Manual of Petroleum Measurement Standards Chapter 2.2G

Calibration of Upright Cylindrical Tanks Using the Total Station Reference Line Method

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Foreword

Chapter 2.2G of the *Manual of Petroleum Measurement Standards* should be used in conjunction with API *MPMS* Chapter 2.2A, *Measurement and Calibration of Upright Cylindrical Tanks by the Manual Tank Strapping Method*. Units of measure in this publication are in International System (SI) and U.S. customary (USC) units consistent with North American industry practices.

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Contents

Page

1 Scope 1

2 Normative References. 1

3 Terms and Definitions 1

4 Application of the Total Station Reference Line Method. 1

5 Electro-optical Device General Requirements 1

6 Electro-optical Device Calibration and Recalibration 2

7 Electro-optical Device Field Verification. 2
7.1 Field Verification 2
7.2 Verification Procedure 2
7.3 Acceptability Criteria. 4

8 Electro-optical Device Field Setup Procedure 4
8.1 General 4
8.2 Horizontal and Vertical Stations. 4
8.3 Horizontal Station Setup 4
8.4 Instrument Setup for Vertical Stations at Horizontal Station 5
8.5 Electro-optical Device Stability 5

9 Measurements 5
9.1 Master Tape 5
9.2 Master Working Tape 6
9.3 Working Tape 6
9.4 Reference Circumference. 7
9.5 Distance and Angular Measurements 9

10 Computation of Course Diameters 9

11 Development of the Capacity Table. 10

Tables
1 Number of Horizontal Stations. 4
2 Reference Circumference Tolerances (Soft Conversions) 9

Figures
1 TSRLM Device Verification at Site: Stadia Horizontal 11
2 TSRLM Device Verification at Site: Stadia Vertical 12
3 Distance and Vertical Angle 13
4 Setting Location of Vertical Station Tangential Traverse Method 14

Introduction

The Total Station Reference Line Method (TSRLM) is an alternative to the Manual Tank Strapping Method (MTSM) for determining tank diameter. The primary difference between TSRLM and MTSM is the procedure for determining tank diameter at shell courses other than the bottom course. TSRLM requires measuring a reference circumference on the bottom course by manual strapping with a tape that is traceable to the National Institute of Standards and Technology (NIST) or other national metrology institute. The other required special measurements, procedures, methods, and analytical tools for the development of a tank capacity table are identical to those stated in API *MPMS* Chapter 2.2A.

In addition, TSRLM requires the measurement of deviations in tank diameter at other predetermined horizontal and vertical stations by using a total station electro-optical device.

This method eliminates the use of a magnetic trolley that is required in the external Optical Reference Line Method (ORLM, reference API *MPMS* Chapter 2.2B) for the calibration of upright cylindrical tanks; thus, it provides significant safety enhancements by being able to do all the offset measurement work from ground level.

Calibration of Upright Cylindrical Tanks Using the Total Station Reference Line Method

1 Scope

This standard describes measurement and calculation procedures for determining the diameters of upright cylindrical tanks by taking vertical offset measurements externally using Electro-optical Distance Ranging (EODR) equipment rather than conventional ORLM plummet/trolley equipment. This standard is an alternate standard to API *MPMS* Ch. 2.2B. This standard is used in conjunction with API *MPMS* Ch. 2.2A. Calibration of insulated tanks is covered by API *MPMS* Ch. 2.2D. Abnormally deformed tanks that are dented or have other visible signs of damage are not covered by this standard.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API *Manual of Petroleum Measurement Standards (MPMS)*, Chapter 2.2A, *Measurement and Calibration of Upright Cylindrical Tanks by the Manual Tank Strapping Method*

3 Terms and Definitions

For the purposes of this document, the following terms and definitions apply. Terms of more general use may be found in the API *MPMS* Chapter 1 Online Terms and Definitions Database.

3.1
horizontal station
Preestablished location in the horizontal plane at ground level along the tank circumference.

3.2
slope distance
Distance measured from an EODR instrument to a vertical station on the tank.

3.3
vertical station
Preestablished location in the vertical plane along the tank shell, corresponding to a given horizontal station.

4 Application of the Total Station Reference Line Method

This method is for the external calibration of upright cylindrical tanks. For tanks that are insulated, the insulation shall be removed for application of this method, or the calibration may be undertaken internally per API *MPMS* Ch. 2.2D.

5 Electro-optical Device General Requirements

The total station instrument should preferably have a locking device, the objective being to keep the horizontal angle constant while vertical station measurements are taken at any given horizontal station.

The electro-optical device shall be capable of reading distances to within 2 mm and angles to within 5 sec or better.

For the proper operation of the electro-optical device being used, follow manufacturer's instructions.

6 Electro-optical Device Calibration and Recalibration

The electro-optical device shall carry a certificate of calibration that is traceable to the national reference standard. The factory calibration is acceptable provided that it carries traceability.

The calibration certificate shall be renewed at a set frequency depending on the usage of the device that should be established based on the observed drift from base calibration. In any case the recalibration shall be undertaken at least once every 12 months.

The certificate should carry residual uncertainty associated with distance and the angle (vertical and horizontal) as well as the drift in these parameters prior to calibration.

7 Electro-optical Device Field Verification

7.1 Field Verification

The term verification involves checking that the angle and the distance the device measures are within acceptable limits. Such verification should be carried out using a stadia at each site at least once prior to the start of the actual tank calibration. See Figure 1 and Figure 2.

A stadia is a graduated rod, 2 m in length between two marks. It may be made of a nickel ferrous alloy (NiFe), or other suitable material, with a thermal linear coefficient of 0.0000008 in./in. °F.

Alternately, a steel rod of equivalent length, measured with a master tape at the prescribed tension, and compensated for ambient temperature, may be used.

7.2 Verification Procedure

The verification procedure is as follows.

1) Position the stadia at Location 1, approximately 10 ft away from the electro-optical device.

2) Put the stadia in an approximately horizontal orientation as in Figure 1.

3) Measure slope distance from the electro-optical device to stadia Target Point 1 (TP 1).

4) Measure slope distance from the electro-optical device to stadia Target Point 2 (TP 2).

5) Record the sweep angle (β) between TP1 and TP2 and calculate the theoretical length of the stadia using Equation (1).

6) Record the X, Y, and Z coordinates for TP1 and TP2 and calculate the theoretical length of the stadia using Equation (3).

7) Compare the theoretical length to its known value and determine its acceptability, as illustrated in 7.3.

8) Put the stadia in an approximately vertical orientation as in Figure 2.

9) Measure slope distance from the electro-optical device to stadia Target Point 3 (TP 3).

10) Measure slope distance from the electro-optical device to stadia Target Point 4 (TP 4).

11) Record the sweep angle (θ) between TP3 and TP4 and calculate the theoretical length of the stadia using Equation (2).

12) Record the X, Y, and Z coordinates for TP3 and TP4 and calculate the theoretical length of the stadia using Equation (4).

13) Compare the theoretical length to its known value and determine its acceptability as illustrated in 7.3.

14) Position the stadia at Location 2, approximately 20 ft away from the electro-optical device.

15) Repeat Steps 2 through 13 for stadia Location 2.

Acceptability calculations using the sweep angle that is not necessarily vertical or horizontal:

$$c = \sqrt{\left(a^2 + b^2 - 2ab \times \cos\beta\right)} \tag{1}$$

where

a is the lope distance from electro-optical instrument to stadia TP 1;

b is the slope distance from electro-optical instrument to stadia TP 2;

c is the computed theoretical length of the stadia or theoretical compensated master tape length;

β is the angle described by sides "a" and "b" to TP 1 and TP 2.

$$f = \sqrt{\left(d^2 + e^2 - 2de \times \cos\theta\right)} \tag{2}$$

where

d is the slope distance from electro-optical instrument to stadia TP 3;

e is the slope distance from electro-optical instrument to stadia TP 4;

f is the computed theoretical length of the stadia or theoretical compensated master tape length;

θ is the angle described by sides "d" and "e" to TP 3 and TP 4.

Acceptability calculations using the polar coordinates:

$$c = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2} \tag{3}$$

where

x_1, x_2, y_1, y_2, z_1, and z_2 are the polar coordinates for TP1 and TP2.

$$f = \sqrt{(x_3 - x_4)^2 + (y_3 - y_4)^2 + (z_3 - z_4)^2} \tag{4}$$

where

x_3, x_4, y_3, y_4, z_3, and z_4 are the polar coordinates for TP3 and TP4.

7.3 Acceptability Criteria

The computed theoretical length (combining the effects of both lengths and angles) of the stadia, or theoretical compensated master tape length, shall be within 2 mm of its known value.

If the verification procedure fails to meet the criteria, the electro-optical instrument shall be recalibrated.

8 Electro-optical Device Field Setup Procedure

8.1 General

The electro-optical device is set up, perpendicular to the shell of the tank, at a predetermined number of equidistant horizontal stations. At each horizontal station, the slope distance is measured to each of the predetermined vertical station points as well as the adjacent vertical angles. The horizontal distances are calculated from the shell of the tank to the intersection of the vertical zenith-nadir line at the electro-optical device.

8.2 Horizontal and Vertical Stations

The number of horizontal stations (N_H) is a function of tank diameter as per the following table:

Table 1—Number of Horizontal Stations

Diameter ft	N_H
50	8
100	12
150	16
200	20
250	24
300	30

The position of vertical stations (N_V) is presented in Figure 3. The bottom course should have one vertical station at approximately 20 % to 25 % below the top horizontal ring seam. All other rings have two vertical stations. One is approximately 20 % to 25 % above the bottom ring seam and the other is approximately 20 % to 25 % below the top ring seam.

8.3 Horizontal Station Setup

In accordance with Table 1, the horizontal stations are located in an approximate equidistant manner around the tank. Horizontal station 1 is normally located in line with the gauge hatch.

Horizontal stations shall be chosen to ensure that all slope measurements are taken at least 12 in. (300 mm) away from any vertical seam.

The preferred vertical angle (α) as presented in Figure 3 should be between 45° and 60°, away from the horizontal at the top most vertical station of the course. Knowing the vertical height (VH) it is possible to set the electro-optical device at a horizontal distance (HD) away from the tank between (VH/tan 60) and (VH/tan 45), or simply VH.

It should be noted that the horizontal distance need not be the same for all horizontal stations. They can vary, but it is preferable to maintain the vertical angle always between 45° and 60° in all cases.

8.4 Instrument Setup for Vertical Stations at Horizontal Station

At any given horizontal station, it is necessary to measure the distance from the horizontal station to the vertical stations on the courses. To target exactly the perpendicular point of vertical station on any given course, the following Tangential Traverse Method is recommended.

Aim the optical device approximately perpendicular to the tank and note the vertical angle.

While keeping the vertical angle constant, as illustrated in Figure 4, set the electro-optical device to the tangent point "A" on the left side of the tank, and note the horizontal angle on the electro-optical device. Then move the device to the tangent point "B" on the right side by traversing the tank in a clockwise direction, while continuing to keep the vertical angle constant. Note the horizontal angle on the electro-optical device. The net angle between the tangents (Φ) is computed as the difference between the two observed angles.

Compute the vertical station set point by adding or subtracting the angle ($\Phi/2$) to the observed angle on the electro-optical device. Set the electro-optical device to this angle that locates the vertical station point on the course; and this ensures that the optical device is perpendicular to the tank at that point.

Once the reference vertical station point is located on the bottom course, if a horizontal locking device is available on the electro-optical unit, the unit may be locked in position but free to traverse vertically, thus scanning all vertical stations.

If no horizontal locking device is available, repeat the Tangential Traverse Method on each of the courses and at each level (approximately 20 % to 25 % above and below the horizontal seams) to set the target vertical station points.

If obstructions are encountered when setting up a horizontal station, an adjustment may be made in the location of the horizontal station. In that case, the tangential traverse procedure shall be repeated.

8.5 Electro-optical Device Stability

The device has to be stable and level in a horizontal plane. Hence, undertaking calibration under windy, rainy, and wet soil conditions, the stability of the device may be questionable, and thus it is not recommended to undertake a tank calibration under these conditions.

Also, it is very important to ensure that there are no sources of vibration close by. This is to make sure that measurements are undertaken under vibration-free conditions.

Additional checks as detailed below will be required during the process of taking field measurements.

9 Measurements

9.1 Master Tape

A master tape, 100 ft in length, has a Report of Calibration from the National Institute of Standards and Technology (NIST) or other National Metrology Institute. It has been calibrated in 25 ft increments from 25 ft through 100 ft at one or more specified tensions, such as 10 lb, and mathematically adjusted to a specified temperature such as 68 °F. The NIST Report of Calibration also provides the coefficient of linear thermal expansion per degree Fahrenheit for the steel used in the tape. A copy of its report of calibration should always accompany the master tape.

A master tape can be used as the primary field standard for measuring reference circumferences, or it can be used to calibrate master and field working tapes. In order for it to qualify as a master tape:

a) it shall not have kinks or suffered other significant damage,

b) it shall not have been used in the field for more than 20 tanks, and

c) it shall not have been in service more than 5 years.

Upon reaching either 5 years of service or 20 tanks, it shall be returned to NIST for recalibration in order to preserve its master tape status. Alternatively, it can be calibrated by another master tape, at which time it becomes a master working tape rather than a master tape.

9.2 Master Working Tape

A master working tape, 100 ft in length, upon reaching 20 tanks, has been recalibrated against a master tape in 25 ft increments from 25 ft through 100 ft at one or more specified tensions, such as 10 lb, and mathematically adjusted to a specified reference temperature such as 68 °F. The original NIST Report of Calibration, now expired or superseded, provides the coefficient of linear thermal expansion per degree Fahrenheit for the steel used in the master working tape. A copy of its report of calibration should always accompany the master working tape.

A master working tape can be used as the primary field standard for measuring reference circumferences, or it can be used to calibrate working tapes on tanks in the field. In order for it to qualify as a master working tape:

a) it shall not have kinks or suffered other significant damage, and

b) it shall not have been used in the field for more than 20 tanks since the last recalibration.

Upon reaching 20 tanks, it shall be recalibrated by a master tape in order to preserve its master working tape status. Alternatively, it can be calibrated by another master working tape, at which time it becomes a working tape rather than a master working tape.

9.3 Working Tape

A full-length tape (e.g; 100 ft, 200 ft, 300 ft, 400 ft, 500 ft, 600 ft, 700 ft, 800 ft, 900 ft, or 1000 ft) that has been calibrated by a master tape on a rail at 25 ft, 50 ft, 75 ft, and 100 ft and each subsequent 100 ft interval, or by a master or master working tape on a tank for that particular tank circumference, at one or more specified tensions such as 10 lb, and mathematically adjusted to a specified reference temperature such as 68 °F. If made of the same material as the master or master working tape that was used in its calibration, its coefficient of linear thermal expansion per degree Fahrenheit for the steel is assumed to be the same as that master or master working tape. A copy of its report of calibration should always accompany the working tape.

A calibrated working tape can be used as a secondary field standard for measuring reference circumferences. In order to qualify as a working tape:

a) it shall not have kinks or suffered other significant damage;

b) it shall not have been used in the field for more than 20 tanks since the last recalibration; and

c) if calibrated on a tank for a particular circumference, it shall not be used on any tank the size of which does not lie within the range of $(\pi d - 50 \text{ ft to } \pi d + 50 \text{ ft})$.

9.4 Reference Circumference

The reference tape path is normally at approximately 20 % to 25 % below the top ring seam of the first course as presented in Figure 3. In the event that the reference circumference cannot be measured at approximately 20 % to 25 % below the top ring seam of the first course, the first course total station offset readings shall be taken at both the reference path position and at approximately 20 % to 25 % below the top ring seam of the first course. In any event, the volume calculation for the first course is based only upon the computed diameter at approximately 20 % to 25 % below the top ring seam of the first course.

The reference circumference at the bottom course is measured either in segments with a 100 ft master or master working tape or in the full circumference using a full-length working tape. One or more of the three procedures described below shall be followed.

a) Successive Tangent Method (requires more space away from the tank).

    1) Mark the tape path every few feet to define a clear tape path.

    2) Mark the starting point for the circumference being measured and begin at that point.

    3) Mark a starting point for the segment being measured.

    4) Person 1 holds the zero end of the tape at the segment starting point.

    5) Person 2 observes and assists as necessary to ensure that the path is followed exactly.

    6) Person 3 holds the other end of the tape fully extended in a straight line away from the tank.

    7) Person 3 maintains the prescribed tension at all times while walking toward the tank so that the tape covers the tank in *successive tangents* starting at the first segment point (zero) and ending at the final segment point (e.g. 100 ft).

    8) Person 3 marks the tank with the measured reading.

    9) Person 3 walks back away from the tank until only the zero point is touching the tank.

    10) Repeat Steps 4 through 9 until three repeat measurements of the segment, within an approximate range of 0.005 ft (2 mm), have been achieved.

    11) Person 3 marks the most representative ending point for that measured segment, which becomes the starting point for the next segment and records the measured length of the segment.

    12) Measure each segment in like manner until the original starting point of the circumference is reached.

    13) Upon reaching the original starting point of the circumference, add up the segments and record the measured length of the circumference.

    14) Move the tape a few feet along the tape path and mark a new starting point for the next circumference measurement.

    15) Repeat Steps 2 through 14 until two repeat measurements of the circumference, within the tolerances shown in Table 2, have been achieved.

b) Sliding Tape Segment Method (requires less space away from the tank).

    1) Mark the tape path every few feet to define a clear tape path.

2) Mark the starting point for the circumference being measured and begin at that point.

3) Mark a starting point for the segment being measured.

4) Person 1 holds the zero end of the tape at the segment starting point.

5) Person 2 observes and assists as necessary to ensure that the path is followed exactly.

6) Person 3 holds the other end of the tape against the tank.

7) Person 3 maintains the prescribed tension at all times.

8) Person 3 signals readiness for the process to begin.

9) Person 1 signals readiness for the process to begin.

10) Person 3 slides tape forward several inches to break the friction.

11) Person 1, in one continuous and coordinated motion, slides the tape back to the zero point and stops.

12) Since the object is to get the tension across the whole tape, there shall be no adjustments (stopping and starting) near the zero point.

13) Person 1 signals whether or not the stop was made directly on the zero.

    i) If yes, Person 3 marks the tank with the measured reading.

    ii) If no, there is no measurement.

14) Repeat Steps 4 through 13 until three repeat measurements of the segment, within an approximate range of 0.005 ft (2 mm), have been achieved.

15) Person 3 marks the most representative ending point for that measured segment, which becomes the starting point for the next segment and records the measured length of the segment.

16) Measure each segment in like manner until the original starting point of the circumference is reached.

17) Upon reaching the original starting point of the circumference, add up the segments and record the measured length of the circumference.

18) Move the tape two or more feet along the tape path and mark a new starting point for the next circumference measurement.

19) Repeat Steps 2 through 18 until two repeat measurements of the circumference, within the tolerances shown in Table 2, have been achieved.

c) Sliding Tape Full Strap Method (requires less space away from the tank).

1) Mark the tape path every few feet to define a clear tape path.

2) Mark the starting point for the circumference being measured and begin at that point.

3) Wrap the tape around the tank on the reference tape path, allowing for some overlap.

4) Person 1 holds the zero and the measuring ends of the tape.

5) Person 2 observes and assists as necessary to ensure that the path is followed exactly.

6) Person 3 observes and assists as necessary to ensure that the path is followed exactly.

7) Person 1 maintains the prescribed tension at all times.

8) Person 2 signals readiness for the process to begin (tape is level and on the reference tape path).

9) Person 3 signals readiness for process the to begin (tape is level and on the reference tape path).

10) Person 1 slides the tape forward several inches to break the friction, while maintaining the prescribed tension at all times, and comes to a full stop with no adjustments.

11) Person 1 marks the tank with the measured reading in the area where the tapes cross.

12) Repeat Steps 4 through 14 until three repeat measurements of the circumference, within the tolerances shown in Table 2, have been achieved.

Table 2—Reference Circumference Tolerances (Soft Conversions)

Diameter ft	**Tolerance** ft	**Tolerance** mm
50	0.015	5
100	0.020	6
150	0.025	7
200	0.030	9
250	0.030	9
300	0.035	10

9.5 Distance and Angular Measurements

Starting from the bottom course and, while maintaining a constant horizontal angle, measure the distance (L) and the vertical angle (α) at each of the vertical stations. See Figure 3.

At each horizontal station, check instrument stability while traversing the tank vertically. Check the instrument levels in both axes at the middle and top of each course. Recheck the reference distance (L_{REF}) and the reference vertical angle (α_{REF}) at the bottom course.

If the reference distance (L_{REF}) varies by more than 2 mm, or if the reference vertical angle varies by more than 5 sec, repeat the measurements from bottom to the top. Follow the above procedure at all horizontal stations.

10 Computation of Course Diameters

See below for computation of course diameters.

— Reference Diameter = Reference circumference/π.

— Reference Radius = Reference diameter/2.

— Horizontal distance at any given horizontal station = $L \times \cos\alpha$ (3)

— Offset deviation (Odev) at any given horizontal station = $L_{\text{REF}} \times \cos\alpha_{\text{REF}} - L \times \cos\alpha$ (4)

— Sum of all offset deviations for the vertical stations in a given course = $\sum_{1}^{N_{\text{H}}}(\text{Odev})$ (5)

— Average offset deviation sat any given vertical station on a course (AOD)

= Sum of all offset deviations/NH

$$= \frac{1}{N_{\text{H}}} \times \sum_{1}^{N_{\text{H}}}(\text{Odev}) \quad (6)$$

— When there are two vertical stations per course, there are two average deviations for each course (20 % below and 20 % above), which are AOD_1 and AOD_2, the average offset deviation (AOD) per course is given by:

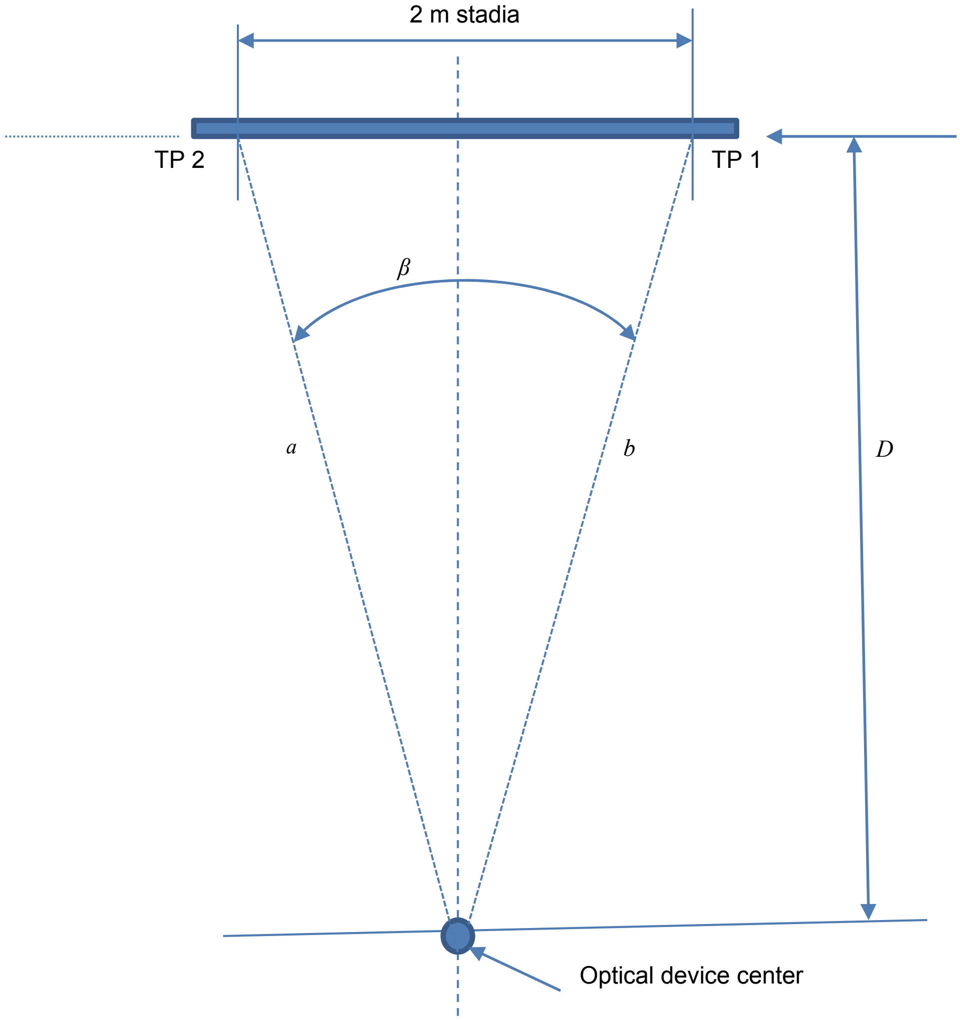
$$\text{AOD} = (\text{AOD}_1 + \text{AOD}_2)/2 \quad (7)$$

— Radius R of each course n is given by:

$$\text{Rn} = (\text{Reference radius} + \text{Reference offset} - \text{AOD})$$

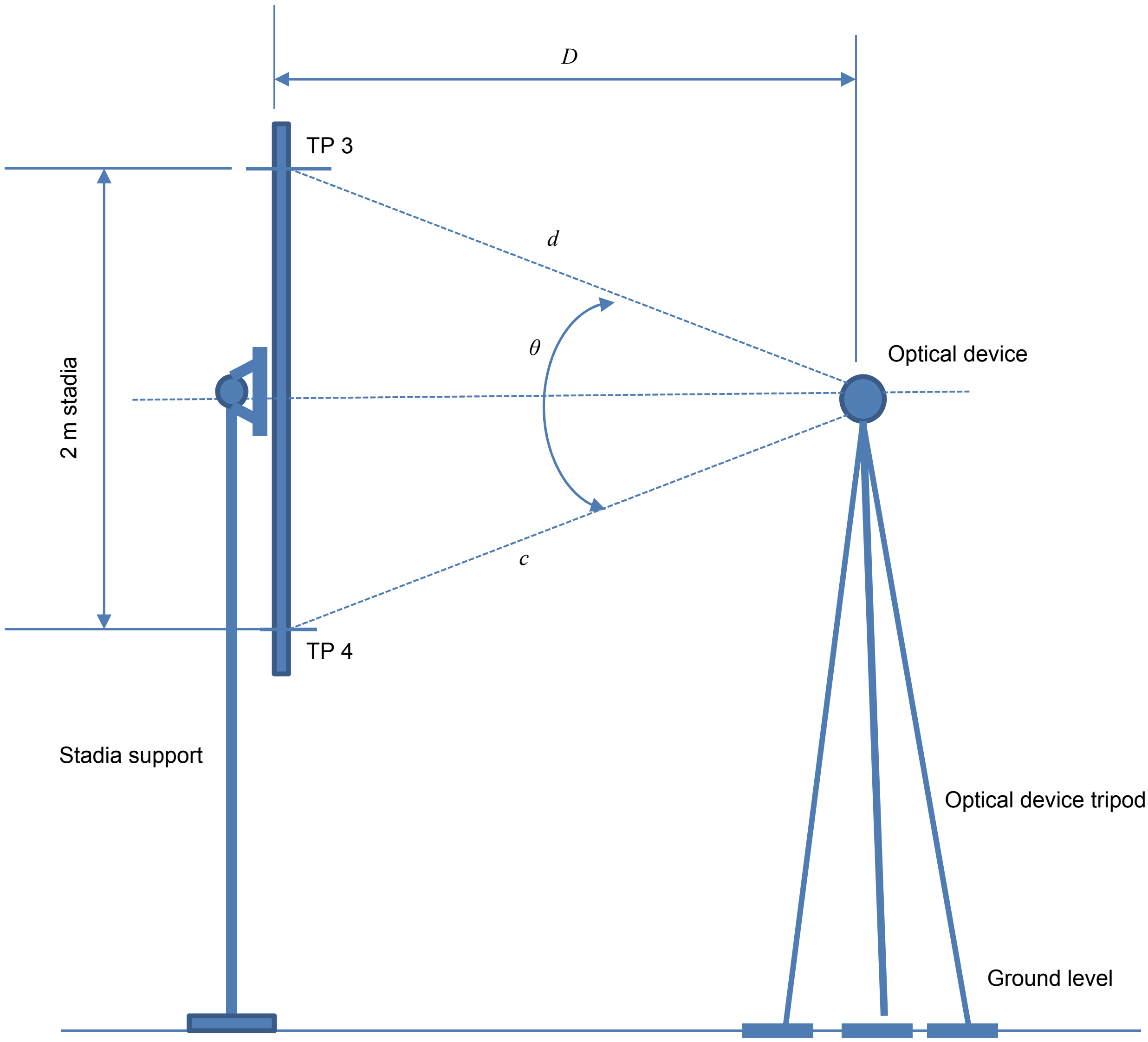
11 Development of the Capacity Table

Once the course radius is determined, the development of the capacity table should be based on the procedures outlined under API *MPMS* Ch. 2.2A.



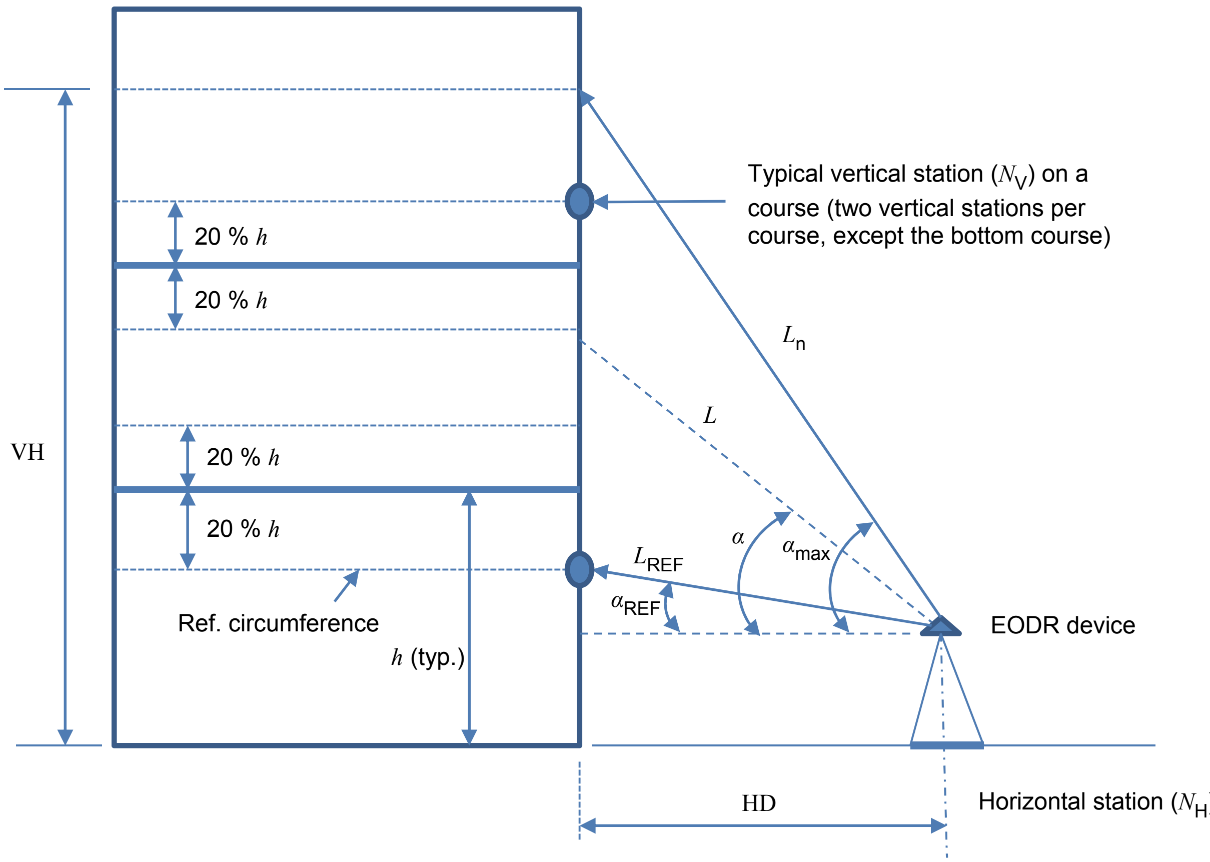
NOTE The angle β is measured optically. "D" may be set from 10 ft to 20 ft. TP: Target point on the stadia lengths "a" and "b" measured optically.

Figure 1—TSRLM Device Verification at Site: Stadia Horizontal



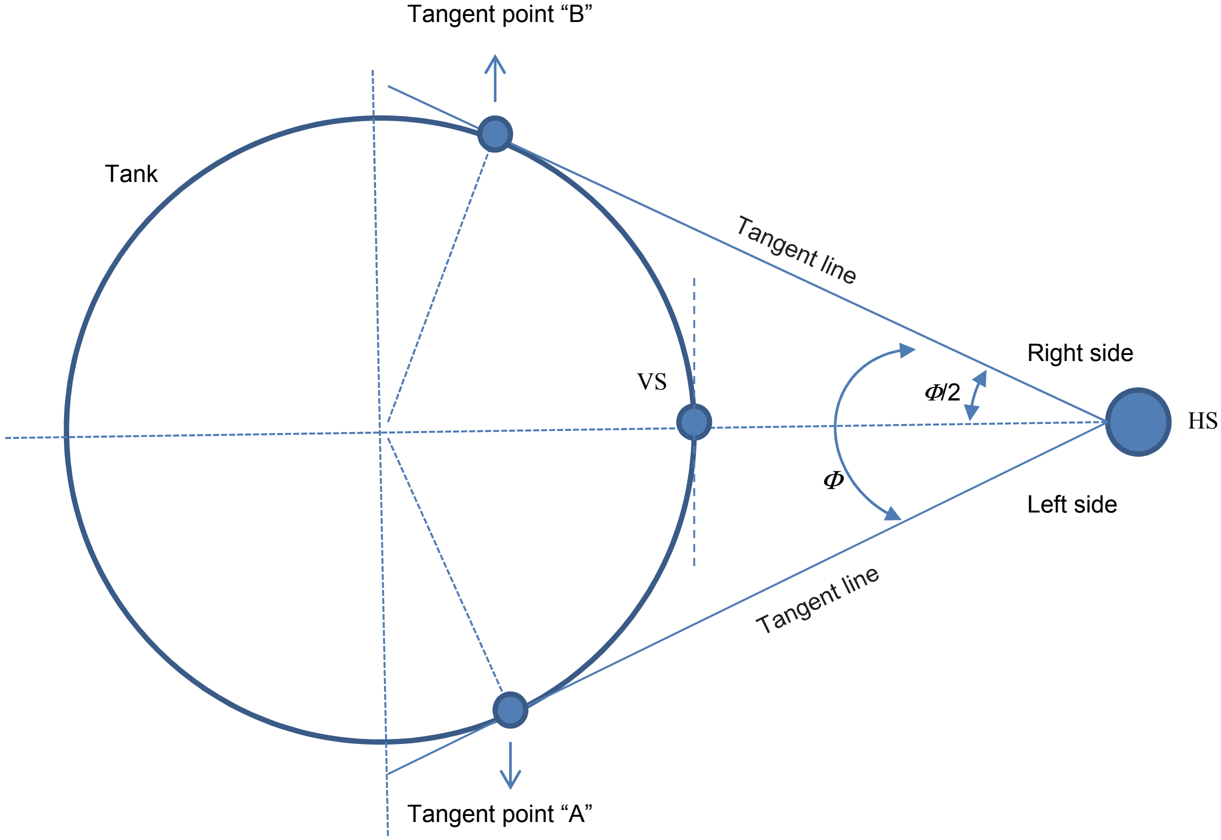
NOTE The angle θ is measured optically. "D" may be set from 10 ft to 20 ft. TP: Target point on the stadia lengths "c" and "d" are measured optically.

Figure 2—TSRLM Device Verification at Site: Stadia Vertical



NOTE α is the maximum angle around 60° and minimum angle around 45°. Using "VH" and angle "α," determine the desired distance "HD."

Figure 3—Distance and Vertical Angle



NOTE VS: vertical station point on a course; HS: horizontal station.

Figure 4—Setting Location of Vertical Station Tangential Traverse Method

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