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Refrigerated light hydrocarbon fluids — Calibration of membrane tanks and independent prismatic tanks in ships — Physical measurement

Hydrocarbures légers réfrigérés — Étalonnage des réservoirs à membrane et réservoirs pyramidaux — Mesurage physique

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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 approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 8311 was prepared by Technical Committee ISO/TC 28, *Petroleum products and lubricants*.

Annexes A to F are for information only.

Introduction

Large quantities of light hydrocarbons consisting of compounds having 1 to 4 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 requires a special technology in ship design and construction to enable shipborne 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. This International Standard, together with others in the series, specifies methods of internal measurement of ships' tanks from which tank calibration tables can be derived.

This International Standard covers calibration techniques applicable to membrane type tanks, i.e. tanks in which the containment system comprises a relatively thin membrane of either stainless steel or high-nickel steel alloy supported by insulation and also, with some modifications, to tanks constructed of aluminium alloy or steel for low-temperature service that are independent, self-supporting and approximately prismatic in shape.

Annex A gives recommendations on safety precautions to be observed during the calibration.

Annex B gives an analysis of the sources of error for a typical membrane tank.

Annex C gives an example of a calibration table relating partial filling volume as a function of liquid level and annexes D, E and F give examples of trim, list and temperature correction tables.

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Refrigerated light hydrocarbon fluids — Calibration of membrane tanks and independent prismatic tanks in ships — Physical measurement

1 Scope

1.1 This International Standard specifies a method for the internal measurement of membrane tanks and independent prismatic tanks used in ships for the transport of refrigerated light hydrocarbon fluids. In addition to the actual process of measurement, it sets out the calculation procedures for compiling the calibration table and correction tables to be used for the computation of cargo quantities.

1.2 For membrane tanks, the procedures of this International Standard utilize the scaffolding used for the installation of the membranes to support the measuring equipment but, for independent prismatic tanks, other safe means of access to the required measuring positions have to be used.

2 Normative references

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

ISO 4512 : —[1], *Petroleum and liquid petroleum products — Equipment — Tank gauging and calibration — Manual methods.*

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

3 Definitions

For the purposes of this International Standard, the following definitions shall apply.

3.1 calibration : The process of determining the total capacity or partial capacities of a tank corresponding to different levels.

3.1.1 bottom calibration : Measurements made to provide calibration of the bottom part of a tank to take account of undulation in the bottom plate.

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

3.3 chamfer : A slanting surface connecting the walls of a tank with its top or bottom surface (see figure 5).

3.4 deadwood : Any tank fitting or structure, including rounded corners or radiussed ends, which affect the capacity of the tank. Deadwood is referred to as "positive deadwood" when the capacity of the fitting adds to the effective capacity of the tank, or "negative deadwood" when the volume of the fitting displaces liquid and reduces the effective capacity.

3.5 gauging : All the measurements taken in a tank necessary to determine the quantity of liquid and vapour contained therein.

3.6 gauge reference point : The point from which the liquid depths are measured.

3.7 horizontal plane : A plane established parallel to the tank bottom.

3.8 liquid level : Height of the liquid surface measured from the gauge reference point. When the ship is in list or trim condition, the height is measured at a right angle to the tank bottom.

3.9 list : Transverse inclination of a ship.

3.10 longitudinal line : A line formed by a longitudinal plane crossing a horizontal plane.

3.11 longitudinal plane : A vertical plane running parallel to the centreline of the tank.

1) To be published.

3.12 measuring line : A line (longitudinal, transverse or vertical) on a three-dimensional rectangular grid with a pitch not greater than 5 m. Measurement for calibration purposes is taken along these measuring lines.

3.13 port : The left-hand side of a ship facing forward.

3.14 reference line : A standard line established by a string or laser. A calibration method using this line is adopted as an alternative to direct measurements, where it is considered impractical to take direct measurements.

3.15 reference offsets : Clearances or offsets between the tank bottom and a horizontal plane set over it, which are measured along all the vertical lines drawn on the fore and aft end walls.

3.16 reference plane : A plane parallel to a side wall, end wall or tank bottom which passes through a reference line.

3.17 section line : A line formed by a section plane crossing a horizontal plane.

3.18 section plane : A plane parallel with the fore and aft end walls of a tank.

3.19 starboard : The right-hand side of a ship facing forward.

3.20 trim : Longitudinal inclination of a ship.

3.21 vertical line : A line formed by a section plane on the side walls and formed by a longitudinal plane on the fore and aft end walls.

4 Precautions

This clause outlines the precautions to be taken during measurement in order to ensure that the required calibration precision is obtained.

4.1 Utmost care and attention shall be exercised in taking measurements, and any unusual occurrence during the measuring work which might affect the results obtained shall be recorded.

The calibration method described in this International Standard may be applied to ships whether afloat or in a dry dock or on a building slip. However, its use for ships in a dry dock is preferred, because trim or list, if any, will remain the same throughout the calibration procedure. The necessary adjustment shall be made to any measurement by optical level or laser transmitter if the ship's attitude has changed.

4.2 If unusual distortion is found in the tank, additional measurement shall be taken by the calibrator as considered necessary and sufficient to provide the required accuracy in the calibration table. Notes by the calibrator detailing the extra measurements and the reasons for them shall be included in the calibration report.

The calibrator shall provide detailed sketches of any abnormality of the tank or its fittings where such sketches will materially assist the interpretation of the recorded data.

4.3 If drawings for the tank are available, all measurements taken shall be compared with the corresponding dimensions shown on the drawings. Any measurement showing a significant discrepancy in this comparison shall be rechecked.

4.4 Measurements shall be taken twice to check whether they agree within the following tolerances; if they do not agree, measurements shall be continued until two consecutive readings agree, and their average shall be taken as the result.

Measurement	Tolerance
up to 20 m	± 2 mm
over 20 m	± 3 mm
for offset	± 0,5 mm

If the measurements have been interrupted, the last measurements taken shall be repeated. If the new measurements do not agree, within the required tolerance, with the earlier measurements, then the earlier set shall be rejected.

4.5 When measurements are made with a measuring tape, the tension specified in the tape calibration certificate shall be applied.

4.6 The measuring tape shall be supported, if necessary, so as to prevent it from sagging. If tape sag is unavoidable, the calibrator shall note this and a catenary correction shall be applied during calculation.

4.7 When measuring a membrane tank, care shall be taken to ensure that the membrane is in contact with the supporting material.

NOTE — In some cases it may be possible to ensure this contact by applying a vacuum to the space beneath the membrane.

4.8 The trim and list of the ship shall be kept unchanged while the optical level or laser transmitter is used.

5 Equipment

5.1 Dynamometer, to check the tension specified for a measuring tape.

5.2 End-to-end rule, graduated in centimetres and millimetres, to be used to measure deadwood, etc. A wooden rule shall be free of warping. The rule shall bear the identification of a recognized standardizing authority or certificate of identification.

5.3 Laser transmitter, emitting a low-power laser beam with a divergence of less than 4 mm at a distance of 35 m, which can be rotated through 360° vertically and horizontally.

5.4 Measuring tape, complying with the specifications given in ISO 4512, clause 20.

5.5 Optical level, having an erect image and a magnification of ×20 or greater, capable of being focussed to 1,5 m or less and with a spirit level sensitivity of 40 seconds of arc per 2 mm or less.

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

5.7 Thermometer, of suitable range, having an accuracy of ± 0,5 °C.

5.8 Tension handle, fastened to the measuring tape to apply tension to pull it into a straight line (see ISO 4512).

6 Measurement

6.1 Method

This clause and clause 7 set out a method of measurement and calculation applicable to tanks constructed using a membrane containment system.

Measurements of the distances between opposite walls of a tank shall be taken by tensioning the tape as specified on the tape certificate.

Tanks constructed of aluminium alloy or steel for low-temperature service, and of independent, self-supporting and approximately prismatic shape, may exhibit significant deformation or building inaccuracy. If such distortion has been identified, additional measurement, as indicated in 4.2, shall be carried out.

The decision to adopt an alternative method shall be made by the calibrator. The reasons for the decision shall be included in the field notes.

6.2 Determination of measuring positions

Tank calibration is basically the measurement of the tank length, width and height between known positions. These positions are determined by setting out a number of horizontal, longitudinal and section planes.

These planes intersect to form lines along which the measurements of length, width and depth shall be taken. The various planes shall be set out at intervals not greater than 5 m; the interval shall be adjusted so that the resulting measurements reflect any change of section and adequately describe any deformation. The positions at which measurements are to be taken shall be determined by the calibrator but shall not be more than 5 m apart.

6.3 Marking

Having determined the positions at which measurements are to be taken, mark the lines which run on the tank inner walls. Mark the section and longitudinal lines on the top and bottom plates, horizontal and vertical lines on the fore and aft end walls and horizontal and vertical lines on the port and starboard end walls.

6.4 Tank length measurement

Measure tank lengths along all the longitudinal lines at each level of the horizontal planes as described in 6.4.1 to 6.4.3.

6.4.1 Length measurement on the bottom plate

Measure distances between the fore and aft end walls along all the longitudinal lines marked on the bottom plate with a measuring tape stretched thereon.

6.4.2 Length measurement on the top plate

Measure distances on the top plate in a manner similar to that for the bottom plate (see 6.4.1). Care shall be taken to keep the measuring tape in contact with the top plate.

6.4.3 Length measurement in an intermediate horizontal plane

To avoid inaccurate measurement due to excessive sagging of the measuring tape, apply the reference line method using a string line (6.4.3.1) or laser beam (6.4.3.2).

As shown in figure 1, lengths in these imaginary planes can be obtained by applying offset corrections at both ends, a_2, a_3 . . . a_{n-1} and b_2, b_3 . . . b_{n-1}, to the length measured directly on the side wall.

6.4.3.1 String line

1) Mark P_1 and P_2, S_1 and S_2, on both side walls at equal distances from the end walls. Measure the lengths (L_P, L_S) between the fore and aft end walls with a measuring tape extended along both side walls, supporting the tape on the wall to prevent it from sagging.

2) Stretch strings between the opposite points P_1 and S_1, P_2 and S_2, and measure the offsets between the strings and the end walls (a_1, a_2 . . . a_n and b_1, b_2 . . . b_n) with a rule.

3) In measuring these offsets, take care to put the measuring rule at a right angle to the string.

6.4.3.2 Laser beam line

1) Mount a laser transmitter on one of the end walls with an appropriate clearance, then align the laser beam horizontally and approximately parallel to the end wall.

2) Mark P_1 on the port side wall where the laser beam strikes the wall, then rotate the beam through 180° and mark S_1 where the beam strikes the starboard wall.

3) Measure offsets between the centre of the beam and the end wall (a_1, a_2 . . . a_n) with a rule.

4) Repeat the same procedure on the opposite end wall. Mark P_2, S_2 and measure b_1, b_2 . . . b_n.

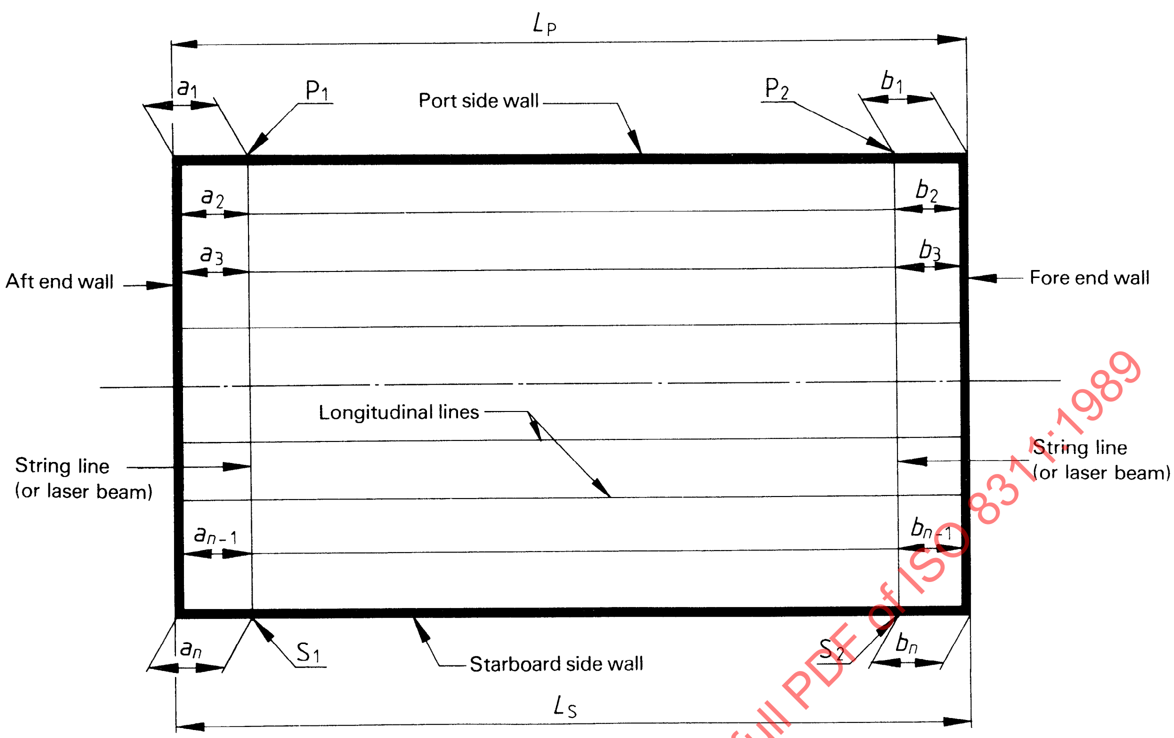

Figure 1 — Plan view of an intermediate horizontal plane

6.4.3.3 Average length

The purpose of the measurement using a string line (6.4.3.1) or laser beam (6.4.3.2) is to obtain the average length, L, of each intermediate horizontal plane, which is calculated from the equation

$$L = \frac{L_P + L_S - (a_1 + a_n + b_1 + b_n)}{2} + \frac{\sum_{i=1}^{n} (a_i + b_i)}{n}$$

Alternatively, another formula of equal or better precision may be used when it is considered adequate in the light of the shape of the tank.

6.4.3.4 Laser beam plane

As an alternative to the laser beam reference line method described in 6.4.3.2, the single beam laser may be replaced by a laser producing a laser plane. A rotating laser is set up adjacent to and approximately parallel with each inner surface. The plane will pass through the laser reference lines described in 6.4.3.2. Offset measurements are taken between the plane and the positions on the wall determined as described in 6.2.

6.5 Tank width measurement

Tank widths are measured along all the section lines set in each horizontal plane as described in 6.5.1 to 6.5.3.

6.5.1 Width measurement on an intermediate horizontal plane

Measure tank width in the same way as in the length measurement by actual measurement of w_f and w_a in combination with the string or laser beam method as shown in figure 2.

The average width, w, for each intermediate horizontal plane is given by the equation

$$w = \frac{w_f + w_a - (c_1 + c_n + d_1 + d_n)}{2} + \frac{\sum_{i=1}^{n} (c_i + d_i)}{n}$$

6.5.2 Chamfer portions

Measure the width on the end walls at the tank top as well as at the bottom of the upper chamfer. Likewise, measure the width on the end walls at the tank bottom and at the top of the lower chamfer.

6.5.3 Trapezoidal tank

If the tank width is less at one end, measure the width in the intermediate horizontal planes in the same way as in 6.5.1, as shown in figure 3.

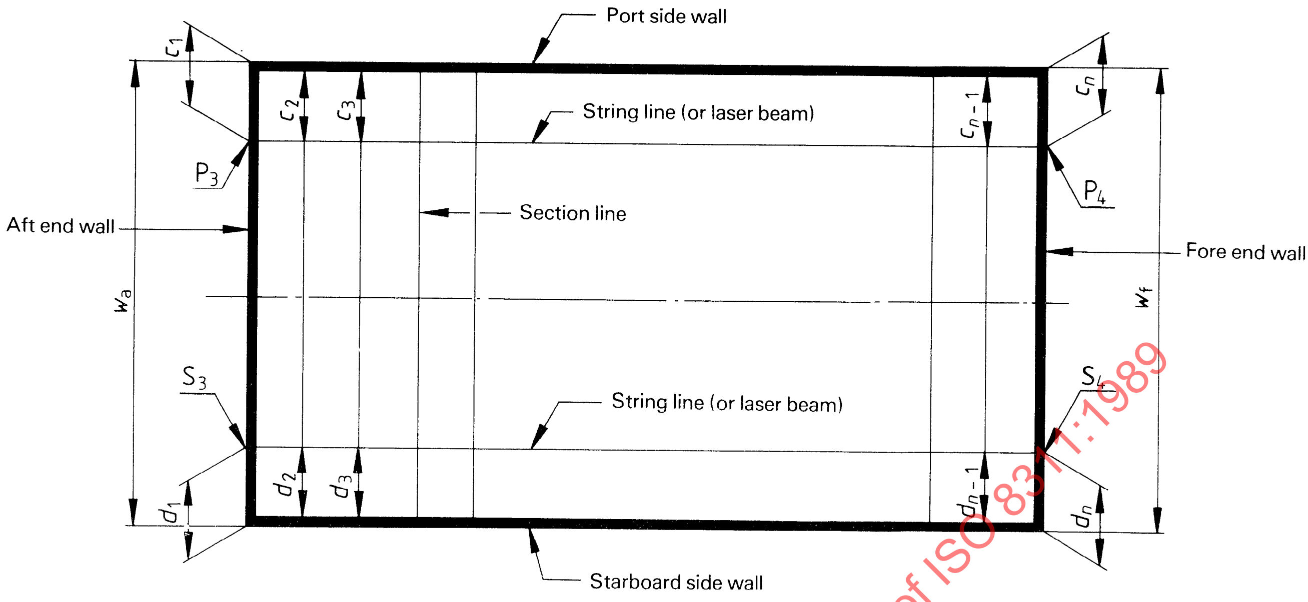

Figure 2 — Plan view of an intermediate horizontal plane

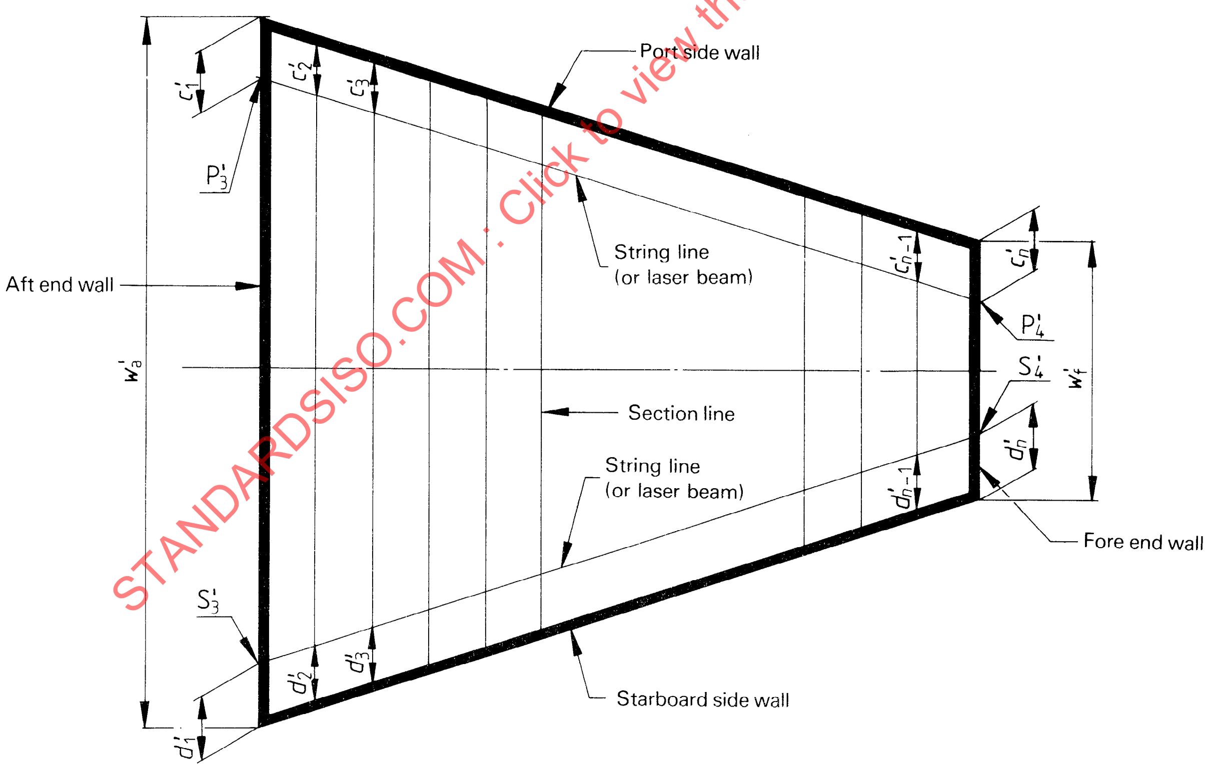

Figure 3 — Plan view of an intermediate horizontal plane (trapezoidal tank)

The average width (w_f) of the fore end wall and the average width (w_a) of the aft end wall are calculated from the equations

$$w_f = w'_f - \frac{c'_1 + c'_n + d'_1 + d'_n}{2} + \frac{\sum_{i=1}^{n} (c'_i + d'_i)}{n}$$

and

$$w_a = w'_a - \frac{c'_1 + c'_n + d'_1 + d'_n}{2} + \frac{\sum_{i=1}^{n} (c'_i + d'_i)}{n}$$

As shown in figure 3, the offsets to be taken in measuring the widths should theoretically be the ones parallel to the fore and aft end walls ($c'_1 \ldots c'_n$, $d'_1 \ldots d'_n$), and the offsets d_i measured at right angles to the side wall should be corrected, as shown in figure 4, to d'_i measured parallel to the fore and aft walls by the formula $d'_i = d_i \times \sec \theta$ where θ is the angle between the side wall and the plane at right angles to the fore and aft walls.

6.6 Tank height measurement

Figure 5 shows a transverse section view of a tank indicating where measurements are required and the values used in calculating chamfer.

6.6.1 Measurement of total height, h_t

6.6.1.1 Total height at the fore and aft end walls

Measure distances between the top and bottom plates with a measuring tape along all vertical lines, and calculate the arithmetic mean, h_t.

6.6.1.2 Total height at an intermediate section plane

On the top and bottom plates, draw section lines and longitudinal lines which will make grids on both plates. Using a measuring tape, measure the distances between the intersections of these lines on the top plate and the corresponding points on the bottom plate.

6.6.2 Partial height measurement

6.6.2.1 Height h_m at the side walls

Measure the distance between the bottom of the upper chamfer and the top of the lower chamfer, along all vertical lines drawn on both side walls, and obtain the average thereof by the arithmetic mean, which is denoted as h_m.

6.6.2.2 Height h_l of lower chamfer at the fore and aft end walls

a) Set a reference line with an optical level or a laser beam approximately parallel to the bottom and the end walls with some clearance from the top of the lower chamfer.

b) Measure height d_1 between this reference line and the bottom plate along all the vertical lines, and take another measurement d_2 between the reference line and the top of the lower chamfer at the corners of the tank.

c) The height h_l of the lower chamfer is calculated from the equation

$$h_l = \text{average value of } d_1 - \text{average value of } d_2$$

6.6.2.3 Height of upper chamfer h_u at the fore and aft end walls

Now that heights h_t, h_m and h_l have been obtained, the height of the upper chamfer h_u is calculated from the equation

$$h_u = h_t - h_m - h_l$$

6.7 Bottom calibration

Figure 6 shows an oblique projection view of a tank bottom to indicate the positions where measurements are required.

Figure 7 shows an expanded transverse section of the tank bottom to illustrate the measurements used in the assessment of bottom undulation.

6.7.1 Set a reference plane with an optical level or a laser beam with some clearance from the tank bottom.

6.7.2 Measure reference offsets between the bottom plate and the reference plane along all the vertical lines set on the fore and aft end walls. The average of the measurements is denoted as RB.

6.7.3 Likewise, take measurements of the depths at all intersections of the longitudinal lines with the section lines on the bottom plate. The average of these measurements as well as of the measurements used in obtaining RB is denoted as RA.

6.7.4 Calculate the numerical difference AB between the average reference offset RB and the average depth measurement RA from the equation

$$AB = |RA - RB|$$

The increase or decrease in volume due to bottom undulation is obtained by multiplying the difference AB by the area of the tank bottom plate.

6.7.5 Measure the depth RC between the reference plane and gauge reference point (see figure 7). The clearance BC of the gauge reference point in relation to the tank bottom is then calculated from the equation

$$BC = RB - RC$$

6.8 Location of level gauge

The location of the level gauge shall be indicated by the distances from the nearby wall and the bottom of the lower chamfer and recorded for inclusion in the calculation of trim and list corrections.

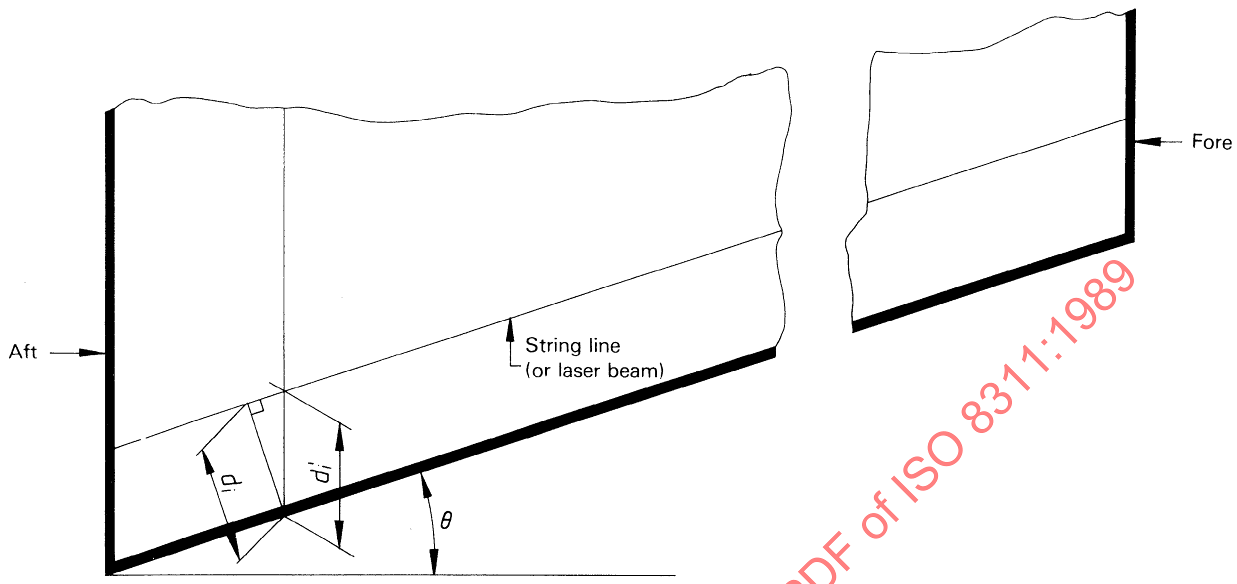

Figure 4 — Correction of offsets

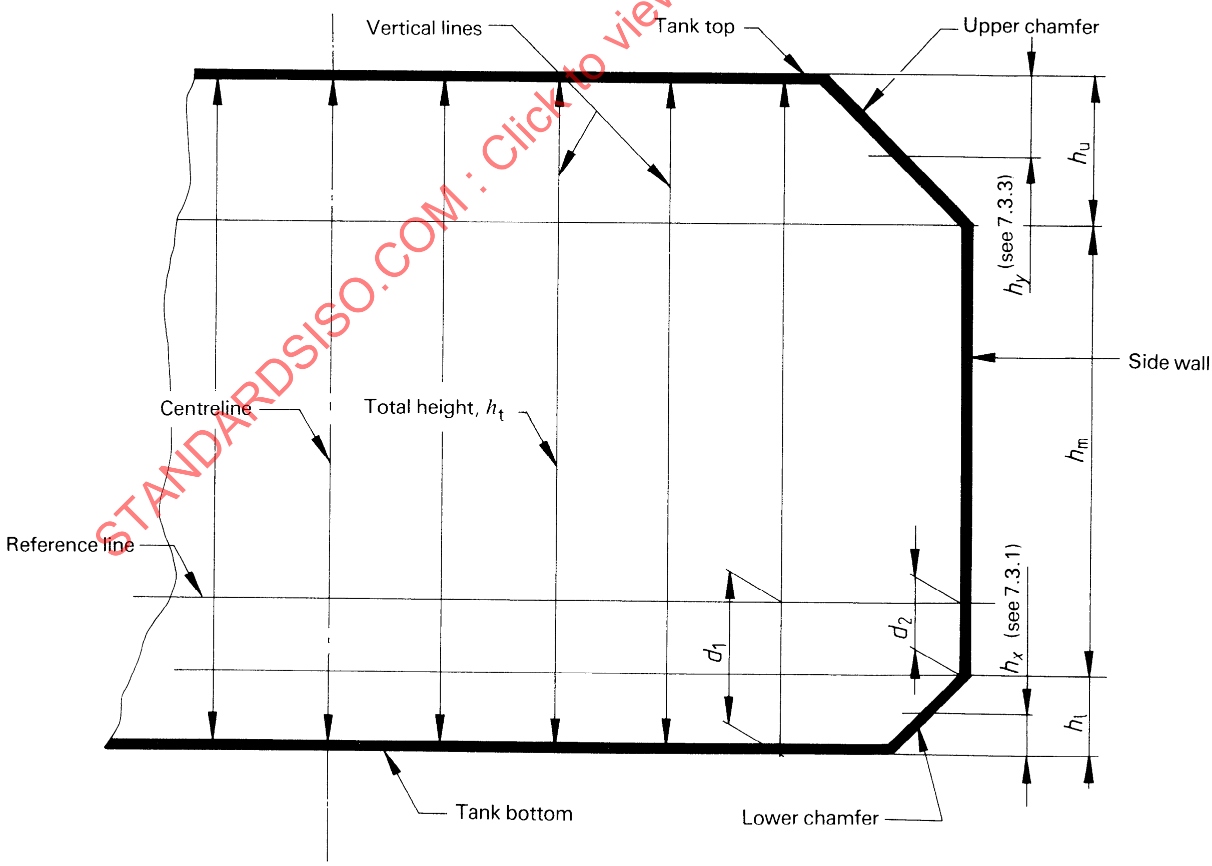

Figure 5 — Transverse section view

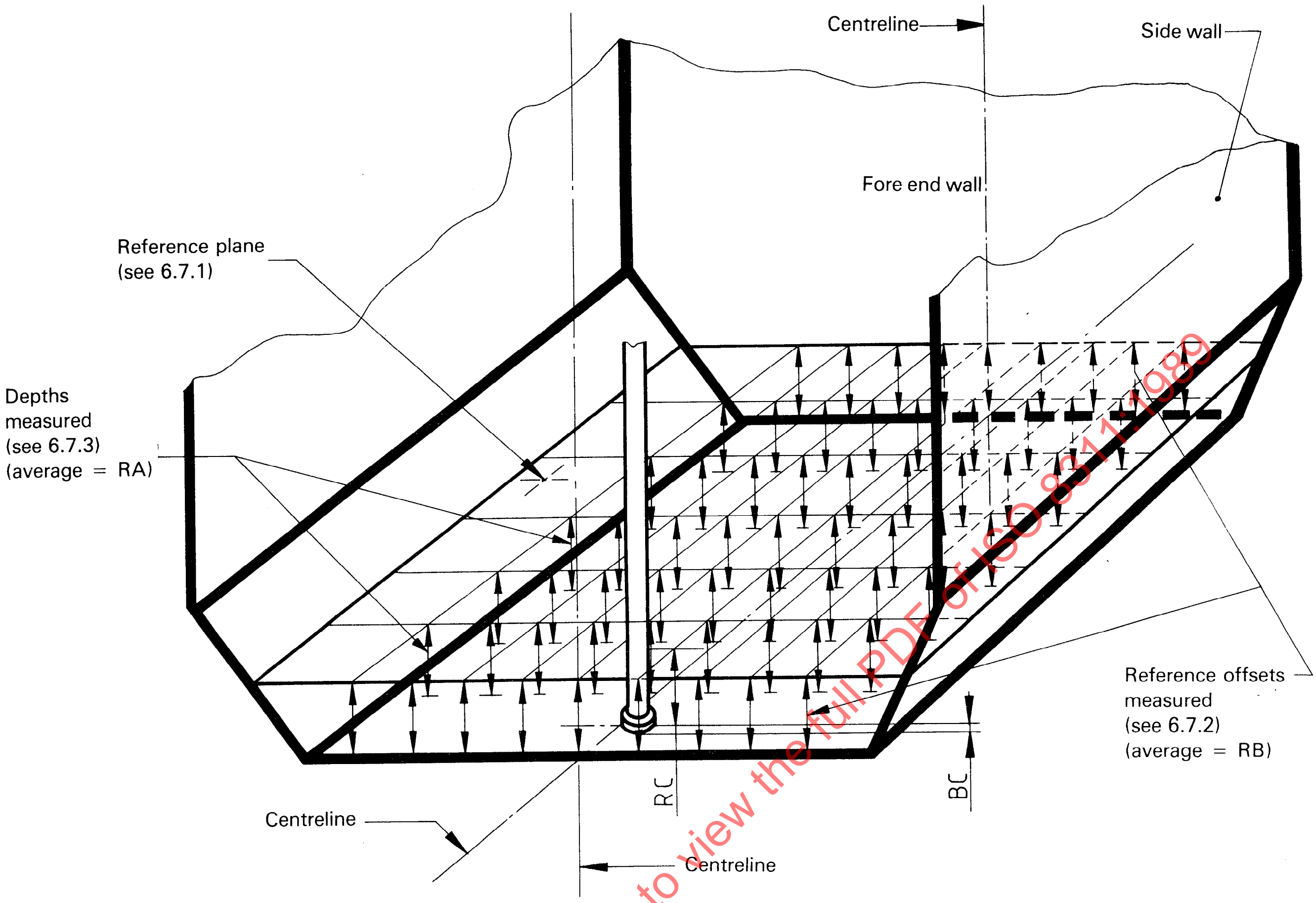

Figure 6 — Oblique projection view of tank bottom

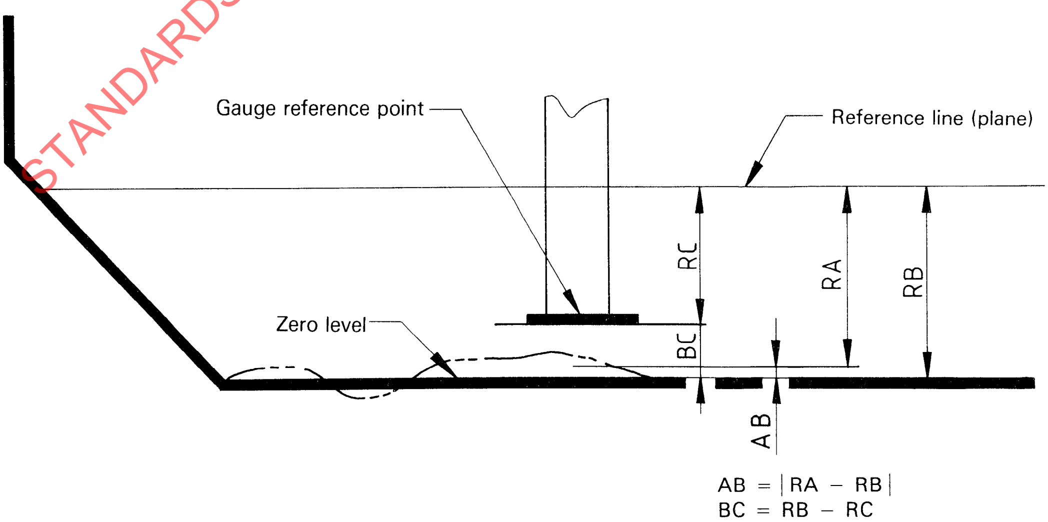

Figure 7 — Transverse section view of tank bottom

6.9 Temperature

The atmospheric temperature in the tank shall be measured at intervals of 2 h or less and, when this differs from the calibration temperature of the measuring tape (normally 20 °C), the measurements shall be corrected for the expansion or contraction of the tape. In the case of independent self-supporting tanks, the measurements shall be corrected for the contraction or expansion of the measuring tape and tank material using the equation

$$C = D \times (\alpha_s - \alpha_t) \times (T - t)$$

where

C is the total correction to the measured length for the effect of temperature;

D is the measured length;

α_s is the mean coefficient of linear expansion of the measuring tape;

α_t is the mean coefficient of linear expansion of the metal from which the tank is constructed;

T is the calibration temperature of the measuring tape;

t is the average temperature of the tank during measurement.

If C, calculated from this equation, is less than 0,5 mm, the correction may be ignored.

6.10 Deadwood

6.10.1 The volume of deadwood such as pipe columns, ladders, submerged pumps and any other structures in the tank shall be calculated from their dimensions. However, when the dimensions are not readily obtainable due to the complexity of the shape, the volume may be calculated from the mass of the item and the density of its material of construction, provided that the degree of uncertainty of the calculated volume is negligible with respect to the overall measurement accuracy.

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

6.10.3 The volume of membrane tongues shall be calculated from the dimensions of the tongues; the volume of corrugations or ridges of membrane plates shall be assessed in a laboratory using liquid calibration procedures with a typical section placed in a horizontal position.

6.10.4 For tank volume calibrations, the height of the deadwood above the gauge reference point and volume of the deadwood at that level shall be measured.

7 Calculation procedure

The tank calibration table shall be compiled in accordance with the principles set out in 7.1 and 7.2 and taking account of chamfer portions (see 7.3).

Corrections shall be made in accordance with 7.4 to 7.7.

7.1 Calculation of tank volume

The tank table shall be compiled by means of multiple horizontal areas calculated at each centimetre of height starting from the tank bottom as the zero level. Each horizontal area shall be obtained from the average length L and the average width w, taking into account the deadwood affecting the area.

7.2 Effect of bottom undulation

Any increase or decrease in volume arising from tank bottom undulation shall be adjusted in relation to the gauge reference point (see 6.7.5).

7.3 Area of chamfer portion

7.3.1 The area at an arbitrary height in the lower chamfer portion of the tank shall be calculated as a function of h_x (see figure 5) employing h_l (see 6.6.2.2) as well as horizontal areas at the top and the bottom of the chamfer.

7.3.2 For the main (middle) part of the tank, one and the same area may be used for calculation.

7.3.3 The area at an arbitrary height in the upper chamfer portion of the tank shall be calculated as a function of h_y (see figure 5) employing h_u (see 6.6.2.3) as well as horizontal areas at the top and the bottom of the chamfer.

7.4 Trim corrections

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 upright and in the condition of trim under consideration.

7.5 List corrections

List corrections shall be given as an addition to or subtraction from the apparent liquid level as 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 on even keel and in the list condition under consideration.

7.6 Combined trim and list corrections

The trim and list corrections compiled in accordance with 7.4 and 7.5 may be combined in one table.

7.7 Correction for tank shell expansion or contraction

Correction for the fact that the tank shell is contracted in the cryogenic loaded condition shall be made by means of the coefficient of expansion of the material of the tank shell, using the equation

$$F_v = 1 - 3\alpha_t (t_1 - t_2)$$

where

F_v is the correction factor for tank shell expansion or contraction;

α_t is the mean coefficient of linear expansion of the metal from which the tank is constructed;

t_1 is the certified reference temperature for the tank table;

t_2 is the actual temperature of the liquid or vapour.

This correction is unnecessary for membrane tanks where the construction or construction materials are such that thermal contraction effects on volume are insignificant.

8 Calibration tables

The calibration tables shall consist of the following report and tables.

8.1 Calibration report

The tank calibration report shall include the following :

a) name of calibrator;

b) place of calibration;

c) date of calibration;

d) tank configuration;

e) measurement method applied;

f) reference temperature of tank table;

g) average temperature of tank during measurement;

h) total capacity of tank, including dome capacity;

i) description of deadwood;

j) tank calibration accuracy;

k) method of use of main gauge table and correction tables;

l) any other information.

8.2 Main gauge table

The tank volume at the calibration reference temperature is tabulated against the gauge readings at suitable intervals. For ease of interpolation, a second column shall give the differences between the readings. A typical format for the gauge table is given in annex C by way of an example.

8.3 Trim correction table

The corrections to be applied to gauge readings are tabulated at suitable intervals of gauge reading for various conditions of trim both by head and by stern. A typical format for a trim correction table is given in annex D by way of an example.

8.4 List correction table

The corrections to be applied to gauge readings are tabulated at suitable intervals of gauge reading for conditions of list at 0,5° intervals. A typical format for a list correction table is given in annex E by way of an example.

8.5 Correction table for tank shell expansion or contraction

Corrections to be applied for the difference between the certified reference temperature of the main gauge table and the actual temperature of the liquid and vapour, to correct the volume of liquid and vapour at reference temperature to that at the observed temperature, are shown in annex F by way of an example. The error is negligible in the case of a membrane tank.

8.6 Correction for float-type level gauge

8.6.1 Correction table for difference in temperature

The gauge reading correction to allow for expansion of a measuring tape which is calibrated at a certified temperature shall be made using the temperature in the vapour phase of the tank.

8.6.2 Correction table for difference in density

For different density, e.g. different LNG densities or propane and butane, float immersion shall be corrected.

Annex A
(informative)

Safety precautions for work in membrane tanks

In addition to the general precautions (see ISO 7507-1) required for the ordinary tank calibration, the following should also be observed.

a) Watch your step, especially at the corners of the scaffolding. It is not uncommon for a plank to be moved from its position on the scaffolding when the tank wall is being lined with membranes.

b) In tanks constructed with a membrane containment system consisting of flat plates of high-nickel steel alloy welded to anchor plates projecting from the primary insulation barrier [1]), the edges of the anchor plates can be sharp. The use of protective gloves and helmets is especially advised.

c) Tank measuring is often carried out while membrane lining work is going on. Avoid looking at welding arcs in order to avoid eye damage.

d) Take care not to damage the tank walls, especially the membranes, with shoes, measuring equipment, tools, etc.

e) A mercury thermometer should not be used in an aluminium tank.

1) Such tanks are commonly referred to as "Gaz Transport" tanks.

Annex B
(informative)

Example of calculation of errors for a typical membrane tank

The causes of error are examined in detail for a membrane tank, but similar results are obtained for an independent prismatic tank.

Table B.1 — Errors in measuring lengths, widths and heights using a tape measure and rule
(approx. tank dimensions : 35 m × 35 m × 23 m)

	Maximum error	Nature of error
Inherent tape error (after correction for temperature effect by means of calibration certificate)	$\pm 10^{-4}$ of distance measured	Systematic
Tape error due to the uncertainty as to the ambient temperature (± 2 °C)	$\pm 2,4 \times 10^{-5}$ of distance measured	Can be systematic
Tape reading error (considered negligible at the D-loop)	± 1 mm	Random
Error due to incorrect positioning of the tape	± 2 mm	Random
Inherent rule error	negligible (0,2 mm)	Systematic
Rule error due to temperature effect	negligible (0,1 mm)	Systematic
Rule reading error	± 1 mm	Random
Error due to incorrect positioning of the rule	± 2 mm	Random
Error due to incorrect setting of the laser beam	± 2 mm	Systematic

Using the maximum error values in table B.1, the error in the total volume of the tank can be obtained from the theory of errors as follows :

The systematic error for horizontal (length and width) measurements $M_{s,h}$ is given by

$$M_{s,h}^2 = (1 \times 10^{-4})^2 + (2,4 \times 10^{-5})^2 + (2/35\,000)^2$$
$$= 1,38 \times 10^{-8}$$
$$\therefore M_{s,h} = 1,17 \times 10^{-4}$$

Assuming that horizontal measurements are made at 20 points, by means of a tape or rule, then the random error ($M_{r,h}$) is given by

$$M_{r,h}^2 = (1^2 + 2^2 + 1^2 + 2^2) \times 10^{-6}/35^2/20$$
$$= 1,83 \times 10^{-9}$$
$$\therefore M_{r,h} = 4,28 \times 10^{-5}$$

The uncertainty for length measurements (M_L) is given by

$$M_L^2 = M_{s,h}^2 + M_{r,h}^2$$
$$= 1,38 \times 10^{-8} + 1,83 \times 10^{-9}$$
$$\therefore M_L = 1,25 \times 10^{-4}$$

The uncertainty for width measurements (M_W) will have the same value.

Likewise, assuming that vertical measurements are made at 20 points, the uncertainty for vertical measurements (M_H) is calculated as follows :

$$M_{s,v}^2 = (1 \times 10^{-4})^2 + (2,4 \times 10^{-5})^2 + (2/23\,000)^2$$
$$= 1,81 \times 10^{-8}$$
$$\therefore M_{s,v} = 1,35 \times 10^{-4}$$
$$M_{r,v}^2 = (1^2 + 2^2 + 1^2 + 2^2) \times 10^{-6}/23^2/20$$
$$= 4,23 \times 10^{-9}$$
$$\therefore M_{r,v} = 6,50 \times 10^{-5}$$
$$M_H^2 = M_{s,v} + M_{r,v}^2$$
$$= 1,81 \times 10^{-8} + 4,23 \times 10^{-9}$$
$$\therefore M_H = 1,49 \times 10^{-4}$$

Error due to the volume located under the zero of the scale

This will depend on the precision of the levelling and of the determination of the trim and list of the ship at the time of measurement. This error in volume (ΔV) is estimated to correspond to a height of 10 mm.

$$\Delta V = 10^{-2} \times 35 \times 35 = 12,3 \text{ m}^3$$

For a total tank capacity of 24 000 m³, the relative error is therefore

$$\Delta V / V = 5,13 \times 10^{-4}$$

Error due to irregularities in the shape of the tank

Even though a large number of measurements are made, it is impossible to take into account all the irregularities in the tank. Comparison of the different values obtained, for a particular tank, from different sets of data shows that the maximum error introduced by these irregularities is approximately 5×10^{-4} of the volume.

Thus, the overall uncertainty for the volume of the tank in this example (M_V) is given by

$$M_V^2 = M_L^2 + M_W^2 + M_H^2 + (\Delta V/V)^2$$
$$= (1{,}25 \times 10^{-4})^2 + (1{,}25 \times 10^{-4})^2 + (1{,}49 \times 10^{-4})^2 + (5{,}13 \times 10^{-4})^2$$
$$= 3{,}17 \times 10^{-7}$$
$$\therefore M_V = 5{,}63 \times 10^{-4} \text{ (or 0,06 \%)}$$