INTERNATIONAL STANDARD

ISO 9091-2

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Refrigerated light hydrocarbon fluids — Calibration of spherical tanks in ships —

Part 2:
Triangulation measurement

Hydrocarbures légers réfrigérés — Jaugeage des réservoirs sphériques à bord des navires —

Partie 2: Méthode par triangulation

Reference number
ISO 9091-2:1992(E)

Contents

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 9091-2 was prepared by Technical Committee ISO/TC 28, *Petroleum products and lubricants*, Sub-Committee SC 5, *Measurement of light hydrocarbon fluids*.

ISO 9091 consists of the following parts, under the general title *Refrigerated light hydrocarbon fluids — Calibration of spherical tanks in ships*:

— *Part 1: Stereo-photogrammetry*

— *Part 2: Triangulation measurement*

Annexes A, B, C, D, E and F of this part of ISO 9091 are for information only.

Introduction

Large quantities of light hydrocarbons consisting of compounds having one to four carbon atoms are stored and transported by sea as refrigerated liquids at pressures close to atmospheric. These liquids can be divided into two main groups: liquefied natural gas (LNG) and liquefied petroleum gas (LPG). Bulk transportation of these liquids by sea requires special technology in ship design and construction to enable such transportation to be safe and economical.

Measurement of cargo quantities in ships' tanks for custody transfer purposes has to be of a high order of accuracy. The two parts of this International Standard, together with other standards in the series, specify methods of internal measurement of ships' tanks from which tank calibration tables can be derived.

For internal measurement, methods of liquid calibration, physical measurement, optical measurement and stereo-photogrammetry, etc. are in general use. Liquid calibration cannot be used for large spherical tanks designed to operate at near atmospheric pressure with refrigerated light hydrocarbons because the hydrostatic pressure exerted by the calibrating liquid may exceed the design pressure when filled higher than a certain level. This part of ISO 9091 covers a calibration technique applicable to spherical tanks equipped with a central pipe/instrumentation column.

Refrigerated light hydrocarbon fluids — Calibration of spherical tanks in ships —

Part 2:
Triangulation measurement

1 Scope

1.1 This part of ISO 9091 specifies a triangulation method for the internal measurement of spherical tanks in liquefied gas carriers.

1.2 This part of ISO 9091 also sets out the calculation procedures for compiling the calibration tables to be used for the measurement of cargo quantities.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 9091. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 9091 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 7507-1:—[1)], *Petroleum and liquid petroleum products — Calibration of vertical cylindrical tanks — Part 1: Strapping method.*

ISO 8311:1989, *Refrigerated light hydrocarbon fluids — Calibration of membrane tanks and independent prismatic tanks in ships — Physical measurement.*

3 Definitions

For the purposes of this part of ISO 9091, the following definitions apply.

3.1 base point: Centre point of the theodolite set above the traverse point.

3.2 basic pentagon: Pentagon connecting base points.

3.3 basic target: Portable target mounted on a tripod with a tribrach.

3.4 benchmark: Point on which a staff is erected to determine the height of the theodolite above the south pole.

3.5 calibration: Process of determining the total capacity or partial capacities of a tank corresponding to different levels.

3.6 calibration table; main gauge table: Table, often referred to as a tank table or a tank capacity table, showing the capacities of or volumes in a tank corresponding to various liquid levels measured from the gauge reference point, with the ship on an even keel and upright.

3.7 datum point: Position used as the datum in the preparation of a calibration table.

NOTE 1 This position may differ from the gauge reference point.

3.8 deadwood: Any tank fitting which affects the capacity of a tank.

3.8.1 positive deadwood: Fitting whose capacity adds to the effective capacity of the tank.

1) To be published.

3.8.2 negative deadwood: Fitting whose volume displaces liquid and reduces the effective capacity.

3.9 equator: Largest horizontal circumference of a spherical tank.

3.10 gauge reference point: Point from which the liquid depth is measured.

3.11 latitude: Horizontal circumferences on the surface of the sphere parallel to the equator.

3.12 longitude: Vertical circumferences on the surface of the sphere passing through the north and south poles.

3.13 list: Transverse inclination of a ship.

3.14 north pole: Zenith, or highest point, of a spherical tank shell, an imaginary point in most spherical tanks due to the pipe tower or other appurtenances.

3.15 pipe tower: Large-diameter pipe coaxial with the tank's north-south axis, containing pipes for loading and discharging, measuring instrumentation, ladder, wiring and other in-tank facilities.

3.16 port: Left-hand side of a ship facing forward.

3.17 south pole: Nadir, or lowest point, of a spherical tank.

3.18 starboard: Right-hand side of a ship facing forward.

3.19 target: Position distinctively marked on the inside surface of the tank for the triangulation method (see 6.1).

3.20 traverse point: Position on the inside surface of the tank above which a theodolite is set for determining the coordinates of a target.

3.21 trim: Longitudinal inclination of a ship.

4 Precautions during measurement

4.1 Utmost care and attention shall be exercised in taking measurements and anything unusual occurring during the measurement which might affect the results shall be recorded. The calibration method described in this part of ISO 9091 may be applied to ships whether afloat or in dry-dock. However, its use in dry-dock may be preferable, because trim or list, if any, will remain the same throughout the measurement.

4.2 If any unusual distortions are found in the tank shell, additional measurements shall be taken by the calibrator to obtain sufficient data for correct calculation in the calibration table, and the calibrator's notes should be provided in connection with such extra measurements.

4.3 Duplicate measurements of angles shall be taken to check whether they agree within 16 s, and if they do not agree, measurement shall be continued until two consecutive readings agree. The average of the two shall be recorded.

If consecutive measurements do not agree, the reason for the disagreement shall be clarified and, if necessary, the entire calibration procedure shall be repeated.

If the measurement has been interrupted, the last angle measurement taken should be repeated. If the new angle values do not agree, within the required tolerance of 16 s, with the earlier measurements, then the earlier set should be rejected.

4.4 Measurement shall be carried out when the temperature fluctuation of the wall is limited to the minimum.

NOTE 2 Temperature fluctuations should be checked during measurement procedures.

4.5 Measurements shall not be carried out when there is any motion of the ship, or vibration of the tank.

If calibration is carried out before installation of the tank in the hull of the ship, the distance between predetermined points on the interior of the tank shall be measured after installation to ensure that no distortion of the tank has occurred. If distortion has occurred, the calibration shall be repeated.

4.6 The paint used to mark the targets shall be manufactured from materials which are resistant to liquids at cryogenic temperatures.

5 Equipment

5.1 Basic target

A target mounted on a tribrach indicating a base point.

5.2 End-to-end rule

A rule graduated in centimetres and millimetres, to be used to measure deadwood, etc. The rule should bear the identification of a recognized standardizing authority or certificate of identification.

5.3 Measuring tape

A tape bearing the identification of a recognized standardizing authority or a certificate of identification.

5.4 Optical level

An optical level having an erect image, a magnification of × 20 or greater, capable of being focussed to 1,5 m or less and with a spirit-level sensitivity of 40 s per 2 mm or less.

5.5 Staff

A scale graduated in millimetres to be erected on a benchmark.

5.6 Steel rule

A rule, to be used to measure clearances, etc., graduated in millimetres. The rule should bear the identification of a recognized standardizing authority or certificate of identification.

5.7 Subtense bar

A subtense bar having a length greater than 5 % of the distance between the base points with a length uncertainty of less than 0,01 % of its length.

5.8 Surface thermometer

A thermometer used to measure the temperature of the surface of the tank with an accuracy of ± 0,5 °C in order to convert the coordinates of the targets at the temperature at the time of measurement to those at the certified reference temperature.

5.9 Theodolite

A theodolite, recommended to have an erect image with a minimum circular reading of 1 s and a spirit plate level sensitivity of 20 s per 2 mm or less.

5.10 Tribrach

A levelling platform, mounted on the tripod, with three levelling screws and a clamping device to fasten the theodolite.

6 Preparation

6.1 Marking of targets

During construction of the tank and prior to the installation of the pipe tower, targets (see figure 1) shall be stencilled on the inside surface of the tank shell at each intersection of latitude and longitude at 20° intervals. The marking error shall be less than 10 mm in both vertical and horizontal directions.

Dimensions in millimetres

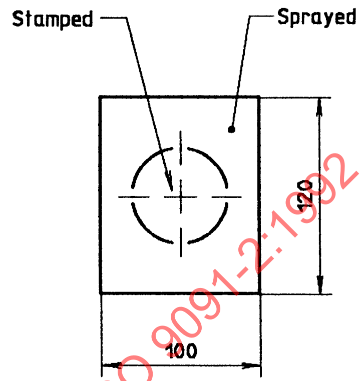


Figure 1 — Example of marking

6.2 Basic pentagon

6.2.1 Determination of traverse points

Mark five traverse points so that each target can be measured from at least four traverse points without being obstructed by the pipe tower.

6.3 Marking of benchmark

Mark the benchmark at an arbitrary position near the south pole of the tank (see figure 2).

6.4 Set-up of measuring instruments (see figure 2)

6.4.1 Set staffs upright on the benchmark and on the south pole of the tank.

6.4.2 Set up a level (for the basic target) using a tripod and tribrach, on an arbitrary point at which the staff on the south pole can be observed through the opening of the pipe tower (see figure 3).

6.4.3 Set up a levelled tribrach (for the base point) on a tripod at each of five traverse points (see figure 4).

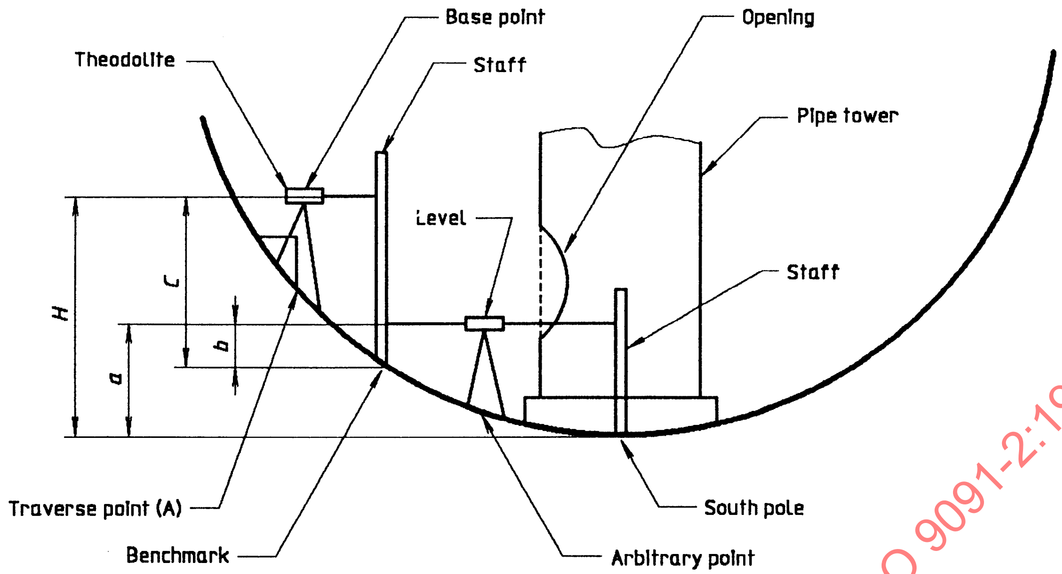


Figure 2 — Set-up of instruments for determining the height of the base point

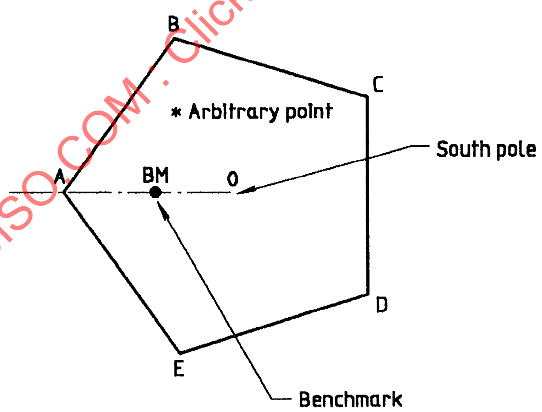


Figure 3 — Location of benchmarks and target

Dimensions in millimetres

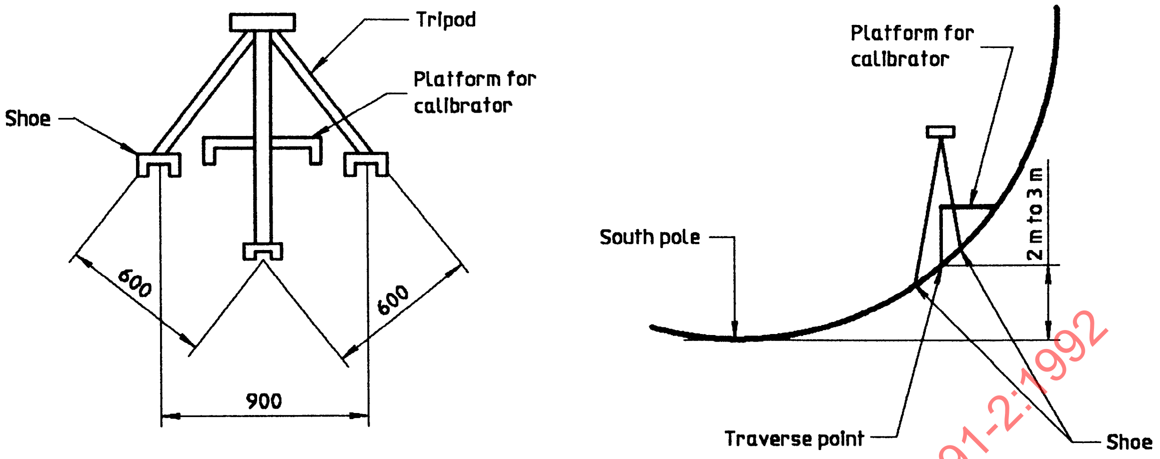


Figure 4 — Example of shoe arrangement for platform

7 Measurement

7.1 Elevation of base point from south pole

7.1.1 With the level, read the scale of the staffs set up on the south pole and on the benchmark respectively, as shown in figure 2.

7.1.2 With the theodolite mounted on the tripod of the traverse point (A) as shown in figure 2, read the scale of the staff set up on the benchmark.

7.1.3 Elevation H of the base point is determined as follows:

$$H = C + (a - b)$$

where

H is the elevation of the theodolite from the south pole;

C is the reading of the theodolite on the benchmark staff;

$(a - b)$ is the elevation of the benchmark from the south pole,

where

a is the level reading on the south pole staff;

b is the level reading on the benchmark staff.

7.2 Horizontal distance of base points

Horizontal distances can be obtained using the subtense bar method. This part of ISO 9091 describes the subtense bar method, but an alternative method is acceptable if it gives an accuracy equivalent to the subtense bar method.

7.2.1 Set a subtense bar on the tribrach of point B, as shown in figure 5.

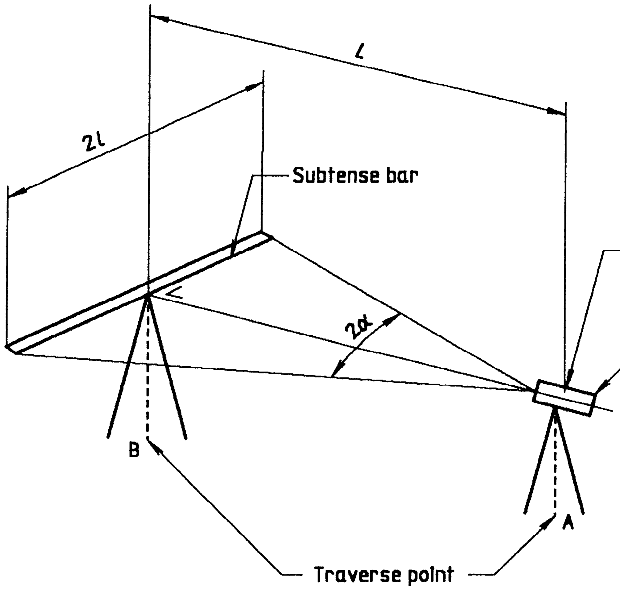


Figure 5 — Setting of subtense bar

7.2.2 Measure the horizontal angle 2α subtended at point A between the end-marks of the subtense bar. This measurement shall be taken at least twice (see 4.3).

7.2.3 Calculate the mean horizontal angle at each traverse point from the average of two consecutive readings.

7.2.4 The horizontal distance L can be calculated from equation (1):

$$L = l \frac{1}{\tan \alpha} \quad \ldots (1)$$

where l is one-half the length of the subtense bar.

7.3 Vertical height and horizontal angle of base point

7.3.1 Repeat the same procedure as described in 7.1.

7.3.2 Set up a basic target on each of the tripods at points B, C, D and E.

7.3.3 With the theodolite at point A, collimate the basic target at point B and adjust the scale of the horizontal angle to 0°00′00″.

7.3.4 Measure the horizontal angles of ∠BAC, ∠BAD and ∠BAE as shown in figure 6.

7.3.5 Remove the theodolite from point A and reset it on the tripod at point B. Set up a basic target on point A.

Repeat the measurement procedures given in 7.3.3 and 7.3.4.

7.3.6 Repeat the same procedure of measurement at points C, D and E.

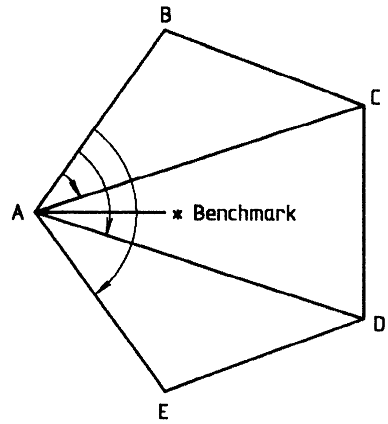


Figure 6 — Measurements with the theodolite on point A

7.4 Horizontal and vertical angles of target

7.4.1 Set up the theodolite on the tripod at base point A and the basic target on the tripod at base point B.

7.4.2 Collimating the basic target with the theodolite, adjust the horizontal scale to an angle of 0°00′00″.

7.4.3 Measure and record the horizontal and vertical angles to each target (see figure 7). If the line of sight to a target is obstructed by the pipe tower, then record this fact in the calibrator's notes.

7.4.4 Shift the theodolite and the basic target onto the other base points and measure the angles in the manner described in 7.4.2 and 7.4.3.

7.5 Temperature

Take the average temperature of the inside surface of the tank with a surface thermometer.

7.6 Height of gauge reference point

If the gauge reference point and the datum point differ, measure the height of the gauge reference point from the datum point (south pole) of the tank by means of an optical level or any other levelling device.

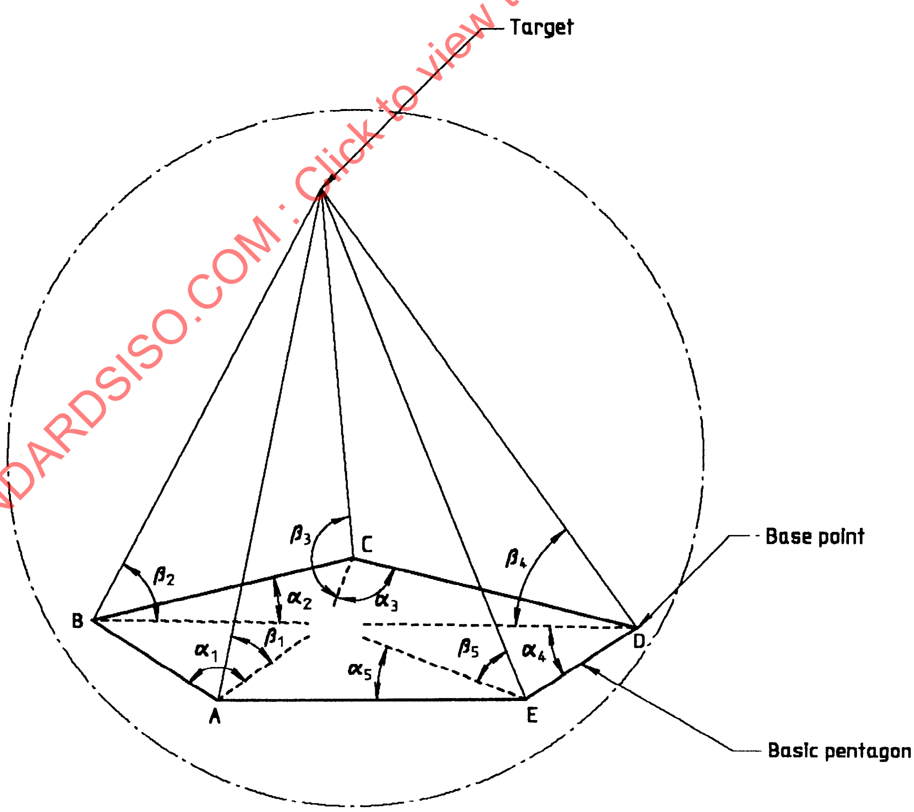
7.7 Location of level gauge

For trim and list corrections, measure the horizontal distance of the level gauge on the tank bottom from the vertical axis connecting the south and north poles.

7.8 Vertical diameter

If the tank has a dome with a built-in north pole, measure the distance between the north and south poles with a steel tape.

In the case of a dome that lacks the north pole and has only the grating top floor of the pipe tower, set an optical level by standing a theodolite in the middle of the above-mentioned floor, above the imaginary north pole, and measure with a steel tape the distance H between the above-mentioned optical level and the south pole.



Measured horizontal angles: α_1, α_2, α_3, α_4, α_5

Measured vertical angles: β_1, β_2, β_3, β_4, β_5

Figure 7 — Measurement of the target

Then measure the height h of the optical level from the bottom edge of the dome along the coaming of the dome and calculate the imaginary height Δh of the north pole from the above-mentioned edge by means of the curvature of the tank, which is obtainable from the design value of the vertical diameter.

The vertical diameter between the north and south poles is given by the formula

$$\text{Diameter} = H - h + \Delta h$$

As an alternative, measure the vertical inside height at a convenient distance from the centre-line. From the vertical inside height, the vertical diameter can later be calculated.

7.9 Deadwood

7.9.1 The volume of deadwood such as ladders, submerged pumps and any other structures in the tank shall be calculated from their dimensions, or any other suitable means of assessing their volumes.

7.9.2 The volume of internal piping containing cargo fluid shall be calculated as the difference between the internal and external volumes of the piping, i.e. the volume of the metal.

7.9.3 The volume of the deadwood shall be calculated at the respective heights where pipes and other fittings are present.

8 Coordinate system

The coordinate system is shown in figure 8. The x-axis is taken on the extension of the base line ($\overline{AB}$) on the horizontal plane, the y-axis perpendicular to the x-axis on the same horizontal plane and the z-axis on the vertical plane.

9 Calculation

9.1 Calculation of coordinates of base points (A, B) on the basic pentagon

Calculate the distance between A and B using the data measured with the subtense bar (see figure 9).

As the subtense bar is set horizontally, the projected length of the subtense bar on the horizontal plane is $2l$. Therefore, the horizontal distance (h_{AB}) is given in equation (2):

$$h_{AB} = \frac{l}{\tan \alpha} \qquad \ldots (2)$$

With the point A as the origin of the coordinates, the coordinates of the point B can be given as in equations (3) to (5):

$$x_B = -h_{AB} = \frac{-l}{\tan \alpha} \qquad \ldots (3)$$

$$y_B = 0{,}0 \qquad \ldots (4)$$

$$z_B = V_{AB} \qquad \ldots (5)$$

where V_{AB} is the vertical distance from A to B.

9.2 Determination of coordinates of base points (C, D, E) on the basic pentagon

Measure the horizontal angle and the relative height between every pair of base points on the basic pentagon, and obtain the data as shown in figure 10.

Calculate the lengths a_2 and a_3 as shown in figure 11 from equations (10) and (11), using the length a_1 and angles α_1, α_2 and α_3.

By using equations (10) and (11) and the horizontal distance (h_{AB}) given in equation (2), calculate the horizontal distance between points (B, C) from equation (6) and likewise, obtain other distances in the order shown in figure 12.

$$h_{BC} = h_{AB} \frac{\sin \alpha_{BAC}}{\sin(\alpha_{DCB} - \alpha_{DCA})} \qquad \ldots (6)$$

Obtain the relative heights for each base point directly from the data measured on the staff.

Obtain the coordinates of the base point C (x_C, y_C, z_C) from equations (7) to (9) using the horizontal distance h_{AB} in equation (6) and horizontal angle θ_B as shown in figure 13 and likewise, obtain the coordinates of other base points.

$$x_C = x_B + h_{BC} \cos \theta_B \qquad \ldots (7)$$

$$y_C = y_B + h_{BC} \sin \theta_B \qquad \ldots (8)$$

$$z_C = z_B + V_{BC} \qquad \ldots (9)$$

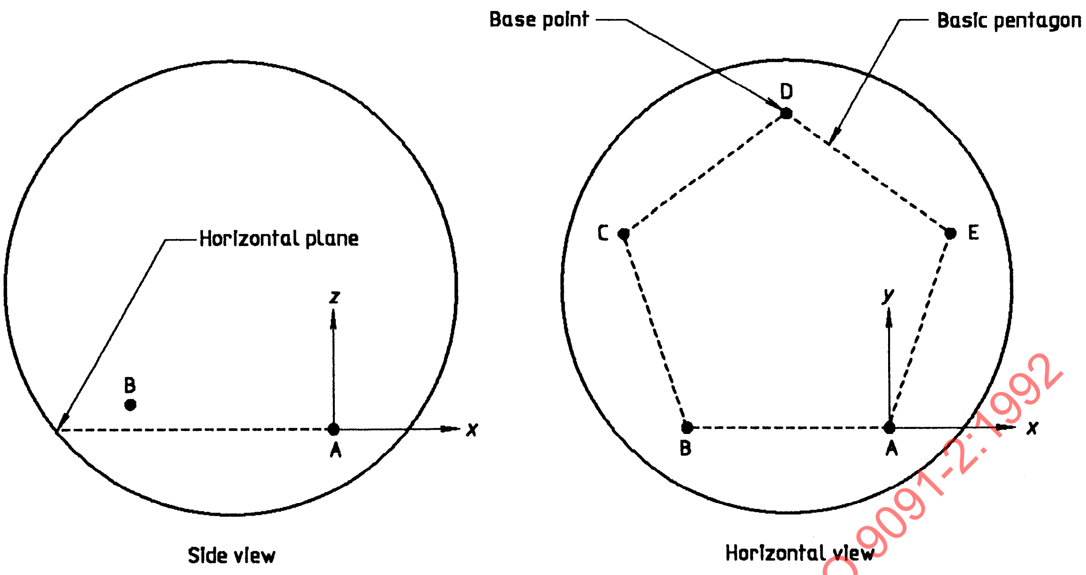
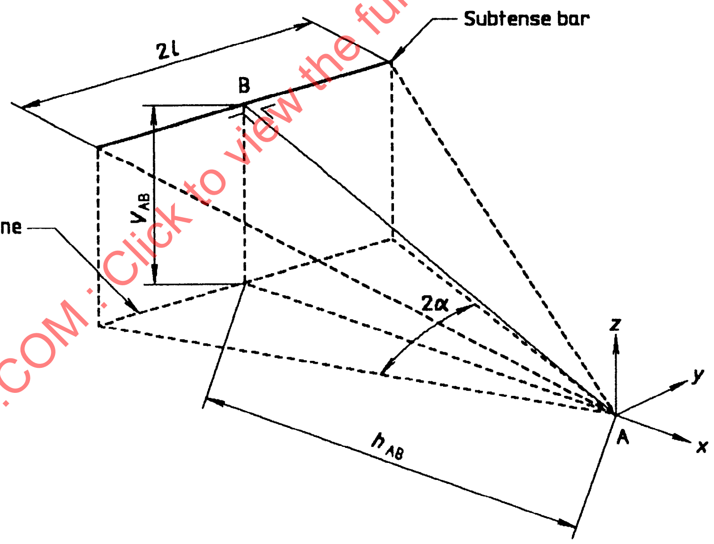


Figure 8 — Coordinate system for calculation



Known values:

length of the subtense bar = $2l$
horizontal angle = 2α

Figure 9 — Data for calculation of the coordinates of base points (A, B)

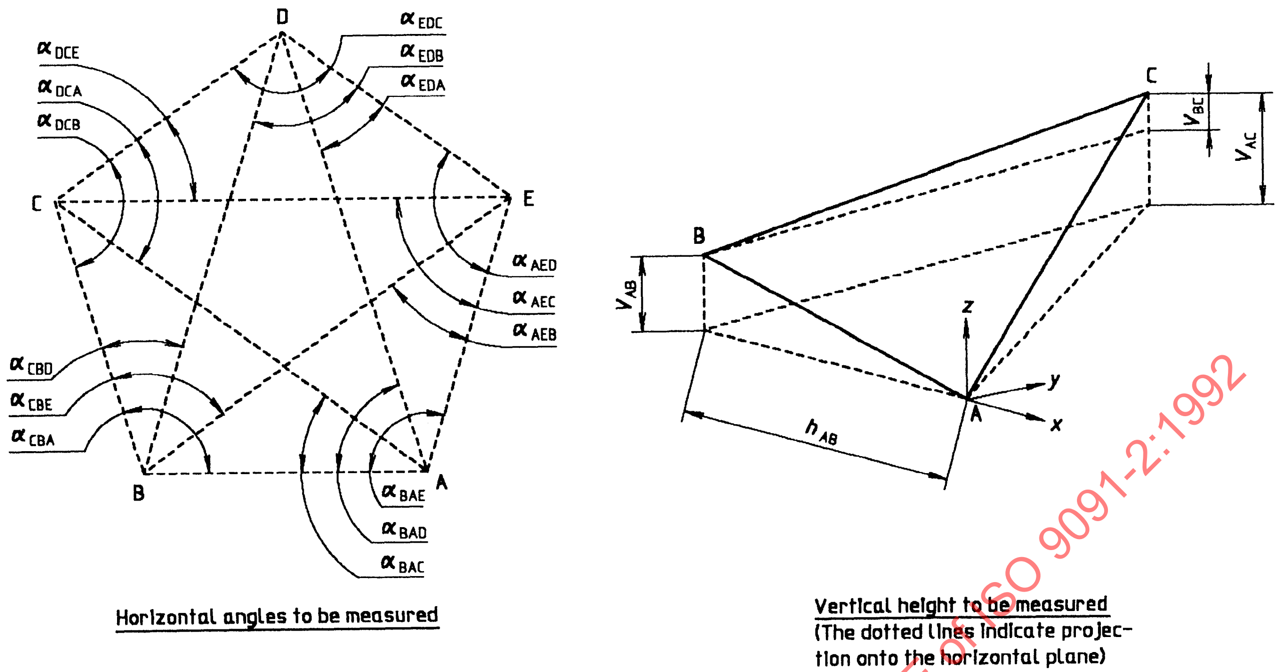
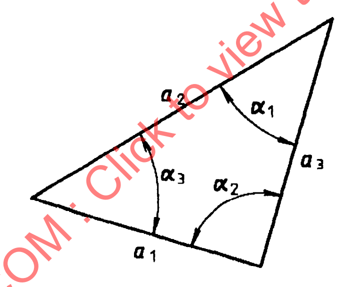


Figure 10 — Data measured for coordinate determination



The following equations are valid for the triangle shown:

$$a_2 = a_1 \frac{\sin \alpha_2}{\sin \alpha_1} \quad \ldots (10)$$

$$a_3 = a_1 \frac{\sin \alpha_3}{\sin \alpha_1} \quad \ldots (11)$$

Figure 11 — Data for calculation of relative lengths

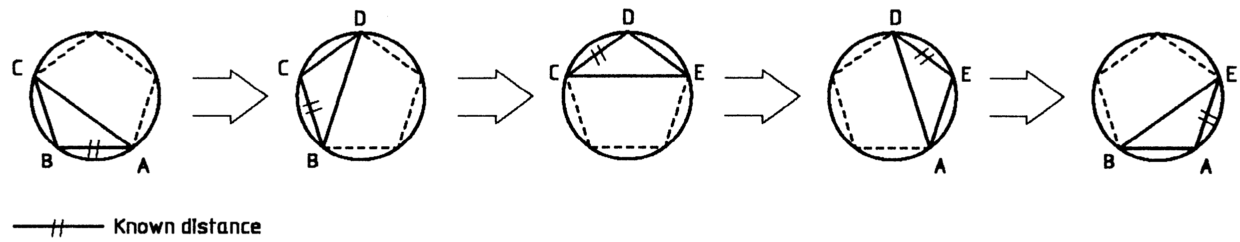
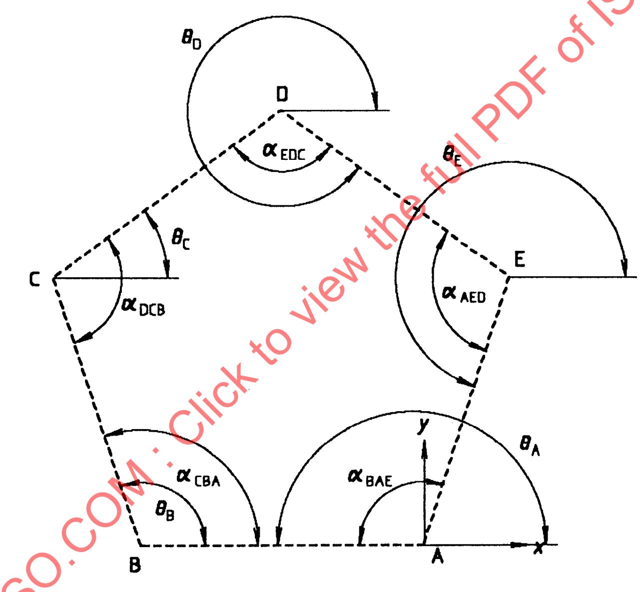


Figure 12 — Calculation order



$\theta_A = \pi$

$\theta_B = \alpha_{CBA} + \theta_A - \pi$

$\theta_C = \alpha_{DCB} + \theta_B - \pi$

$\theta_D = \alpha_{EDC} + \theta_C - \pi$

$\theta_E = \alpha_{AED} + \theta_D - \pi$

Figure 13 — Horizontal angles for determining base point coordinates

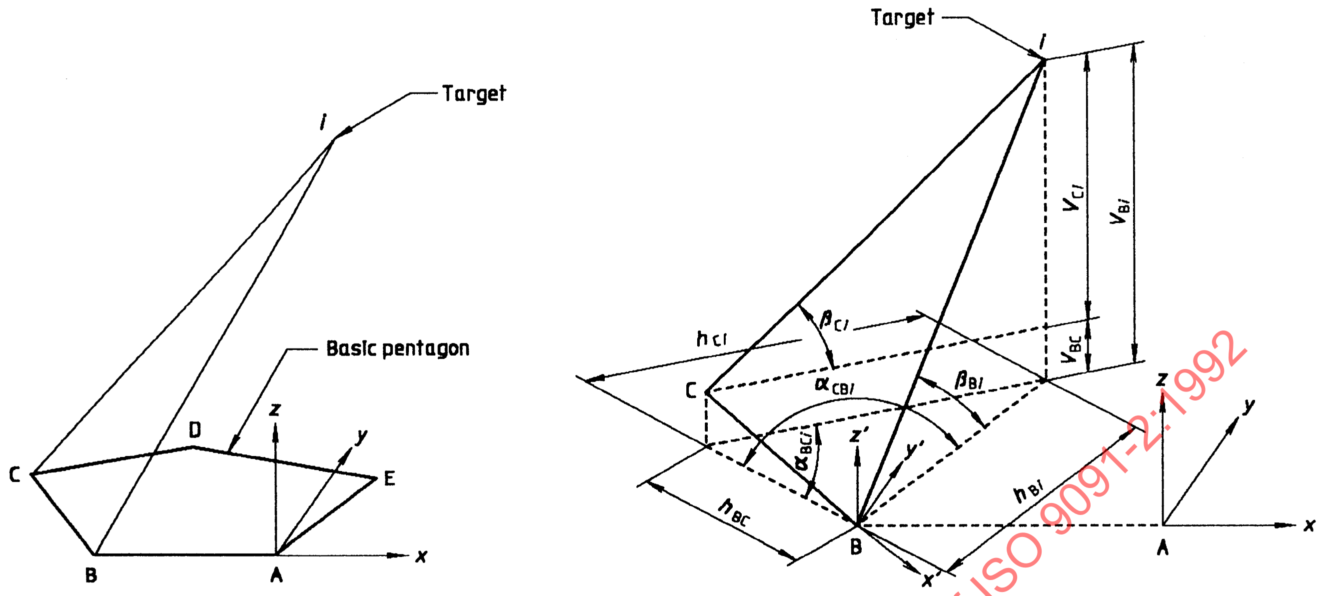


Figure 14 — Coordinates of a target

9.3 Calculation of coordinates of targets

Determine the coordinates of the targets using the triangle which is formed by a target and two arbitrary base points out of the five (A, B, C, D, E).

Figure 14 is an example of calculation given when the base points B and C are selected as a base line of a triangle. Apply the same procedure to other arbitrary points selected.

Obtain the horizontal and the vertical distances between the target (i) and the base points (B or C) shown in figure 12 using equations (12) to (15).

$$h_{Bi} = h_{BC} \frac{\sin \alpha_{BCi}}{\sin(\pi - \alpha_{BCi} - \alpha_{CBi})} \quad \ldots (12)$$

$$V_{Bi} = h_{Bi} \tan \beta_{Bi} \quad \ldots (13)$$

$$h_{Ci} = h_{BC} \frac{\sin \alpha_{CBi}}{\sin(\pi - \alpha_{BCi} - \alpha_{CBi})} \quad \ldots (14)$$

$$V_{Ci} = h_{Ci} \tan \beta_{Ci} \quad \ldots (15)$$

Obtain the coordinates of point (i) ($x'i$, $y'i$, $z'i$) as indicated in equations (16) to (18) against the local coordinate system (x', y', z') where the x'-axis is taken in the projection of line $\overline{BC}$ onto the horizontal plane, the y'-axis perpendicular to the x'-axis on the same plane, the z'-axis vertically, and the origin is point B.

$$x'i = h_{Bi} \cos(\pi - \alpha_{CBi}) \text{ or } h_{Ci} \cos \alpha_{BCi} - h_{BC} \quad \ldots (16)$$

$$y'i = h_{Bi} \sin(\pi - \alpha_{CBi}) \text{ or } h_{Ci} \sin \alpha_{BCi} \quad \ldots (17)$$

$$z'i = V_{Bi} \text{ or } V_{Ci} + V_{BC} \quad \ldots (18)$$

Transform the coordinates shown in equations (16) to (18) to the basic coordinate system (x, y, z) as shown in equations (19) to (21) using the rotation angle θ and distance (x_B, y_B, z_B) between both coordinate systems (see figure 15).

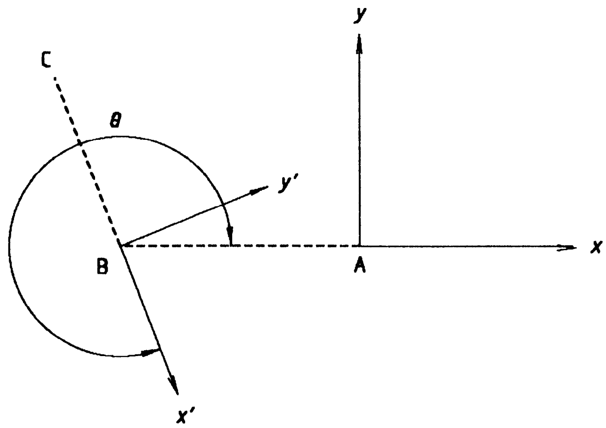


Figure 15 — Transformation from local coordinate (x', y', z') system to basic coordinate (x, y, z) system

$$xi = xB + x'i \cos \theta - y'i \sin \theta \quad \ldots (19)$$

$$yi = yB + x'i \sin \theta + y'i \cos \theta \quad \ldots (20)$$

$$zi = zB + z'i \quad \ldots (21)$$

where

$$\theta = \tan^{-1} \frac{yB - yC}{xB - xC}$$

The probability combination to select two arbitrary base points out of the five is

$$\frac{5!}{2!\,(5-2)!} = 10$$

This indicates that theoretically, the maximum number of triangles to determine the location of the target (i) is 10. Furthermore, as shown in equations (16) to (18), two kinds of coordinates for one target can be obtained from one triangle. Therefore, the coordinates of one target can be given in a maximum of 20 different ways. Determine the mean value of them to obtain the coordinates to be used.

9.4 Correction for trim or list

If the tank was measured in tilted condition, all the data obtained shall be corrected to those in upright condition.

10 Data processing

Calculate the radius of each level using the coordinates of the targets set on each level, and obtain the average radius of the best-fit circle of each level by least-square adjustment or other suitable mathematical solution. The average radii obtained as above and their level heights are converted to those at the reference temperature at which calibration tables are certified, using the certified coefficient of linear expansion of the tank material.

11 Calculation procedure

11.1 Calculation of tank volume

Compute the fractional volume of the space encircled by a spherical band between the two adjoining levels comprising the targets marked on the tank surface at each level by using the radii of the respective levels, and obtain the total volume of the spherical tank at the certified reference temperature of the calibration table by adding the above fractional volumes.

The fractional volumes for the remainder of the tank, below the lowest targets and above the highest targets, are calculated from the data of the appropriate sub-divided level. Calculate fractional volume below the lowest level using the coordinate of the south pole and designated curvature of the surface. Likewise, calculate fractional volume above the highest level. Then the volumes at one-centimetre intervals, starting from the south pole, the volume of deadwood being deducted, are obtained also by computation to compile a main gauge table.

11.2 Calculation of liquid head

Calculate the volume of the tank in the loaded condition with the contents at the density at which the calibration table is certified, then compare the above volume with that in the empty condition. The difference in volume is treated as deadwood.

11.3 Trim correction

Trim corrections shall be given as an addition to or subtraction from the apparent liquid level measured by the tank gauge. Trim corrections are calculated by comparison of the liquid levels given by the same volume of liquid in the tank with the ship upright and on even keel and with the ship in trimmed condition and upright for the condition of trim under consideration.

11.4 List correction

List corrections shall be given as an addition to or subtraction from the apparent liquid level measured by the tank gauge. List corrections are calculated by comparison of the liquid levels given by the same volume of liquid in the tank with the ship on even keel and upright and with the ship listed and on even keel for the condition of list under consideration.

11.5 Combined trim and list corrections

The trim and list corrections compiled in accordance with 11.3 and 11.4 may be combined in one table.

11.6 Correction for tank shell expansion or contraction

Corrections for the tank shell expansion or contraction, due to the temperature in the loaded condition deviating from the reference temperature at which the tank table was certified, shall be made by multiplying the coefficient of expansion of the material of the tank shell.

NOTE 3 The coefficient of expansion is not constant, but varies with temperature.

12 Calibration table

Calibration tables shall consist of the following report and tables:

12.1 Calibration report

The tank calibration report shall include the following items:

a) name of the calibrator;

b) place of calibration;

c) date of calibration;

d) tank configuration;

e) measurement method applied;

f) reference temperature of the tank table;

g) average temperature of the tank during measurement;

h) total capacity of the tank including dome capacity;

i) description of the deadwood;

j) tank calibration accuracy;

k) equipment certification;

l) method of use of the main gauge table and the correction tables;

m) any other information considered necessary or useful.

12.2 Main gauge table

See 3.6 for definition; annex C contains an example of such a table.

12.3 Trim correction table

Corrections to be applied to gauge readings due to the ship's trim. An example of such a table is given in annex D.

12.4 List correction table

Corrections to be applied to gauge readings due to the ship's list. An example of such a table is given in annex E.

12.5 Correction tables for tank shell expansion or contraction

Such tables give correction factors to be applied to the tabulated tank capacities to compensate for the volume change in the tank shell between the reference temperature used for the Main Gauge Table and the actual temperature of the tank at the time of liquid level measurement. The factors correct the volume of liquid and vapour at the reference temperature to volumes at the observed temperature. An example of such a table is given in annex F.

12.6 Correction for float-type level gauges

12.6.1 Correction table for difference in temperature

Gauge reading corrections due to expansion of a tape which is calibrated at the certified temperature should be made by means of the temperature of the vapour phase in the tank.

12.6.2 Correction tables for float buoyancy

These tables contain corrections to the apparent liquid level for the difference in the float immersion caused by the liquid density varying from the density at which the float was certified.

Annex A
(informative)

Safety precautions

In addition to the general precautions (see ISO 7507-1), the following should also be observed:

a) suitable footwear with non-slip soles should be worn on slippery tank surfaces;

b) a mercury thermometer should not be used in an aluminium tank.

Annex B
(informative)

Calibration uncertainty

B.1 Measurement uncertainty of tank radius σR

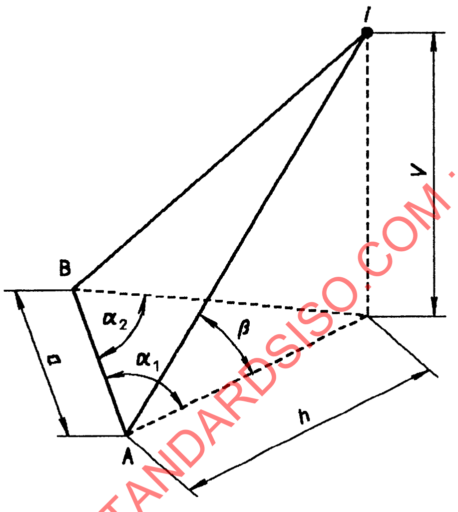
Tank radius R is expressed, using the relative position of highest target i, as:

$$R = \frac{1}{2}\sqrt{V_2 + h_2}$$

$$\therefore \sigma R^2 = \left(\frac{\partial R}{\partial V}\right)^2 (\sigma V)^2 + \left(\frac{\partial R}{\partial h}\right)^2 (\sigma h)^2$$

$$= \left(\frac{1}{2}\frac{V}{\sqrt{V^2 + h^2}}\right)^2 (\sigma V)^2 +$$

$$+ \left(\frac{1}{2}\frac{h}{\sqrt{V^2 + h^2}}\right)^2 (\sigma h)^2$$



Assuming (for a spherical tank with a diameter of 36,5 m)

$h = 15$ m

$V = 30$ m

and substituting them into the above formula, R, is expressed as:

$$(\sigma R)^2 = 0{,}20(\sigma V)^2 + 0{,}05(\sigma h)^2$$

B.2 Calculation of σh, σV

$$h = a\frac{\sin \alpha_2}{\sin(\pi - \alpha_1 - \alpha_2)} = a\frac{\sin \alpha_2}{\sin(\alpha_1 + \alpha_2)}$$

$$(\sigma h)^2 = \left(\frac{\partial h}{\partial a}\right)^2 (\sigma a)^2 + \left(\frac{\partial h}{\partial \alpha_1}\right)^2 (\sigma \alpha_1)^2 +$$

$$+ \left(\frac{\partial h}{\partial \alpha_2}\right)^2 (\sigma \alpha_2)^2$$

$$= \left[\frac{\sin \alpha_2}{\sin(\alpha_1 + \alpha_2)}\right]^2 (\sigma a)^2 +$$

$$+ \left[a\frac{\sin \alpha_2 \cos(\alpha_1 + \alpha_2)}{\sin^2(\alpha_1 + \alpha_2)}\right]^2 (\sigma \alpha_1)^2 +$$

$$+ \left[\alpha\frac{\sin \alpha_1}{\sin^2(\alpha_1 + \alpha_2)}\right]^2 (\sigma \alpha_2)^2$$

where (for the above spherical tank)

$a = 10$ m

$\alpha_1 = \alpha_2 = 70°$

are substituted, to give:

$$(\sigma h)^2 = 2{,}13(\sigma a)^2 + 303(\sigma \alpha_1)^2 + 515(\sigma \alpha_2)^2$$

For σa, σa_1, σa_2, the following figures are assumed (from the results of actual applications):

$\sigma a = 2$ mm

$$\sigma \alpha_1 = \sigma \alpha_2 = \frac{8''}{206\ 265''}$$

$$= 3{,}88 \times 10^{-5}$$

Therefore:

$\sigma h^2 = 9{,}75 \times 10^{-6}$

$\sigma h = 3{,}12 \times 10^{-3}$ (3,12 mm)

On the other hand,

$$V = h \tan \beta$$

$$\therefore \sigma V^2 = \left(\frac{\partial V}{\partial h}\right)^2 (\sigma h)^2 + \left(\frac{\partial V}{\partial \beta}\right)^2 (\sigma \beta)^2$$

$$= \tan^2 \beta (\sigma h)^2 + (h \sec^2 \beta)^2 (\sigma \beta)^2$$

The following figures are assumed (for the highest target):

$$\beta = 65°$$

$$h = 10 \text{ m} \frac{\sin 70°}{\sin 40°} = 14{,}6 \text{ m}$$

Therefore:

$$(\sigma V)^2 = 4{,}58 (\sigma h)^2 + 6\ 670 \sigma \beta$$

σh and $\sigma \beta$ can be estimated in the following manner:

$$(\sigma \beta)^2 = (\sigma \beta_0)^2 + (\sigma \beta_1)^2$$

where $\sigma \beta_0$ is the uncertainty of the collimation using the theodolite and $\sigma \beta_1$ the uncertainty due to the vertical axis of the theodolite being deviated from the complete vertical. They can be expressed (from the results of actual applications) as:

$$\sigma \beta_0 = \frac{8''}{206\ 265''} = 3{,}88 \times 10^{-5}$$

$$\sigma \beta_1 = \frac{4''}{206\ 265''} = 1{,}94 \times 10^{-5}$$

$$\sigma \beta = 4{,}34 \times 10^{-5}$$

Substituting σh already obtained, and the above $\sigma \beta$ into the formula gives:

$$\sigma V^2 = 57{,}2 \times 10^{-6}$$

$$\sigma V = 7{,}56 \times 10^{-3} \text{ (7,56 mm)}$$

B.3 Overall uncertainty

From the above:

$$\sigma h = 3{,}12 \times 10^{-3} \text{m}$$

$$\sigma V = 7{,}56 \times 10^{-3} \text{m}$$

Going back to the expression of σR, it can be calculated using σh and σV as:

$$(\sigma R)^2 = 0{,}05(3{,}12 \times 10^{-3})^2 + 0{,}20(7{,}56 \times 10^{-3})^2$$

$$= 11{,}92 \times 10^{-6}$$

$$\therefore \sigma R = 3{,}45 \times 10^{-3} \text{ m (3,5 mm to 4 mm)}$$

Annex C
(informative)

Example of main gauge table at − 160 °C

Gauge	Volume	Difference	Gauge	Volume	Difference	Gauge	Volume	Difference
cm	m^3	m^3	cm	m^3	m^3	cm	m^3	m^3
0-00	0,000	0,005	0-50	14,345	0,577	1-00	56,864	1,140
01	0,005	0,018	51	14,922	0,588	01	58,004	1,150
02	0,023	0,029	52	15,510	0,599	02	59,154	1,161
03	0,052	0,040	53	16,109	0,611	03	60,315	1,172
04	0,092	0,052	54	16,720	0,622	04	61,487	1,183
05	0,144	0,064	55	17,342	0,633	05	62,670	1,193
06	0,208	0,075	56	17,975	0,644	06	63,863	1,204
07	0,283	0,087	57	18,619	0,656	07	65,067	1,215
08	0,370	0,098	58	19,275	0,667	08	66,282	1,225
09	0,468	0,109	59	19,942	0,678	09	67,507	1,236
0-10	0,577	0,122	0-60	20,620	0,689	1-10	68,743	1,247
11	0,699	0,132	61	21,309	0,700	11	69,990	1,258
12	0,831	0,145	62	22,009	0,712	12	71,248	1,268
13	0,976	0,156	63	22,721	0,723	13	72,516	1,279
14	1,132	0,167	64	23,444	0,734	14	73,795	1,289
15	1,299	0,179	65	24,178	0,745	15	75,084	1,300
16	1,478	0,190	66	24,923	0,756	16	76,384	1,311
17	1,668	0,201	67	25,679	0,768	17	77,695	1,322
18	1,869	0,214	68	26,447	0,778	18	79,017	1,332
19	2,083	0,224	69	27,225	0,790	19	80,349	1,342
0-20	2,307	0,236	0-70	28,015	0,801	1-20	81,691	1,354
21	2,543	0,248	71	28,816	0,812	21	83,045	1,364
22	2,791	0,259	72	29,628	0,823	22	84,409	1,374
23	3,050	0,270	73	30,451	0,835	23	85,783	1,386
24	3,320	0,282	74	31,286	0,845	24	87,169	1,395
25	3,602	0,293	75	32,131	0,857	25	88,564	1,407
26	3,895	0,305	76	32,988	0,867	26	89,971	1,417
27	4,200	0,316	77	33,855	0,879	27	91,388	1,427
28	4,516	0,328	78	34,734	0,890	28	92,815	1,439
29	4,844	0,339	79	35,624	0,901	29	94,254	1,448
0-30	5,183	0,350	0-80	36,525	0,912	1-30	95,702	1,460
31	5,533	0,362	81	37,437	0,923	31	97,162	1,469
32	5,895	0,373	82	38,360	0,934	32	98,631	1,481
33	6,268	0,384	83	39,294	0,946	33	100,112	1,491
34	6,652	0,396	84	40,240	0,956	34	101,603	1,501
35	7,048	0,407	85	41,196	0,967	35	103,104	1,512
36	7,455	0,419	86	42,163	0,979	36	104,616	1,523
37	7,874	0,429	87	43,142	0,989	37	106,139	1,533
38	8,303	0,442	88	44,131	1,001	38	107,672	1,543
39	8,745	0,452	89	45,132	1,011	39	109,215	1,555
0-40	9,197	0,464	0-90	46,143	1,023	1-40	110,770	1,564
41	9,661	0,475	91	47,166	1,033	41	112,334	1,575
42	10,136	0,487	92	48,199	1,045	42	113,909	1,586
43	10,623	0,498	93	49,244	1,055	43	115,495	1,596
44	11,121	0,509	94	50,299	1,067	44	117,091	1,606
45	11,630	0,520	95	51,366	1,077	45	118,697	1,617
46	12,150	0,532	96	52,443	1,089	46	120,314	1,628
47	12,682	0,543	97	53,532	1,099	47	121,942	1,638
48	13,225	0,554	98	54,631	1,111	48	123,580	1,648
49	13,779	0,566	99	55,742	1,122	49	125,228	1,659