00 \times 367.105^2}{0.3125} = 0.135 \text{ ft}$$

$$\text{Circumference } E = K\frac{1 \times 6.167 \times 367.024^2}{0.3125} = 0.076 \text{ ft}$$

$$\text{Circumference } F = K\frac{1 \times 0.501 \times 366.795^2}{0.25} = 0.008 \text{ ft}$$

Circumference G: No Correction.

$$\text{Correction for Tape Rise (Butt Straps)} = \frac{2NtW}{12d} + \frac{8Nt}{12 \times 3}\sqrt{\frac{t}{d}}$$

$$\text{Circumference } A \text{ Correction} = \frac{2 \times 20 \times 0.5625 \times 12}{12 \times 1404} + \frac{8 \times 20 \times 0.5625}{12 \times 3}\sqrt{\frac{0.5625}{1404}} = 0.066 \text{ ft}$$

$$\text{Circumference } B \text{ Correction} = \frac{2 \times 20 \times 0.4375 \times 10}{12 \times 1404} + \frac{8 \times 20 \times 0.4375}{12 \times 3}\sqrt{\frac{0.4375}{1404}} = 0.045 \text{ ft}$$

$$\text{Correction for Tape Rise (Lap Joints)} = \frac{4}{12 \times 3} Nt\sqrt{\frac{t}{2d}}$$

$$\text{Circumference } C \text{ Correction} = \frac{4 \times 20 \times 0.4375}{12 \times 3}\sqrt{\frac{0.4375}{2 \times 1404}} = 0.012 \text{ ft}$$

$$\text{Circumference } D \text{ and } E \text{ Correction} = \frac{4 \times 20 \times 0.3125}{12 \times 3}\sqrt{\frac{0.3125}{2 \times 1404}} = 0.007 \text{ ft}$$

$$\text{Circumference } F \text{ Correction} = \frac{4 \times 20 \times 0.25}{12 \times 3}\sqrt{\frac{0.25}{2 \times 1404}} = 0.005 \text{ ft}$$

Circumference G: No Correction.

Circumference Deduction for Plate Thickness $= \frac{\pi t}{6}$

Ring No.	1	2	3	4	5	6
Thickness, in.	0.625	0.500	0.4375	0.3125	0.250	0.250
Correction, ft	0.327	0.262	0.229	0.164	0.131	0.131

TABLE VI.—SUMMARY OF CIRCUMFERENCE CORRECTIONS.

Circumference	Measured Circumference, ft	Deductions, ft			Corrected Inside Circumference, ft
		Tape Rise	Liquid Head	Steel Thickness	
A	367.630	0.066	none	0.327	367.237
B	367.240	0.045	0.175	0.262	366.758
C	367.555	0.012	0.147	0.229	367.167
D	367.105	0.007	0.135	0.164	366.799
E	367.024	0.007	0.076	0.164	366.777
F	366.795	0.005	0.008	0.131	366.651
G	366.745	none	none	0.131	366.614

The following calculations determine the inch incremental volume for each ring when it is just full of oil—in this case, 34.9° API gravity (0.8504 sp gr) at 60 F:

Ring No. 1—From 0 ft 0 in. to 5 ft 11 in.

Circumference A, Table VI .... 367.237 ft
Circumference B, Table VI, plus 0.262 steel .... 367.020 ft

734.257 ft

Ring full stressed $= \frac{734.257}{2}$ .... 367.1285 ft

Incremental volume $= 367.1285 \times 367.1285 \times 0.04960673 = 6686.16$ gal per in.

Ring No. 2—From 5 ft 11 in. to 12 ft 0 in.

Circumference B, Table VI, plus liquid head stress of 6.083 ft .... 366.758 ft
$K \frac{0.8504 \times 6.083 \times 366.758^2}{0.500}$ .... 0.040 ft

Circumference B, ring full stressed .... 366.798 ft
Circumference C, Table VI, minus 0.262 steel .... 366.905 ft

733.703 ft

Ring full stressed $= \frac{733.703}{2}$ .... 366.8515 ft

Incremental volume $= 366.8515 \times 366.8515 \times 0.04960673 = 6676.07$ gal per in.

Ring No. 3—From 12 ft 0 in. to 17 ft 9 in.

Circumference C, Table VI, plus liquid head stress of 5.75 ft .... 367.167 ft
$K \frac{0.8504 \times 5.750 \times 367.167^2}{0.4375}$ .... 0.043 ft

Circumference C, ring full stressed .... 367.210 ft
Circumference D, Table VI, plus 0.164 steel .... 366.963 ft

734.173 ft

Ring full stressed $= \frac{734.173}{2}$ .... 367.0865 ft

Incremental volume $= 367.0865 \times 367.0865 \times 0.04960673 = 6684.64$ gal per in.

Ring No. 4—From 17 ft 9 in. to 23 ft 7 in.

Circumference D, Table VI, plus liquid head stress of 5.833 ft .... 366.799 ft

$K \frac{0.8504 \times 5.833 \times 366.799^2}{0.3125}$ .... 0.061 ft

Circumference D, ring full stressed .... 366.860 ft

Circumference E, Table VI, plus liquid head stress of 1.00 ft .... 366.777 ft

$K \frac{0.8504 \times 1.00 \times 366.777^2}{0.3125}$ .... 0.010 ft

Circumference E, ring full stressed .... 366.787 ft

Circumference D, ring full stressed .... 366.860 ft

733.647 ft

Ring full stressed $= \frac{733.647}{2}$ .... 366.8235 ft

Incremental volume = 366.8235 × 366.8235 × 0.04960673 = 6675.07 gal per in.

Ring No. 5—From 23 ft 7 in. to 29 ft 5 in.

Circumference F, Table VI, plus liquid head stress of 1.167 ft .... 366.651 ft

$K \frac{0.8504 \times 1.167 \times 366.651^2}{0.25}$ .... 0.015 ft

Circumference F, ring full stressed .... 366.666 ft

Incremental volume = 366.666 × 366.666 × 0.04960673 = 6669.33 gal per in.

Ring No. 6—From 29 ft 5 in. to 36 ft 11 in.

Circumference G, Table VI, plus liquid head stress of 1.50 ft .... 366.614 ft

$K \frac{0.8504 \times 1.50 \times 366.614^2}{0.25}$ .... 0.020 ft

Circumference G, ring full stressed .... 366.634 ft

Incremental volume = 366.634 × 366.634 × 0.04960673 = 6668.16 gal per in.

Volumetric increase for each ring, for each inch of liquid head above the ring:

$$\Delta v = \frac{\pi W G d^3 h}{4Et}$$

where:

W = 62.30 lb.

G = 0.8504 sp gr, at 60 F, of liquid to be stored in the tank.

d = 116.77 average inside diameter (from ring-full-stressed circumference).

Let: $K = \frac{\pi W G d^3}{4E}$; then, $K = 2.28338$, and $\Delta v = K \frac{h}{t}$

Ring No. 1: $\Delta v = \frac{71}{0.625} \times \frac{2.28338}{231} = 1.12$ gal per in.

Ring No. 2: $\Delta v = \frac{73}{0.500} \times \frac{2.28338}{231} = 1.44$ gal per in.

Ring No. 3: $\Delta v = \frac{69}{0.4375} \times \frac{2.28338}{231} = 1.56$ gal per in.

Ring No. 4: $\Delta v = \frac{70}{0.3125} \times \frac{2.28338}{231} = 2.21$ gal per in.

Ring No. 5: $\Delta v = \frac{70}{0.25} \times \frac{2.28338}{231} = 2.77$ gal per in.

Ring No. 6: Δv = None

Incremental correction:

Ring No. 1: 0
Ring No. 2: 1.12 = 1.12 gal per in.
Ring No. 3: 1.12 + 1.44 = 2.56 gal per in.
Ring No. 4: 1.12 + 1.44 + 1.56 = 4.12 gal per in.
Ring No. 5: 1.12 + 1.44 + 1.56 + 2.21 = 6.33 gal per in.
Ring No. 6: 1.12 + 1.44 + 1.56 + 2.21 + 2.77 = 9.10 gal per in.

Deadwood deductions:

From	To	Description		Deductions for Deadwood, gal per in.
0 ft 0 in.	0 ft 6 in.	Bottom Angle	$\frac{367.5 \times 16.2}{0.2833 \times 231 \times 6} =$	15.16
0 ft 0 in.	0 ft 8 in.	Column Bases	$\frac{16 \times 7.416667 \times 11.5}{0.2833 \times 231 \times 8} =$	2.61
0 ft 1 in.	36 ft 11 in.	Column	$\frac{1 \times 20.7}{0.2833 \times 231 \times 12} =$	0.03
0 ft 1 in.	36 ft 11 in.	Column	$\frac{15 \times 15.3}{0.2833 \times 231 \times 12} =$	0.29
0 ft 8 in.	36 ft 11 in.	Column	$\frac{1 \times 13.4}{0.2833 \times 231 \times 12} =$	0.02
0 ft 8 in.	36 ft 11 in.	Column	$\frac{15 \times 11.5}{0.2833 \times 231 \times 12} =$	0.22
0 ft 6 in.	5 ft 11 in.	Butt Straps	$\frac{20 \times 28.9}{0.2833 \times 231 \times 12} =$	0.74
5 ft 11 in.	12 ft 0 in.	Butt Straps	$\frac{20 \times 19.13}{0.2833 \times 231 \times 12} =$	0.49
36 ft 5 in.	36 ft 11 in.	Rafters	$\frac{80 \times 8 \times 8.2}{2 \times 0.2833 \times 231 \times 6} =$	6.68
1 ft 6 in.	3 ft 6 in.	Manhead	$2 \times 3.141593 = 6.283186$ ft circumference	
			$6.283186^2 \times 0.04960673 = 1.96$ gal per in.	
			$\frac{1.96 \times 6}{24} =$	+0.49

SUMMARY

From	To	Deductions for Deadwood, gal per in.
0 ft 0 in.	0 ft 1 in.	17.77
0 ft 1 in.	0 ft 6 in.	18.09
0 ft 6 in.	0 ft 8 in.	3.67
0 ft 8 in.	1 ft 6 in.	1.30
1 ft 6 in.	3 ft 6 in.	0.81
3 ft 6 in.	5 ft 11 in.	1.30
5 ft 11 in.	12 ft 0 in.	1.05
12 ft 0 in.	36 ft 5 in.	0.56
36 ft 5 in.	36 ft 11 in.	7.24

TANK TABLE RUN SHEET

From	To	No. Inches	Incremental Volume, gal per in.	Liquid Head Correction, gal per in.	Deduction for Deadwood, gal per in.	Net Inch Vol., gal	Net Inch Vol. Times No. of Inches Affected	Accumulated Vol., nearest whole gal
0 ft 0 in.	0 ft 1 in.	1	6686.16	0	17.77	6668.39	6668.39	6668
0 ft 1 in.	0 ft 6 in.	5	6686.16	0	18.09	6668.07	33340.35	40009
0 ft 6 in.	0 ft 8 in.	2	6686.16	0	3.67	6682.49	13364.98	53374
0 ft 8 in.	1 ft 6 in.	10	6686.16	0	1.30	6684.86	66848.60	120222
1 ft 6 in.	3 ft 6 in.	24	6686.16	0	0.81	6685.35	160448.40	280671
3 ft 6 in.	5 ft 11 in.	29	6686.16	0	1.30	6684.86	193860.94	474532
5 ft 11 in.	12 ft 0 in.	73	6676.07	1.12	1.05	6676.14	487358.22	961890
12 ft 0 in.	17 ft 9 in.	69	6684.64	2.56	0.56	6686.64	461378.16	1423268
17 ft 9 in.	23 ft 7 in.	70	6675.07	4.12	0.56	6678.63	467504.10	1890772
23 ft 7 in.	29 ft 5 in.	70	6669.33	6.33	0.56	6675.10	467257.00	2358029
29 ft 5 in.	36 ft 5 in.	84	6668.16	9.10	0.56	6676.70	560842.80	2918872
36 ft 5 in.	36 ft 11 in.	6	6668.16	9.10	7.24	6670.02	40020.12	2958892

Average $\frac{1}{16}$-in. proportional parts may be computed from the data in the Tank Table Run Sheet as follows:

$$\frac{6684.86 + 6676.14 + 6686.64 + 6678.63 + 6675.10 + 6676.70}{6 \times 16} = 417.48 \text{ gal per } \tfrac{1}{16} \text{ in.}$$

TABLE VII.—FACSIMILE OF A TANK GAGE TABLE WITH VOLUMES RECORDED IN GALLONS CUMULATED HORIZONTALLY.

55,000 BARREL TANK (CONE ROOF) NO. 101

Midwest Division - S. H. Co. 114'-6" DIAMETER X 30'-0-1/4" HIGH Table No. 103

FEET	INCHES 0	1	2	3	4	5	6	7	8	9	10	11	FEET	FRACTIONS OF AN INCH:
0	53	6430	12840	19249	25658	32077	38496	44915	51334	57753	64172	70591	0	1/16" = 401
1	77010	83429	89848	96267	102686	109106	115525	121944	128363	134782	141201	147620	1	1/8" = 802
2	154039	160458	166877	173296	179715	186134	192553	198972	205391	211810	218229	224648	2	3/16" = 1203
3	231067	237460	243872	250284	256703	263122	269541	275960	282378	288797	295216	301635	3	1/4" = 1603
4	308054	314473	320892	327310	333729	340148	346567	352986	359405	365824	372242	378661	4	5/16" = 2004
5	385080	391492	397903	404315	410725	417136	423547	429958	436369	442780	449191	455602	5	3/8" = 2405
6	462013	468424	474835	481246	487657	494068	500479	506890	513301	519712	526123	532534	6	7/16" = 2806
7	538945	545356	551767	558178	564589	571000	577411	582822	590233	596644	603055	609466	7	1/2" = 3207
8	615877	622288	628699	635110	641521	647932	654343	660754	667165	673576	679987	686398	8	9/16" = 3608
9	692809	699220	705631	712042	718453	724864	731275	737686	744097	750508	756919	763328	9	5/8" = 4008
10	769738	776148	782558	788968	795378	801788	808198	814608	821018	827428	833837	840247	10	11/16" = 4409
11	846657	853067	859477	865887	872297	878707	885117	891527	897936	904346	910756	917166	11	3/4" = 4810
12	923576	929986	936396	942806	949216	955626	962036	968445	974855	981265	987675	994085	12	13/16" = 5211
13	1000495	1006905	1013315	1019725	1026135	1032545	1038954	1045364	1051774	1058184	1064594	1071004	13	7/8" = 5612
14	1077414	1083824	1090234	1096644	1103053	1109463	1115873	1122283	1128693	1135103	1141513	1147924	14	15/16" = 6013
15	1154334	1160719	1167122	1173525	1179936	1186346	1192756	1199166	1205577	1211987	1218397	1224808	15	1" = 6413
16	1231218	1237628	1244039	1250449	1256859	1263269	1269680	1276090	1282500	1288911	1295321	1301731	16	
17	1308142	1314552	1320962	1327373	1333783	1340193	1346603	1353014	1359424	1365834	1372245	1378655	17	
18	1385065	1391476	1397886	1404296	1410706	1417117	1423527	1429937	1436348	1442758	1449168	1455579	18	
19	1461989	1468399	1474808	1481217	1487627	1494037	1500448	1506858	1513268	1519679	1526089	1532501	19	
20	1538914	1545327	1551740	1558153	1564566	1570979	1577392	1583805	1590218	1596630	1603043	1609456	20	
21	1615869	1622282	1628695	1635108	1641521	1647934	1654347	1660760	1667173	1673586	1679999	1686412	21	
22	1692824	1699237	1705650	1712063	1718476	1724889	1731302	1737715	1744128	1750541	1756954	1763367	22	
23	1769780	1776193	1782605	1789018	1795431	1801844	1808257	1814670	1821083	1827496	1833909	1840322	23	
24	1846735	1853148	1859560	1865974	1872387	1878799	1885212	1891625	1898038	1904451	1910864	1917276	24	
25	1923688	1930101	1936512	1942924	1949336	1955747	1962159	1968571	1974983	1981394	1987806	1994218	25	
26	2000629	2007041	2013453	2019865	2026276	2032688	2039100	2045512	2051923	2058335	2064747	2071158	26	
27	2077570	2083982	2090394	2096805	2103217	2109629	2116040	2122452	2128864	2135276	2141687	2148099	27	
28	2154511	2160922	2167334	2173745	2180157	2186568	2192980	2199391	2205802	2212214	2218625	2225037	28	
29	2231448	2237859	2244271	2250682	2257094	2263505	2269916	2276328	2282738	2289147	2295557	2301966	29	
30	2308376													

2,309,978 Gals. at 30'-0-1/4"

TABLE VIII.—FACSIMILE OF A TANK GAGE TABLE WITH VOLUMES RECORDED IN GALLONS CUMULATED VERTICALLY.

LOCATION CORLEY, ILLINOIS TERMINAL

STRAPPED BY J. A. DOE COMPUTED BY N. A. ROE CHECKED BY J. B. HANCOCK

FEET	GALLONS	FEET	GALLONS	FEET	GALLONS	FEET	GALLONS	FEET	GALLONS	FEET	GALLONS	FEET	GALLONS
0	53	6	462,013	12	923,576	18	1,385,065	24	1,846,735	30	2,308,376	36	
1	6,430	1	468,424	1	929,986	1	1,391,476	1	1,853,148	1	2,309,978	1	
2	12,840	2	474,835	2	936,396	2	1,397,886	2	1,859,560	2	at 30'-0-1/4"	2	
3	19,249	3	481,246	3	942,806	3	1,404,296	3	1,865,974	3		3	
4	25,658	4	487,657	4	949,216	4	1,410,706	4	1,872,387	4		4	
5	32,077	5	494,068	5	955,626	5	1,417,117	5	1,878,799	5		5	
6	38,496	6	500,479	6	962,036	6	1,423,527	6	1,885,212	6		6	
7	44,915	7	506,890	7	968,445	7	1,429,937	7	1,891,625	7		7	
8	51,334	8	513,301	8	974,855	8	1,436,348	8	1,898,038	8		8	
9	57,753	9	519,712	9	981,265	9	1,442,758	9	1,904,451	9		9	
10	64,172	10	526,123	10	987,675	10	1,449,168	10	1,910,864	10		10	
11	70,591	11	532,534	11	994,085	11	1,455,579	11	1,917,276	11		11	
1	77,010	7	538,945	13	1,000,495	19	1,461,989	25	1,923,688	31		37	
1	83,429	1	545,356	1	1,006,905	1	1,468,399	1	1,930,101	1		1	
2	89,848	2	551,767	2	1,013,315	2	1,474,808	2	1,936,512	2		2	
3	96,267	3	558,178	3	1,019,725	3	1,481,217	3	1,942,924	3		3	
4	102,686	4	564,589	4	1,026,135	4	1,487,627	4	1,949,336	4		4	
5	109,106	5	571,000	5	1,032,545	5	1,494,037	5	1,955,747	5		5	
6	115,525	6	577,411	6	1,038,954	6	1,500,448	6	1,962,159	6		6	
7	121,944	7	582,822	7	1,045,364	7	1,506,858	7	1,968,571	7		7	
8	128,363	8	590,233	8	1,051,774	8	1,513,268	8	1,974,983	8		8	
9	134,782	9	596,644	9	1,058,184	9	1,519,679	9	1,981,394	9		9	
10	141,201	10	603,055	10	1,064,594	10	1,526,089	10	1,987,806	10		10	
11	147,620	11	609,466	11	1,071,004	11	1,532,501	11	1,994,218	11		11	
2	154,039	8	615,877	14	1,077,414	20	1,538,914	26	2,000,629	32		38	
1	160,458	1	622,288	1	1,083,824	1	1,545,327	1	2,007,041	1		1	
2	166,877	2	628,699	2	1,090,234	2	1,551,740	2	2,013,453	2		2	
3	173,296	3	635,110	3	1,096,644	3	1,558,153	3	2,019,865	3		3	
4	179,715	4	641,521	4	1,103,053	4	1,564,566	4	2,026,276	4		4	
5	186,134	5	647,932	5	1,109,463	5	1,570,979	5	2,032,688	5		5	
6	192,553	6	654,343	6	1,115,873	6	1,577,392	6	2,039,100	6		6	
7	198,972	7	660,754	7	1,122,283	7	1,583,805	7	2,045,512	7		7	
8	205,391	8	667,165	8	1,128,693	8	1,590,218	8	2,051,923	8		8	
9	211,810	9	673,576	9	1,135,103	9	1,596,630	9	2,058,335	9		9	
10	218,229	10	679,987	10	1,141,513	10	1,603,043	10	2,064,747	10		10	
11	224,648	11	686,398	11	1,147,924	11	1,609,456	11	2,071,158	11		11	
3	231,067	9	692,809	15	1,154,334	21	1,615,869	27	2,077,570	33		39	
1	237,460	1	699,220	1	1,160,719	1	1,622,282	1	2,083,982	1		1	
2	243,872	2	705,631	2	1,167,122	2	1,628,695	2	2,090,394	2		2	
3	250,284	3	712,042	3	1,173,525	3	1,635,108	3	2,096,805	3		3	
4	256,703	4	718,453	4	1,179,936	4	1,641,521	4	2,103,217	4		4	
5	263,122	5	724,864	5	1,186,346	5	1,647,934	5	2,109,629	5		5	
6	269,541	6	731,275	6	1,192,756	6	1,654,347	6	2,116,040	6		6	
7	275,960	7	737,686	7	1,199,166	7	1,660,760	7	2,122,452	7		7	
8	282,378	8	744,097	8	1,205,577	8	1,667,173	8	2,128,864	8		8	
9	288,797	9	750,508	9	1,211,987	9	1,673,586	9	2,135,276	9		9	
10	295,216	10	756,919	10	1,218,397	10	1,679,999	10	2,141,687	10		10	
11	301,635	11	763,328	11	1,224,808	11	1,686,412	11	2,148,099	11		11	
4	308,054	10	769,738	16	1,231,218	22	1,692,824	28	2,154,511	34		40	
1	314,473	1	776,148	1	1,237,628	1	1,699,237	1	2,160,922	1		1	
2	320,892	2	782,558	2	1,244,039	2	1,705,650	2	2,167,334	2		2	
3	327,310	3	788,968	3	1,250,449	3	1,712,063	3	2,173,745	3		3	
4	333,729	4	795,378	4	1,256,859	4	1,718,476	4	2,180,157	4		4	
5	340,148	5	801,788	5	1,263,269	5	1,724,889	5	2,186,568	5		5	
6	346,567	6	808,198	6	1,269,680	6	1,731,302	6	2,192,980	6		6	
7	352,986	7	814,608	7	1,276,090	7	1,737,715	7	2,199,391	7		7	
8	359,405	8	821,018	8	1,282,500	8	1,744,128	8	2,205,802	8		8	
9	365,824	9	827,428	9	1,288,911	9	1,750,541	9	2,212,214	9		9	
10	372,242	10	833,837	10	1,295,321	10	1,756,954	10	2,218,625	10		10	
11	378,661	11	840,247	11	1,301,731	11	1,763,367	11	2,225,037	11		11	
5	385,080	11	846,657	17	1,308,142	23	1,769,780	29	2,231,448	35		41	
1	391,492	1	853,067	1	1,314,552	1	1,776,193	1	2,237,859	1		1	
2	397,903	2	859,477	2	1,320,962	2	1,782,605	2	2,244,271	2		2	
3	404,315	3	865,887	3	1,327,373	3	1,789,018	3	2,250,682	3		3	
4	410,725	4	872,297	4	1,333,783	4	1,795,431	4	2,257,094	4		4	
5	417,136	5	878,707	5	1,340,193	5	1,801,844	5	2,263,505	5		5	
6	423,547	6	885,117	6	1,346,603	6	1,808,257	6	2,269,916	6		6	
7	429,958	7	891,527	7	1,353,014	7	1,814,670	7	2,276,328	7		7	
8	436,369	8	897,936	8	1,359,424	8	1,821,083	8	2,282,738	8		8	
9	442,780	9	904,346	9	1,365,834	9	1,827,496	9	2,289,147	9		9	
10	449,191	10	910,756	10	1,372,245	10	1,833,909	10	2,295,557	10		10	
11	455,602	11	917,166	11	1,378,655	11	1,840,322	11	2,301,966	11		11	

FRACTIONS							
1/16	401	5/16	2,004	9/16	3,608	13/16	5,211
1/8	802	3/8	2,405	5/8	4,008	7/8	5,612
3/16	1,203	7/16	2,806	11/16	4,409	15/16	6,013
1/4	1,603	1/2	3,207	3/4	4,810	1	6,413

CAPACITY 2,309,978 GALS.

SIZE 114'-6" DIA. X 30'-0-1/4" HIGH

ROOF CONE

TANK No. 101

APPENDIX II

CONSTANTS, EQUATIONS, CONVERSION FACTORS, AND TABLES

For the purpose of this standard, the following constants, equations, conversion factors, and tables apply:

Constants:

Modulus of Elasticity, E = 29,000,000 psi, English System (for mild steel)
Linear coefficient of thermal expansion of mild steel = 0.0000065 in. per in. per degree Fahrenheit
π = 3.141593
1 gal of fresh water at 60 F = 8.328247 lb
1 cu ft of fresh water at 60 F = 62.3 lb, approximately

Areas of Plane Figures:

Area of Circle = one-fourth of the product of π multiplied by the square of the diameter; or, the product of π multiplied by the square of the radius
Area of Triangle = one-half of the base multiplied by the perpendicular height; or, where S is one-half of perimeter and A, B, and C are the sides:

$$\text{Area} = \sqrt{S\,(S - A)\,(S - B)\,(S - C)}$$

Area of Rectangle or Parallelogram = product of the base multiplied by the perpendicular height
Area of Trapezoid = one-half of the sum of the parallel sides multiplied by the perpendicular height
Area of Trapezium = sum of the areas of its two triangles
Area of Regular Polygon = one-half of the perimeter multiplied by the inside radius

NOTE 17.—A regular polygon is both equiangular and equilateral.

Area of Ellipse = long diameter multiplied by short diameter multiplied by one-fourth of π; or, long radius multiplied by short radius multiplied by π
Area of Parabola = base multiplied by two-thirds of the perpendicular height
Area of Irregular Plane Surface may be found, approximately, by means of Simpson's rule, as follows: Draw a set of parallel chords across the area at equal intervals. The smaller the interval magnitude, the more accurate will be the result. Determine the various values of Y and of H by measurement (see the following illustration) and substitute in the equation:

$$\text{Area} = \frac{H}{3}\,(Y_0 + 4Y_1 + 2Y_2 + 4Y_3 + 2Y_4 \,\ldots\ldots + 2Y_{n-2} + 4Y_{n-1} + Y_n)$$

(n must be an even number).

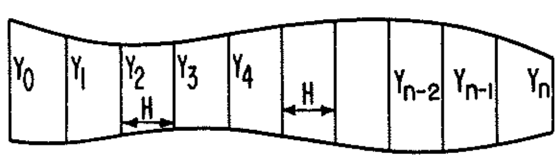


ILLUSTRATION FOR THE AREA OF AN IRREGULAR PLANE SURFACE.

Volumes of Solid Figures:

Volume of Cylinder = product of the area of the base multiplied by the height perpendicular to the base
Volume of Cone = product of one-third of the area of the base multiplied by the height perpendicular to the base

Volume of Frustum of a Cone = product of one-third of the height perpendicular to the bases multiplied by the sum of the combined areas of the two bases plus the square root of the product of the areas of the two bases

Volume of Sphere = product of four-thirds π multiplied by the cube of the radius; or, one-sixth π multiplied by the cube of the diameter

Volume of Spherical Segment of Only One Base = product of one-sixth π multiplied by the height of the segment, multiplied by the sum of three times the square of the radius of the base of the segment, plus the square of the height of the segment, or:

$$\text{Volume} = \frac{\pi}{6} H\ (3r^2 + H^2)$$

where:
H = height of segment.
r = radius of base.

Volume of Spherical Segment of Two Bases = product of the height perpendicular to the bases multiplied by one-half of the sum of the areas of the two bases, plus the volume of a sphere with diameter equal to the perpendicular height of the segment, or:

$$\text{Volume} = \frac{H}{2}(\pi r_1^2 + \pi r_2^2) + \frac{\pi}{6} H^3$$

$$= \frac{\pi}{6} H(3r_1^2 + 3r_2^2 + H^2)$$

where:
H = height of segment.
r_1 and r_2 = radii of two bases with both r_1 and r_2 in the same hemisphere.

Convenient Conversion Factors:

Centigrade Degrees = 5/9 Fahrenheit Degrees − 32
Fahrenheit Degrees = 9/5 Centigrade Degrees + 32
One Barrel = 42 U.S. Gallons
U.S. Gallons × 231 = Cubic Inches
Cubic Inches × 0.004329004 = U.S. Gallons
Cubic Feet × 7.480519 = U.S. Gallons
Circumference × 0.3183098 = Diameter
Diameter × 3.141593 = Circumference

TABLE IX.—WEIGHTS OF STEEL SHEETS AND PLATES, U. S. STANDARD GAGE.

Gage No.	Weight		Approximate Thickness, in.
	oz per sq ft	lb per sq ft	
3	160	10.00	0.2391
4	150	9.38	0.2242
5	140	8.75	0.2092
6	130	8.12	0.1943
7	120	7.50	0.1793
8	110	6.88	0.1644
9	100	6.25	0.1495
10	90	5.62	0.1345
11	80	5.00	0.1196
12	70	4.38	0.1046
13	60	3.75	0.0897
14	50	3.12	0.0747
15	45	2.81	0.0673
16	40	2.50	0.0598
17	36	2.25	0.0538
18	32	2.00	0.0478
19	28	1.75	0.0418
20	24	1.50	0.0359
21	22	1.38	0.0329
22	20	1.25	0.0299
23	18	1.12	0.0269
24	16	1.00	0.0239
25	14	0.875	0.0209
26	12	0.750	0.0179
27	11	0.688	0.0164
28	10	0.625	0.0149
29	9	0.562	0.0135
30	8	0.500	0.0120
31	7	0.438	0.0105
32	6.5	0.406	0.0097
33	6	0.375	0.0090
34	5.5	0.344	0.0082
35	5	0.312	0.0075
36	4.5	0.281	0.0067
37	4.25	0.266	0.0064
38	4	0.250	0.0060

TABLE X.—FRACTIONAL AND DECIMAL INCHES AND FEET WITH EQUIVALENT INCH FRACTIONS.

Fractions and Decimals in in. or ft		Fractional Inch Equivalents to Foot Fraction	Fractions and Decimals in in. or ft		Fractional Inch Equivalents to Foot Fraction	Fractions and Decimals in in. or ft		Fractional Inch Equivalents to Foot Fraction	Fractions and Decimals in in. or ft		Fractional Inch Equivalent to Foot Fraction
	0.0052	1/16		0.2552	3 1/16		0.5052	6 1/16		0.7552	9 1/16
	0.0104	1/8		0.2604	3 1/8		0.5104	6 1/8		0.7604	9 1/8
1/64	0.015625	3/16	17/64	0.265625	3 3/16	33/64	0.515625	6 3/16	49/64	0.765625	9 3/16
	0.0208	1/4		0.2708	3 1/4		0.5208	6 1/4		0.7708	9 1/4
	0.0260	5/16		0.2760	3 5/16		0.5260	6 5/16		0.7760	9 5/16
1/32	0.03125	3/8	9/32	0.28125	3 3/8	17/32	0.53125	6 3/8	25/32	0.78125	9 3/8
	0.0365	7/16		0.2865	3 7/16		0.5365	6 7/16		0.7865	9 7/16
	0.0417	1/2		0.2917	3 1/2		0.5417	6 1/2		0.7917	9 1/2
3/64	0.046875	9/16	19/64	0.296875	3 9/16	35/64	0.546875	6 9/16	51/64	0.796875	9 9/16
	0.0521	5/8		0.3021	3 5/8		0.5521	6 5/8		0.8021	9 5/8
	0.0573	11/16		0.3073	3 11/16		0.5573	6 11/16		0.8073	9 11/16
1/16	0.0625	3/4	5/16	0.3125	3 3/4	9/16	0.5625	6 3/4	13/16	0.8125	9 3/4
	0.0677	13/16		0.3177	3 13/16		0.5677	6 13/16		0.8177	9 13/16
	0.0729	7/8		0.3229	3 7/8		0.5729	6 7/8		0.8229	9 7/8
5/64	0.078125	15/16	21/64	0.328125	3 15/16	37/64	0.578125	6 15/16	53/64	0.828125	9 15/16
	0.0833	1		0.3333	4		0.5833	7		0.8333	10
	0.0885	1 1/16		0.3385	4 1/16		0.5885	7 1/16		0.8385	10 1/16
3/32	0.09375	1 1/8	11/32	0.34375	4 1/8	19/32	0.59375	7 1/8	27/32	0.84375	10 1/8
	0.0990	1 3/16		0.3490	4 3/16		0.5990	7 3/16		0.8490	10 3/16
	0.1042	1 1/4		0.3542	4 1/4		0.6042	7 1/4		0.8542	10 1/4
7/64	0.109375	1 5/16	23/64	0.359375	4 5/16	39/64	0.609375	7 5/16	55/64	0.859375	10 5/16
	0.1146	1 3/8		0.3646	4 3/8		0.6146	7 3/8		0.8646	10 3/8
	0.1198	1 7/16		0.3698	4 7/16		0.6198	7 7/16		0.8698	10 7/16
1/8	0.1250	1 1/2	3/8	0.3750	4 1/2	5/8	0.6250	7 1/2	7/8	0.8750	10 1/2
	0.1302	1 9/16		0.3802	4 9/16		0.6302	7 9/16		0.8802	10 9/16
	0.1354	1 5/8		0.3854	4 5/8		0.6354	7 5/8		0.8854	10 5/8
9/64	0.140625	1 11/16	25/64	0.390625	4 11/16	41/64	0.640625	7 11/16	57/64	0.890625	10 11/16
	0.1458	1 3/4		0.3958	4 3/4		0.6458	7 3/4		0.8958	10 3/4
	0.1510	1 13/16		0.4010	4 13/16		0.6510	7 13/16		0.9010	10 13/16
5/32	0.15625	1 7/8	13/32	0.40625	4 7/8	21/32	0.65625	7 7/8	29/32	0.90625	10 7/8
	0.1615	1 15/16		0.4115	4 15/16		0.6615	7 15/16		0.9115	10 15/16
	0.1667	2		0.4167	5		0.6667	8		0.9167	11
11/64	0.171875	2 1/16	27/64	0.421875	5 1/16	43/64	0.671875	8 1/16	59/64	0.921875	11 1/16
	0.1771	2 1/8		0.4271	5 1/8		0.6771	8 1/8		0.9271	11 1/8
	0.1823	2 3/16		0.4323	5 3/16		0.6823	8 3/16		0.9323	11 3/16
3/16	0.1875	2 1/4	7/16	0.4375	5 1/4	11/16	0.6875	8 1/4	15/16	0.9375	11 1/4
	0.1927	2 5/16		0.4427	5 5/16		0.6927	8 5/16		0.9427	11 5/16
	0.1979	2 3/8		0.4479	5 3/8		0.6979	8 3/8		0.9479	11 3/8
13/64	0.203125	2 7/16	29/64	0.453125	5 7/16	45/64	0.703125	8 7/16	61/64	0.953125	11 7/16
	0.2083	2 1/2		0.4583	5 1/2		0.7083	8 1/2		0.9583	11 1/2
	0.2135	2 9/16		0.4635	5 9/16		0.7135	8 9/16		0.9635	11 9/16
7/32	0.21875	2 5/8	15/32	0.46875	5 5/8	23/32	0.71875	8 5/8	31/32	0.96875	11 5/8
	0.2240	2 11/16		0.4740	5 11/16		0.7240	8 11/16		0.9740	11 11/16
	0.2292	2 3/4		0.4792	5 3/4		0.7292	8 3/4		0.9792	11 3/4
15/64	0.234375	2 13/16	31/64	0.484375	5 13/16	47/64	0.734375	8 13/16	63/64	0.984375	11 13/16
	0.2396	2 7/8		0.4896	5 7/8		0.7396	8 7/8		0.9896	11 7/8
	0.2448	2 15/16		0.4948	5 15/16		0.7448	8 15/16		0.9948	11 15/16
1/4	0.2500	3	1/2	0.5000	6	3/4	0.7500	9	1	1.0000	12

TABLE XI.—PIPE SIZES AND DIMENSIONS, IN INCHES, AND CAPACITIES.

Diameters, in.			Wall Thickness, in.	Cross-Section					
	Actual			Outside			Inside		
Nominal	Outside	Inside		Area, sq. in.	Gallons per Lineal Foot	Barrels per Lineal Foot	Area, sq in.	Gallons per Lineal Foot	Barrels per Lineal Foot
1/8	0.405	0.269	0.068	0.129	0.006701	0.000160	0.057	0.002961	0.000071
1/4	0.540	0.364	0.088	0.229	0.011896	0.000283	0.104	0.005402	0.000129
3/8	0.675	0.493	0.091	0.358	0.018598	0.000443	0.191	0.009922	0.000236
1/2	0.840	0.622	0.109	0.554	0.028779	0.000685	0.304	0.015792	0.000376
3/4	1.050	0.824	0.113	0.866	0.044987	0.001071	0.533	0.027689	0.000659
1	1.315	1.049	0.133	1.358	0.070545	0.001680	0.864	0.044883	0.001069
1 1/4	1.660	1.380	0.140	2.164	0.112416	0.002677	1.495	0.077662	0.001849
1 1/2	1.900	1.610	0.145	2.835	0.147273	0.003506	2.036	0.105766	0.002518
2	2.375	2.067	0.154	4.430	0.230130	0.005479	3.355	0.174286	0.004150
2 1/2	2.875	2.469	0.203	6.492	0.337247	0.008030	4.788	0.248727	0.005922
3	3.500	3.068	0.216	9.621	0.499792	0.011900	7.393	0.384052	0.009144
3 1/2	4.000	3.548	0.226	12.566	0.652779	0.015542	9.886	0.513558	0.012228
4	4.500	4.026	0.237	15.904	0.826182	0.019671	12.730	0.661299	0.015745
4 1/2	5.000	4.506	0.247	19.635	1.020000	0.024286	15.947	0.828416	0.019724
6	6.625	6.065	0.280	34.472	1.790753	0.042637	28.891	1.500831	0.035734
8	8.625	7.981	0.322	58.426	3.035117	0.072265	50.027	2.598805	0.061876
		8.071	0.277				51.162	2.657763	0.062801
		8.125	0.250				51.849	2.693452	0.064130
10	10.750	10.020	0.365	90.763	4.714961	0.112261	78.855	4.096363	0.097532
		10.135	0.307				80.690	4.191684	0.099802
		10.250	0.250				82.515	4.286489	0.102059
12	12.750	11.938	0.406	127.677	6.632571	0.157918	111.932	5.814649	0.138444
		12.090	0.330				114.800	5.963630	0.141991
		12.250	0.250				117.858	6.122487	0.145774
14	14.000	13.125	0.437	153.938	7.996779	0.190399	135.297	7.028415	0.167343
		13.250	0.375				137.886	7.162902	0.170545
		13.375	0.312				140.501	7.298746	0.173780
		13.500	0.250				143.139	7.435785	0.177042
16	16.000	15.000	0.500	201.062	10.444778	0.248685	176.715	9.179999	0.218571
		15.250	0.375				182.654	9.488510	0.225917
		15.375	0.312				185.661	9.644718	0.229636
		15.500	0.250				188.692	9.802172	0.233385
18	18.000	16.875	0.562	254.470	13.219220	0.314743	223.628	11.617038	0.276596
		17.125	0.437				230.330	11.965183	0.284885
		17.375	0.312				237.104	12.317078	0.293264
		17.500	0.250				240.528	12.494948	0.297499
20	20.000	18.812	0.593	314.159	16.319999	0.388571	278.005	14.441817	0.343853
		19.000	0.500				283.529	14.728764	0.350685
		19.250	0.375				291.039	15.118894	0.359974
		19.500	0.250				298.648	15.514166	0.369385
22	22.000	21.000	0.500	380.133	19.747149	0.470170	346.360	17.992709	0.428398
		21.125	0.438				350.496	18.207566	0.433513
		21.250	0.375				354.656	18.423670	0.438659
		21.375	0.312				358.841	18.641072	0.443835
24	24.000	22.875	0.562	452.390	23.500778	0.559542	402.074	20.886960	0.497309
		23.250	0.375				424.556	22.054835	0.525115
		23.500	0.250				433.736	22.531718	0.536469
26	26.000	25.125	0.437	530.929	27.580700	0.656683	495.795	25.755559	0.613228
		25.500	0.250				510.705	26.530103	0.631669

4M—Aug. 1966
2M—Sept. 1973
*1700-8/79-5C

American Petroleum Institute
2101 L Street, Northwest
Washington, D.C. 20037