BS EN ISO 8311:2013

BSI Standards Publication

Refrigerated hydrocarbon and non-petroleum based liquefied gaseous fuels — Calibration of membrane tanks and independent prismatic tanks in ships — Manual and internal electro-optical distance-ranging methods

bsi.

...making excellence a habit.™

National foreword

This British Standard is the UK implementation of EN ISO 8311:2013. It supersedes BS EN ISO 8311:1996 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee PTI/12, Petroleum Measurement and Sampling.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

ISBN 978 0 580 78234 3

ICS 75.180.30

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 December 2013.

Amendments issued since publication

Date	Text affected

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN ISO 8311

December 2013

ICS 75.180.30

Supersedes EN ISO 8311:1995

English Version

Refrigerated hydrocarbon and non-petroleum based liquefied gaseous fuels - Calibration of membrane tanks and independent prismatic tanks in ships - Manual and internal electro-optical distance-ranging methods (ISO 8311:2013)

Hydrocarbures réfrigérés et combustibles gazeux liquéfiés à base non pétrolière - Étalonnage des réservoirs à membrane et réservoirs pyramidaux - Méthodes manuelles et par mesurage électro-optique interne de la distance (ISO 8311:2013)

Gekühlte Kohlenwasserstoffe und verflüssigte, nicht auf Erdöl basierende gasförmige Brennstoffe - Kalibrierung von Membrantanks und unabhängigen Prismentanks in Schiffen - Manuelle Messung und Innenmessung nach dem elektrooptischen Distanzmessverfahren (ISO 8311:2013)

This European Standard was approved by CEN on 9 November 2013.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

Ref. No. EN ISO 8311:2013 E

Foreword

This document (EN ISO 8311:2013) has been prepared by Technical Committee ISO/TC 28 “Petroleum products and lubricants” in collaboration with Technical Committee CEN/TC 19 “Gaseous and liquid fuels, lubricants and related products of petroleum, synthetic and biological origin” the secretariat of which is held by NEN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by June 2014, and conflicting national standards shall be withdrawn at the latest by June 2014.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN ISO 8311:1995.

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Endorsement notice

The text of ISO 8311:2013 has been approved by CEN as EN ISO 8311:2013 without any modification.

Contents

Page

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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2. www.iso.org/directives

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received. www.iso.org/patents

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 28, *Petroleum products and lubricants*, Subcommittee SC 5, *Measurement of refrigerated hydrocarbon and non-petroleum based liquefied gaseous fuels*.

This second edition cancels and replaces the first edition (ISO 8311:1989), which has been technically revised.

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 requires special technology in ship design and construction to enable ship-borne transportation to be safe and economical.

Quantification of these cargoes in ships' tanks for custody transfer purposes has to be of a high order of accuracy. This International Standard (together with others in the group) specifies methods of internal measurement of ships' tanks, from which tank capacity tables can be derived.

This International Standard covers calibration techniques applicable to membrane type tanks, i.e. self-supporting independent tanks in which the containment system comprises a relatively thin membrane of either stainless steel or high-nickel steel alloy. This International Standard, with some modification, can also be applicable to the calibration of independent prismatic tanks.

Annex A gives uncertainty associated with the measurement of membrane tanks.

Annex B gives an example of a tank capacity table relating partial filling volume as a function of liquid level and Annexes C and D give examples of trim correction and list correction tables, respectively.

Refrigerated hydrocarbon and non-petroleum based liquefied gaseous fuels — Calibration of membrane tanks and independent prismatic tanks in ships — Manual and internal electro-optical distance-ranging methods

1 Scope

This International Standard specifies a method for the internal measurement of membrane 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 tank capacity table and correction tables to be used for the computation of cargo quantities. This International Standard, with some modification, can also be applicable to the calibration of independent prismatic tanks.

For the manual measurement of 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 the internal electro-optical distance-ranging (EODR) method, other safe means of access to the required measuring positions are intended to be used.

2 Normative references

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

ISO 7507-1:2003, *Petroleum and liquid petroleum products — Calibration of vertical cylindrical tanks — Part 1: Strapping method*

ISO 7507-4:2010, *Petroleum and liquid petroleum products — Calibration of vertical cylindrical tanks — Part 4: Internal electro-optical distance-ranging method*

IEC 60079-10-1, *Explosive atmospheres — Part 10-1: Classification of areas — Explosive gas atmospheres*

IEC 60079-10-2, *Explosive atmospheres — Part 10-2: Classification of areas — Combustible dust atmospheres*

IEC 60825-1, *Safety of laser products — Part 1: Equipment classification and requirements*

3 Terms and definitions

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

3.1
automatic tank gauge
ATG
automatic level gauge
ALG
instrument that continuously measures liquid height (dip or ullage) in storage tanks

3.2
chamfer
slanting surface connecting the walls of a tank with its top or bottom surface

3.3
deadwood
any tank fitting that affects the capacity of a tank

3.4
gauge reference point
point from which the liquid depth are measured

3.5
horizontal plane
any plane established parallel to the tank bottom

3.6
horizontal reference line
any horizontal line established by a string

Note 1 to entry: A calibration method using this line is adopted as an alternative to direct measurements, where it is considered impractical to take direct measurements.

3.7
list
transverse inclination of a ship

Note 1 to entry: It is expressed in degrees.

3.8
longitudinal line
line formed by a longitudinal plane crossing a horizontal plane

3.9
longitudinal plane
vertical plane running parallel to the centreline of the tank

3.10
measuring point
one of a series of points on the inside surface of the tank shell from/to which the distance is measured by a tape or a hand-held laser distance meter in case of manual method, or to which the slope distance, vertical angles and horizontal angles are measured by use of the electro-optical distance-ranging instrument

3.11
port
left-hand side of a ship facing forward

3.12
reference target point
fixed point clearly marked on the inside surface to the tank shell or a prism mounted on a tripod

3.13
section line
line formed by a section plane crossing a horizontal plane

3.14
section plane
plane parallel with the fore and aft end walls of a ship's tank

3.15
slope distance
distance measured from the electro-optical distance-ranging instrument to any measuring point or a reference target point

3.16
starboard
right-hand side of a ship facing forward

3.17
tank-calibration reference temperature
temperature at which the calibration of a tank has been calculated

3.18
tank capacity table
tank table
calibration table
capacity table
table showing the capacities of, or volumes in, a tank corresponding to various liquid levels measured from a reference point

3.19
trim
difference between the fore and aft draught of the vessel

Note 1 to entry: When the aft draught is greater than the forward draught, the vessel is said to be trimmed by the stern. When the aft draught is less than the forward draught, the vessel is said to be trimmed by the head.

3.20
uncertainty
U()
estimate characterizing the range of values within which the true value of a measurand lies

Note 1 to entry: Various types of uncertainty are defined in ISO/IEC Guide 98-3.

3.21
vertical line
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

4.1 General

This clause outlines the precautions to be taken during measurement. Utmost care and attention shall be exercised in taking measurements, and any unusual occurrence during the measuring work, which might affect the results, shall be recorded.

4.2 Ship's condition during calibration

The calibration methods described in this International Standard may be applied to ships whether afloat or in a dry dock. 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. Adjustments, manually or automatically shall be made to any measurement by optical level and EODR if the ship's attitude has changed.

4.3 Tank distortion

If unusual distortion is found in the tank, additional measurement shall be taken by the calibrator as considered necessary and sufficient. 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 can materially assist the interpretation of the recorded data.

4.4 Comparison with drawings

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; however, the tank capacity table shall be based on the actual measurements.

4.5 Measurements by measuring tape

When measurements are made with a measuring tape:

a) the tension specified in the tape calibration certificate shall be applied;

b) the measuring tape shall be supported 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;

c) take multiple measurements. If the first three consecutive measurements agree within the tolerances specified in d) below, take their mean as the measurement and their standard deviation as the standard uncertainty. If they do not agree within the tolerances specified in d) below, repeat the measurements until two standard deviations of the mean of all measurements is less than the half of the tolerance specified in d) below. Use the mean as the measurement and the standard deviation as the standard uncertainty. Use standard procedures to eliminate obvious outliers;

d) the following table shows the tolerances against the measurement distance:

Measurement	Tolerance within
Up to 25 m	2 mm
over 25 m	3 mm
for offset	0,5 mm

e) if the measurements have been interrupted, the last measurements 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.

4.6 Measurements by electro-optical distance-ranging (EODR) instrument

When measurements are carried out with an EODR instrument:

a) the electro-optical distance-ranging instrument shall be verified prior to calibration. The accuracy of the distance-ranging unit as well as the angular measuring unit shall be verified using the procedures given by ISO 7507-4:2010, Annex A;

b) the tank shall be free from vibration and air-borne dust particles. The floor of the tank should be as free as possible from debris, dust and scales;

c) lighting, when required, shall be placed within the tank so as not to interfere with the operation the EODR instrument;

d) the laser beam fitted to the EODR instrument shall be operated in conformity with IEC 60825-1. The hazards, if any, in the area in which the calibration is to be carried out shall be assessed in accordance with IEC 60079-10. The instrument to be used shall be declared (certified) as being safe for use in the area of operation.

4.7 Condition of membrane

Care shall be taken to ensure that the membrane is in contact with the supporting material. In some cases, it may be possible to ensure this contact by applying a vacuum to the space behind the membrane.

4.8 Safety precautions for work in membrane tanks

a) All regulations covering entry into hazardous areas shall be rigorously observed.

b) Before a tank which has been in use is entered, a safe-entry certificate issued in accordance with local or national regulations shall be obtained. All lines entering the tank shall be disconnected and blanked.

c) Hand lamps and other electric instruments shall be of a type approved for use in explosive atmospheres.

d) The safety of operating personnel shall be safeguarded by strict attention to the following.

  1) Ladders shall be inspected before use, and extendable ladders used only within their safe operating range. The footing for each ladder shall be level and firm, and all ladders shall be securely lashed in position before being used.

  2) Where painters' cradles or boatswains' (bo'suns') chairs are used, blocks, falls, ropes, etc., shall be tested before erection, and any item of questionable strength or condition shall be replaced. Every care shall be paid to the securing of the equipment and its operational use.

  3) If calibration cannot be carried out without the use of scaffoldings, properly constructed steel tube or timber scaffolding shall be erected. Loose bricks, drums, boxes, etc., shall not be used to form staging. Special attention shall be paid 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.

  4) Where appropriate, safety harnesses shall be worn by the calibrator working above ground level.

e) In some cases, edges of the anchor plates projecting from membrane can be sharp. The use of protective gloves and helmets is especially advised.

f) Care shall be taken not to damage the membranes with shoes, measuring equipment, etc.

5 Equipment

The equipment used to calibrate the tanks in accordance with this International Standard are intended to confirm to the relevant national or other standard.

5.1 Electro-optical distance-ranging (EODR) instrument, capable of achieving uncertainties of tank volumes acceptable in legal metrology. The angular measuring part of the instrument should have a resolution of equal to or better than $3{,}142 \times 10^{-6}$ rad (0,2 mgon), and the distance-measuring part of the instrument, which is to be used for direct determination of distances, should have a resolution of equal to or better than 1 mm.

The accuracy of EODR equipment can be affected by variations of temperature. The manufacturer's guidance should be followed.

5.2 Hand-held laser distance meter, which may be used, instead of measuring tape, to measure the distance. The hand-held laser distance meter should have a resolution of equal to or better than 1 mm.

5.3 Measuring tape, complying with the specifications for strapping tapes given in ISO 7507-1 or equivalent.

5.4 Automatic level, having an erect image and a magnification of × 20 or greater, capable of being focused to 1,5 m or less and with a spirit level sensitivity of 40 s of arc per 2 mm or less.

5.5 Rule, with graduations in centimetres and millimetres, used to measure deadwood, the offsets between the strings and the tank walls in the case of the manual method, etc. If a wooden rule is used, it shall be fitted with a brass ferrule at each end and shall be free of warp.

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

A mercury thermometer should not be used.

6 Determination of measuring points

The calibration of membrane tanks is basically the measurement of the tank length, width and height between known points. These measuring points 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 height 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 points at which measurements are to be taken shall be determined by the calibrator but shall not be more than 5 m apart.

Having determined the measuring points, 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. When measurements are made by an EODR, coordinates of the planned measuring points may be stored in the instrument instead of actually marking the lines or points on the tank inner walls.

7 Calibration by manual method

7.1 General

In the manual method, measurements of the distances between opposite walls of a tank shall be taken by tensioning the tape as specified on the tape certificate. A hand-held laser distance meter, in place of a tape, may be used for the direct measurements.

The lengths of the tanks shall be measured along all the longitudinal lines at each level of the horizontal planes in accordance with 7.2.

The widths of the tanks shall be measured along all the section lines set in each horizontal plane in accordance with 7.3.

The total heights, upper chamfer heights and side wall heights shall be measured and from these lower chamfer heights shall be calculated in accordance with 7.4.

Annex A gives uncertainty associated with the measurement of membrane tanks with the manual method.

7.2 Tank length measurement

7.2.1 Length measurement on the bottom plate

Measure the distances between the fore and aft end walls along all the longitudinal lines marked on the bottom plate with a measuring tape stretched thereon. The average length on the bottom plate is calculated using Formula (1):

$$L_\text{l} = \frac{1}{n}\sum_{i=1}^{n} L_\text{l,i} \tag{1}$$

where

$L_\text{l,i}$	is the length of a longitudinal line on the bottom plate;
L_l	is the average length of the bottom plate;
n	is the number of longitudinal lines on the bottom plate.

7.2.2 Length measurement on the top plate

Measure the distances on the top plate in a manner similar to that for the bottom plate (see 7.2.1). Care shall be taken to keep the measuring tape in contact with the top plate. The average length on the top plate is calculated using Formula (2):

$$L_\text{u} = \frac{1}{n}\sum_{i=1}^{n} L_\text{u,i} \tag{2}$$

where

$L_\text{u,i}$	is the length of a longitudinal line on the top plate;
L_u	is the average length of the top plate;
n	is the number of longitudinal lines on the top plate.

7.2.3 Length measurement in an intermediate horizontal plane

To avoid inaccurate measurement due to excessive sagging of the measuring tape, apply the horizontal reference line method using a string line.

As shown in Figure 1, lengths in these imaginary planes can be obtained by applying offset corrections at both ends, a_2, a_3 ... $a_\text{n-1}$ and b_2, b_3 ... $b_\text{n-1}$, to the length measured directly on the side wall. In practice, carry out the following.

a) Mark P_1 and P_2, S_1 and S_2, on both side walls at equal distances from the end walls. Measure the length (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.

b) 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.

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

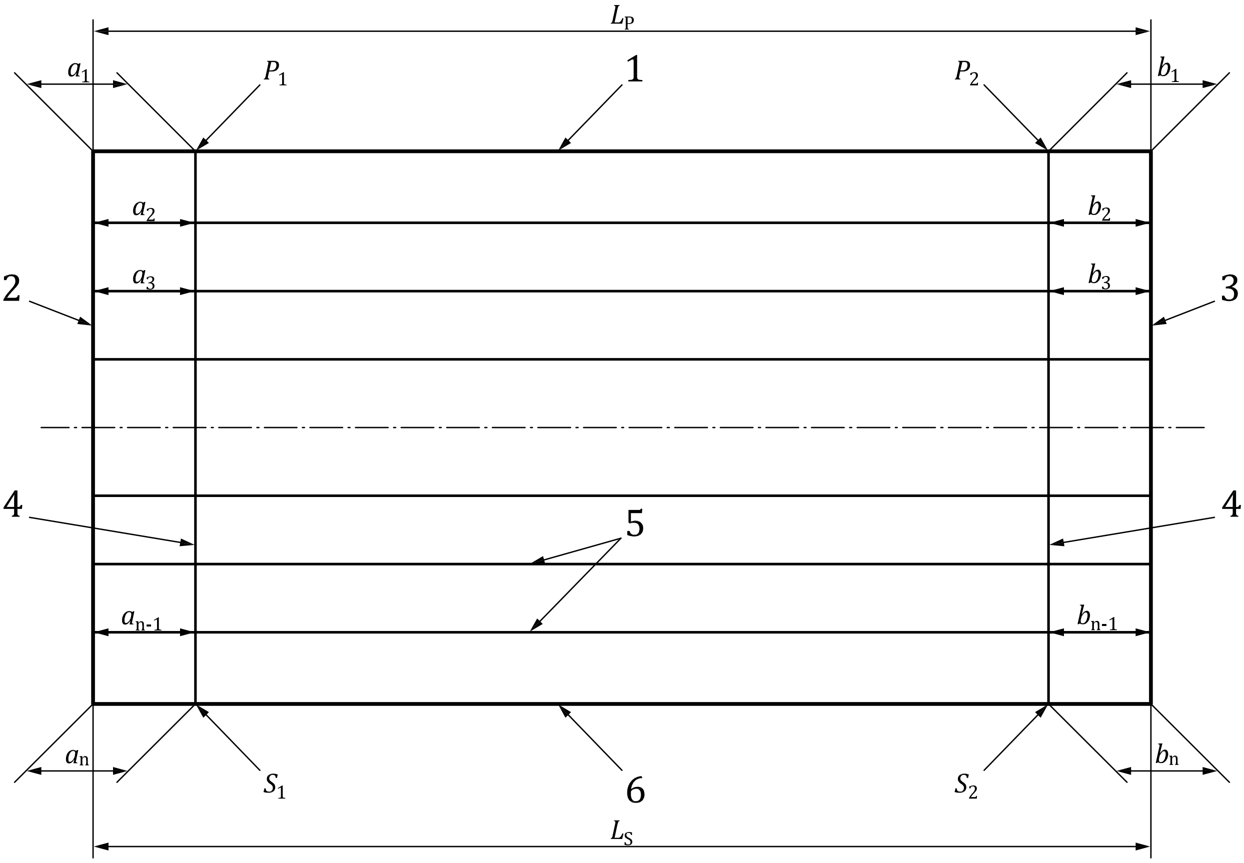
The average length of an intermediate horizontal plane, $L_{m,p}$ is calculated using Formula (3):

$$L_{m,p} = \frac{L_p + L_s - (a_1 + a_n + b_1 + b_n)}{2} + \frac{\sum_{i=1}^{n}(a_i + b_i)}{n} \quad (3)$$

The averaged length of intermediate part, L_m, is calculated using Formula (4):

$$L_m = \frac{1}{p-2}\sum_{j=2}^{p-1} L_{m,p} \quad (4)$$

where p is the number of intermediate planes.



Key

1	port side wall	4	string line
2	aft end wall	5	longitudinal lines
3	fore end wall	6	starboard side wall
L_P	length of port side wall		
L_S	length of starboard side wall		
P_1, P_2, S_1, S_2	markings on both side walls at equal distances from end walls		
a_1, a_2 … a_n and b_1, b_2 … b_n	offsets between strings and end walls		

Figure 1 — Plan view of an intermediate horizontal plane

7.2.4 Tank length

The tank length, L, is calculated from L_u, L_m and L_l:

$$L = \frac{L_m \times (p-2) + L_u + L_l}{p} \tag{5}$$

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

7.3 Tank width measurement

7.3.1 Width measurement on the bottom plate

Measure distances between side walls along all the section lines marked on the bottom plate with a measuring tape stretched thereon. The average width on the bottom plate is calculated using Formula (6):

$$w_l = \frac{1}{n}\sum_{i=1}^{n} w_{l,i} \tag{6}$$

where

$w_{l,i}$	is the width of a section line on the bottom plate;
w_l	is the average width of the bottom plate;
n	is the number of section lines on the bottom plate.

7.3.2 Width measurement on the top plate

Measure distances on the top plate in a manner similar to that for the bottom plate (see 7.3.1). Care shall be taken to keep the measuring tape in contact with the top plate. The average width on the top plate is calculated using Formula (7):

$$w_u = \frac{1}{n}\sum_{i=1}^{n} w_{u,i} \tag{7}$$

where

$w_{u,i}$	is the width of a section line on the top plate;
w_u	is the average width of the top plate;
n	is the number of section lines on the top plate.

7.3.3 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 as shown in Figure 2.

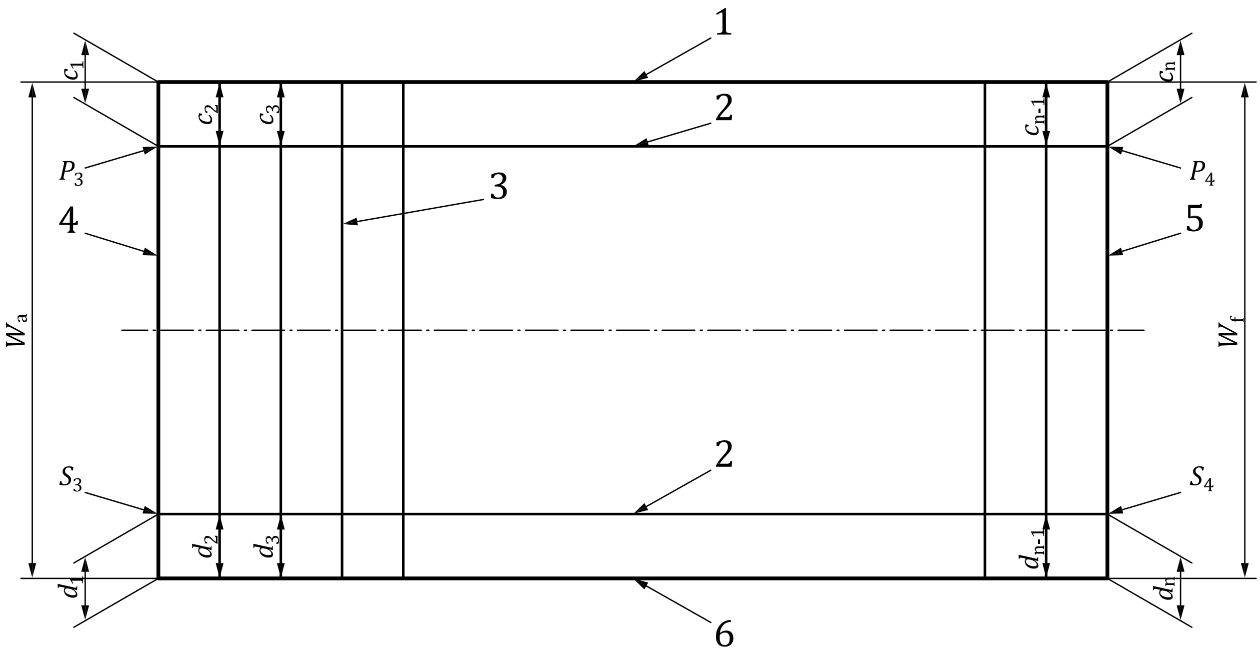
The average width of an intermediate horizontal plane, $w_{m,p}$ is calculated using Formula (8):

$$w_{m,p} = \frac{w_f + w_a - (c_1 + c_n + d_1 + d_n)}{2} + \frac{\sum_{i=1}^{n}(c_i + d_i)}{n} \quad (8)$$

The average of the averaged length of intermediate part, w_m, is calculated using Formula (9):

$$w_m = \frac{1}{p-2}\sum_{j=2}^{p-1} w_{m,p} \quad (9)$$

where p is the number of intermediate planes.



Key

1	port side wall
2	string line
3	section line
4	aft end wall
5	fore end wall
6	starboard side wall
w_a	width of aft end wall
w_f	width of fore end wall
P_3, P_4, S_3, S_4	markings on both end walls at equal distances from side walls
$C_1, C_2 ... C_n$ and $d_1, d_2 ... d_n$	offsets between strings and side walls

Figure 2 — Plan view of an intermediate horizontal plane

Alternatively, another formula of equal or better accuracy may be used when it is considered adequate. For example, side wall may be approximated by a linear regression line of the x- and y-coordinates of each measuring point on the side wall (see 8.3.3).

7.3.4 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 7.3.3, as shown in Figure 3.

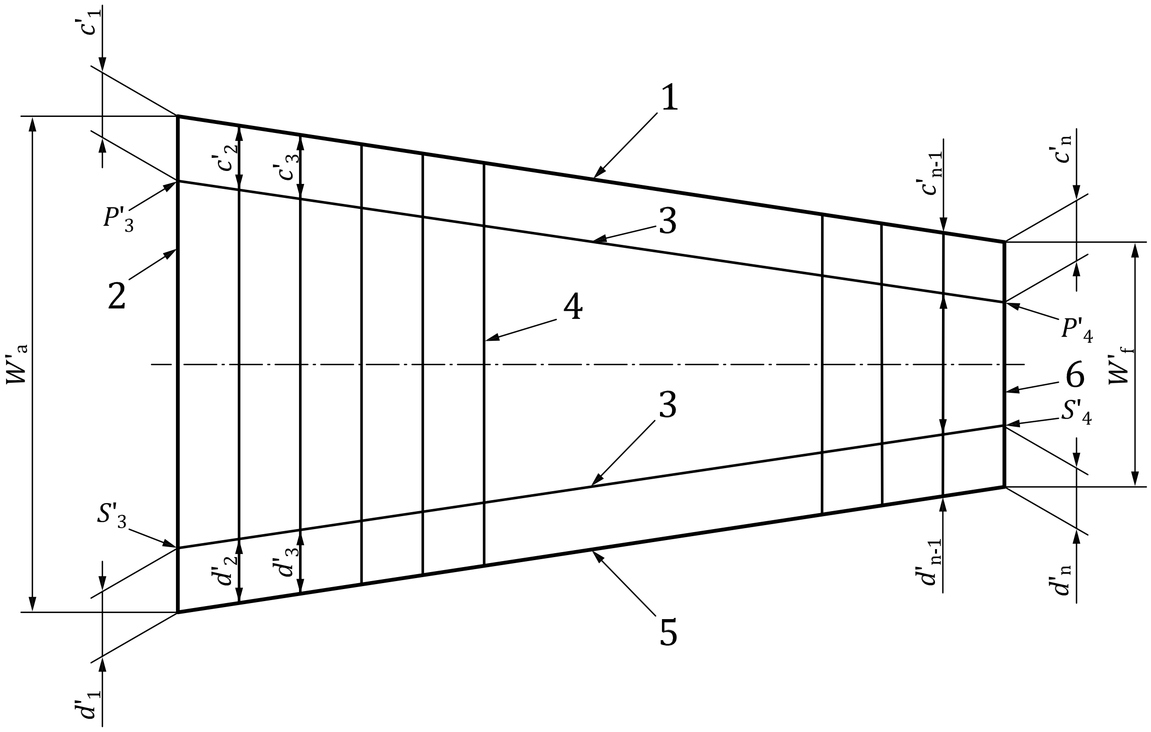
The average width, w_f, of the fore end wall and the average width, w_a, of the aft end wall are calculated using Formulae (10) and (11).

$$w_f = w'_f - \frac{c'_1 + c'_n + d'_1 + d'_n}{2} + \frac{\sum_{i=1}^{n} (c'_i + d'_i)}{n} \quad (10)$$

and

$$w_a = w'_a - \frac{c'_1 + c'_n + d'_1 + d'_n}{2} + \frac{\sum_{i=1}^{n} (c'_i + d'_i)}{n} \quad (11)$$

where c'_1, c'_2... c'_n and d'_1, d'_2 ... d'_n are the offsets between strings and side walls.

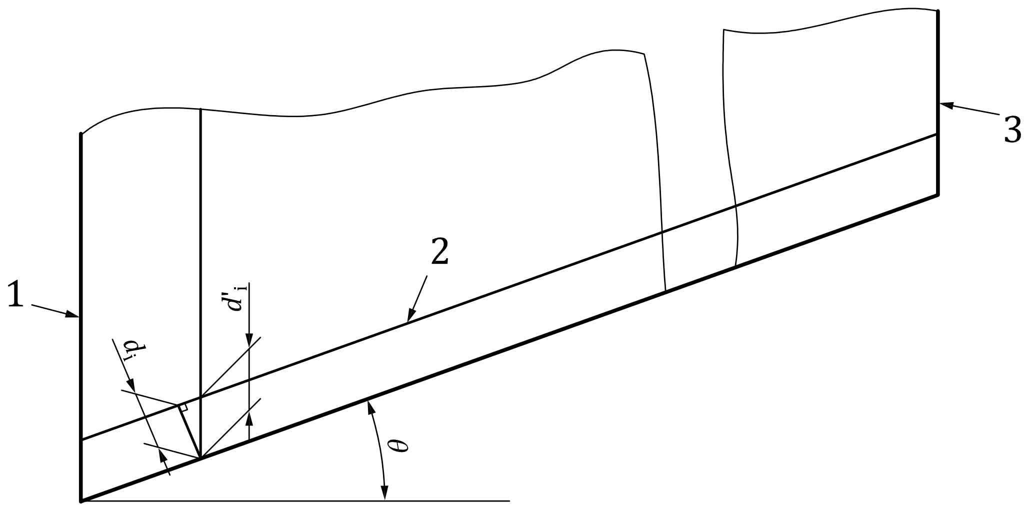


Key

1	port side wall	4	section line
2	aft end wall	5	starboard side wall
3	string line	6	fore end wall
w'_a	width of aft end wall		
w'_f	width of fore end wall		
P'_3, P'_4, S'_3, S'_4	markings on both end walls at equal distances from side walls		
c'_1, c'_2... c'_n and d'_1, d'_2... d'_n	offsets between strings and side walls		

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

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 ... c'_n, d'_1 ... 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 $d'_1 = d_i /\cos\theta$ where θ is the angle between the side wall and the plane at right angles to the fore and aft walls.



Key

1	aft end wall
2	string line
3	fore end wall
d_i	offsets at right angles to side wall
d'_i	parallel to fore and aft walls by a formula, $d_i^{'} = \dfrac{d_i}{\cos\theta}$
θ	angle between side wall and plane at right angles to fore and aft walls, taken from the drawings

Figure 4 — Correction of offsets

Alternatively, another formula of equal or better accuracy may be used when it is considered adequate in the light of the shape of the tank. For example, side wall may be approximated by a linear regression line of the *x*- and *y*-coordinates of each measuring point on the side wall and the width calculated as distances between intersections of the fitted lines with the tank end walls (see 8.3.3).

7.4 Tank height measurement

7.4.1 Measurement of total height

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, i.e. along all vertical lines, and calculate the arithmetic mean using Formula (12):

$$h_t = \frac{1}{n}\sum_{i=1}^{n} h_{t,i} \qquad (12)$$

where

$h_{t,i}$ is the total height along a vertical line;

h_t is the average total height;

n is the number of vertical lines.

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. For example, the arithmetic mean may be the weighted average in case of trapezoidal tanks.

7.4.2 Measurement of side wall height

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 arithmetic mean using Formula (13):

$$h_m = \frac{1}{n}\sum_{i=1}^{n} h_{m,i} \tag{13}$$

where

$h_{m,i}$	is the side wall height along a vertical line;
h_m	is the average side wall height;
n	is the number of vertical lines.

7.4.3 Measurement of lower chamfer height

a) Set a reference plane with an optical level 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 plane and the bottom plate along all the vertical lines, and take another measurement d_2 between the reference plane and the top of the lower chamfer at the corners of the tank.

c) The height of the lower chamfer is calculated using Formulae (14) and (15):

$$h_{l,i} = d_{1,i} - d_{2,i} \tag{14}$$

$$h_l = \frac{1}{n}\sum_{i=1}^{n} h_{l,i} \tag{15}$$

where

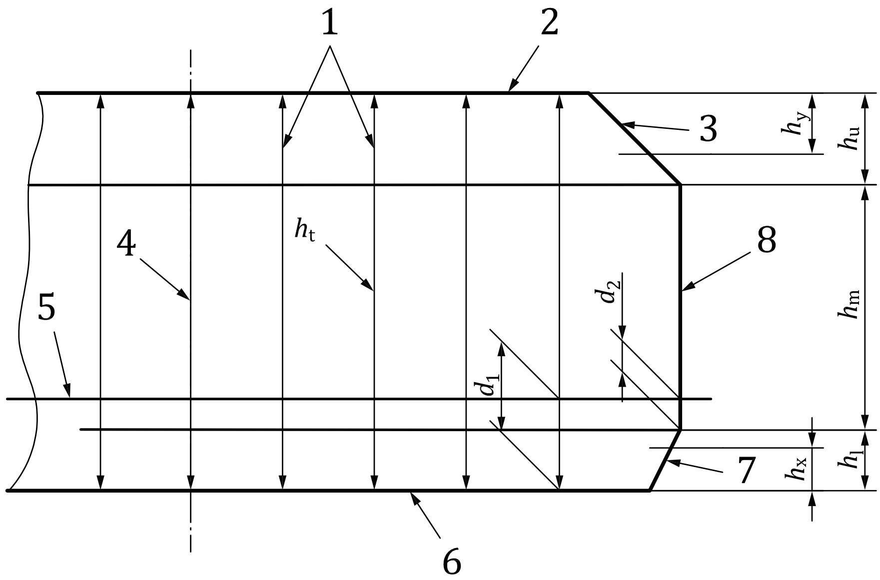
$h_{l,i}$	is the lower chamfer height along a vertical line;
h_l	is the average lower chamfer height;
n	is the number of vertical lines.

7.4.4 Height of upper chamfer

After heights h_t, h_m and h_l have been obtained, the height of the upper chamfer h_u is calculated using Formula (16):

$$h_u = h_t - h_m - h_l \tag{16}$$

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



Key

1 vertical lines

2 tank top

3 upper chamfer

4 centreline

5 horizontal reference line

6 tank bottom

7 lower chamfer

8 side wall

d_1 height between the horizontal reference line and bottom plate along the vertical lines

d_2 height between the horizontal reference line and top of the lower chamfer at the corners of a tank

h_l lower chamfer height

h_m side wall height

h_t total height

h_u height of upper chamfer

h_x arbitrary height in the lower chamfer portion

h_y arbitrary height in the upper chamfer portion

Figure 5 — Transverse section view

7.5 Measurement of bottom undulation and gauge reference height

7.5.1 Set reference lines by an optical level with some clearance from the tank bottom. Figure 6 shows an expanded transverse section of the tank bottom to illustrate the measurements used in the assessment of bottom undulation.

7.5.2 Measure the 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*.

7.5.3 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*.

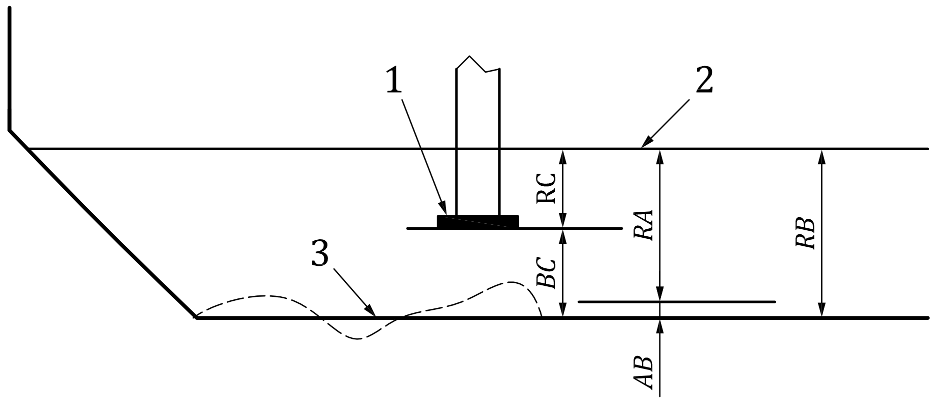
7.5.4 Calculate the numerical difference *AB* between the average reference offset *RB* and the average depth measurement *RA* using Formula (17):

$$AB = |RA - RB| \tag{17}$$

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.

7.5.5 Measure the depth *RC* between the reference plane and gauge reference point (see Figure 6). The clearance *BC* of the gauge reference point in relation to the tank bottom is then calculated using Formula (18):

$$BC = RB - RC \tag{18}$$



Key

1 gauge reference point

2 reference plane

3 zero level

Figure 6 — Transverse section view of tank bottom

7.6 Correction for 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, the measurements shall be corrected for the expansion or contraction of the tape. In the case of independent prismatic tanks, the measurements shall be corrected for the contraction or expansion of the measuring tape and tank material using Formula (19):

$$C = D \times (\alpha_s - \alpha_t) \times (T - t) \quad (19)$$

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 is less than 0,5 mm, the correction may be ignored.

8 Calibration by electro-optical distance-ranging (EODR) method

8.1 General

In EODR method, average distances between opposite walls of a tank shall be calculated from the coordinates of the measuring points on these walls.

Note that as alternatives to the formulae in 8.3.2, 8.3.3 and 8.3.4, other methods of equal or better uncertainties, e.g. least square method, may be used to calculate tank dimensions.

8.2 Setting up of EODR instrument

The EODR instrument shall be set up with the following steps.

a) The number and locations of the instrument stations shall be determined in order not to exceed incidence-angle limitations of equipment. If more than one station is necessary, survey traverse techniques should be used to move from one station to the other.

b) The instrument shall be set up with care, particularly in the horizontal and vertical axes and according to the procedure and instructions given by the manufacturer.

c) The instrument shall be set up so as to be stable and free from external vibrations. If necessary, the tank shell, in the vicinity of the instrument, shall be made firm and steady by placing heavy weights in the area. The legs of the tripod on which the instrument is mounted may be steadied using suitable devices to prevent slippage on the tank bottom.

d) The sighting lines from the instrument to the tank shell shall not be obstructed.

e) At least the minimum settling time recommended by the manufacturer should be allowed before the instrument is used.

f) If the distance-measurement part is separate, parallax adjustment should be made at the start. The distance optical beam and laser beams should be adjusted after temperature equilibrium, to ensure zero parallax, and then locked in position.

g) Select two reference target points. The reference target points should be approximately 100 gon apart and preferably on the same horizontal plane as this instrument.

h) Measure and record the horizontal angle, the vertical angle and the slope distance to each reference target point. Two successive readings, at each point, shall be taken and they shall agree within the following tolerance. Compute and record the average angles and distance to each point.

   1) the **slope distance** to each reference target point at the beginning and end of the calibration shall be within ± 2mm.

   2) the **horizontal and vertical angles** to each reference target point at the beginning and end of the calibration shall be within ± 0,01 gon.

8.3 Calibration procedure

8.3.1 General

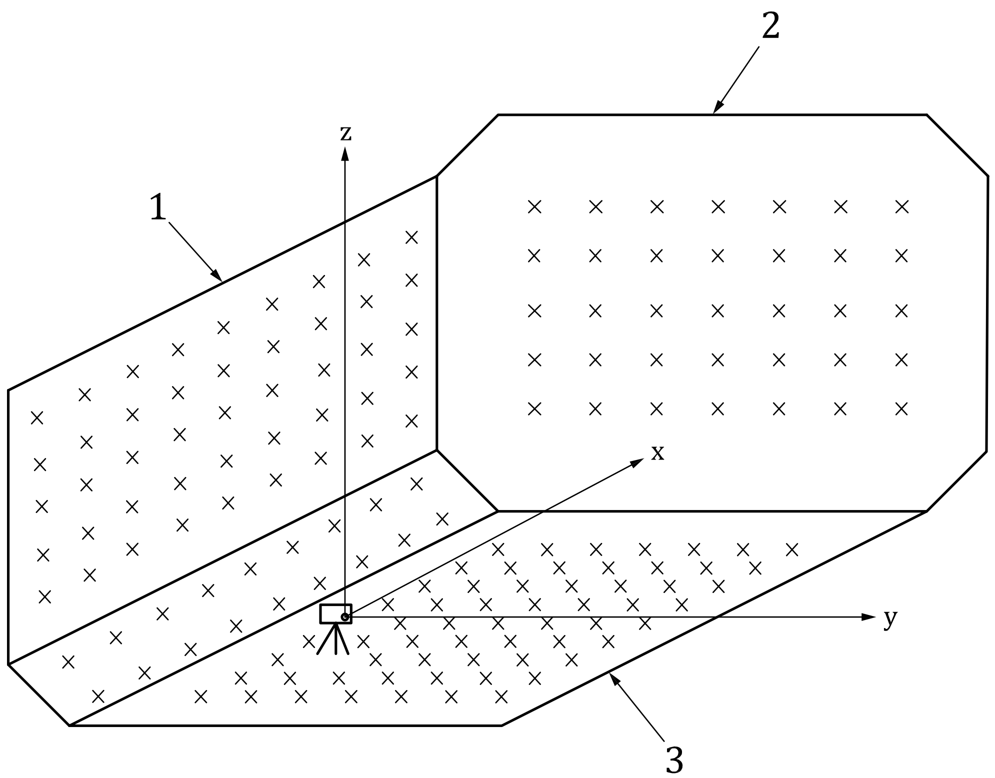
The tanks shall be calibrated with the following steps.

a) Measure the horizontal and vertical angles and the slope distance to each measuring point on a surface and express the position of the targets as a point in the Cartesian coordinate (see Figure 7).

b) After all measurements from one measurement station are completed, repeat the measurements to the reference target points.

c) If the repeated horizontal and vertical angles and slope distances to each reference target point do not agree with measurements taken in 8.2 h), within the tolerances given in that paragraph, determine the reasons for such disagreement, eliminate the cause and repeat the calibration procedure.

d) Carry out all measurements without interruption.



Key

1 side plate

2 end plate

3 bottom plate

Figure 7 — Measuring points

8.3.2 Determination of length

The positions of the fore end wall and aft end wall on the x-axis are determined by averaging the x-coordinate of the measuring points on the respective walls. The length of the tank (L) is given by adding the average of $x_{(aft)}$ and the average of $x_{(fore)}$ i.e.:

$$L = \left| \frac{\sum x_{n(fore)}}{n_{(fore)}} \right| + \left| \frac{\sum x_{n(aft)}}{n_{(aft)}} \right| \tag{20}$$

NOTE $X_{n(fore)}$ and $X_{n(aft)}$ are absolute values of the EODR measurements.

8.3.3 Determination of width

The position of the port and starboard side walls on the y-axis are determined by the averaging the y-coordinate of the measuring points on the respective walls. The width intermediated horizontal plane (w) is given by adding the average of $y_{(port)}$ and the average of $y_{(starboard)}$ i.e.:

$$w = \left| \frac{\sum y_{n(starboard)}}{n_{(starboard)}} \right| + \left| \frac{\sum y_{n(port)}}{n_{(port)}} \right| \tag{21}$$

NOTE $Y_{n(starboard)}$ and $Y_{n(port)}$ are absolute values of the EODR measurements.

In case the horizontal plane of tank is trapezoidal, side wall is assumed as the linear regression line of the x- and y -coordinates of each measuring point on the side wall, i.e.:

$$x = ay + b$$

$$a = \frac{\sum_{i=1}^{n} \left(y_i - \overline{Y} \right) \left(x_i - \overline{X} \right)}{\sum_{i=1}^{n} \left(y_i - \overline{Y} \right)^2}$$

$$b = \overline{X} - a\overline{Y} \tag{22}$$

8.3.4 Determination of height

The position of the bottom and top plates on the z-axis are determined by averaging the z-coordinate of the measuring points on the respective plates. The total height of tank (h_t) is given by adding the average of $z_{(bottom)}$ from the average of $z_{(top)}$ i.e.:

$$h_t = \frac{\sum z_{n(top)}}{n_{(top)}} + \frac{\sum z_{n(bottom)}}{n_{(bottom)}} \tag{23}$$

NOTE $Z_{n(top)}$ and $Z_{n(bottom)}$ are absolute values of the EODR measurements.

Chamfer is assumed as the linear regression line (Z) of the y- and z -coordinates of each measuring points on the chamfer part.

The height of each side of the octagon is given by a set of coordinates thereby $w_{f(top)}$, $w_{a(bottom)}$, $h_{u(upper)}$, $h_{m(middle)}$ and $h_{l(lower)}$ are determined. The heights of each pair of chamfers may be averaged.

9 Additional measurements

9.1 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.

9.2 Deadwood

9.2.1 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 uncertainty of the calculated volume is negligible with respect to the overall measurement accuracy. For each item of deadwood, the volume shall be calculated as function of height above the gauge reference point.

9.2.2 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.

9.2.3 The volume of membrane tongues or corrugations shall be calculated from the drawings.

9.2.4 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.

10 Calculation

10.1 General

The tank capacity table shall be compiled in accordance with the principles set out in 10.2 and 10.3 and taking account of chamfer portions (see 10.4).

The tank volume (see Figure 8) is given by Formula (24):

$$V = \left[\left(\frac{w_\mathrm{u} + w_\mathrm{m}}{2} \times h_\mathrm{u} \right) + w_\mathrm{m} \times h_\mathrm{m} + \left(\frac{w_\mathrm{m} + w_\mathrm{l}}{2} \times h_\mathrm{l} \right) \right] \times L \qquad (24)$$

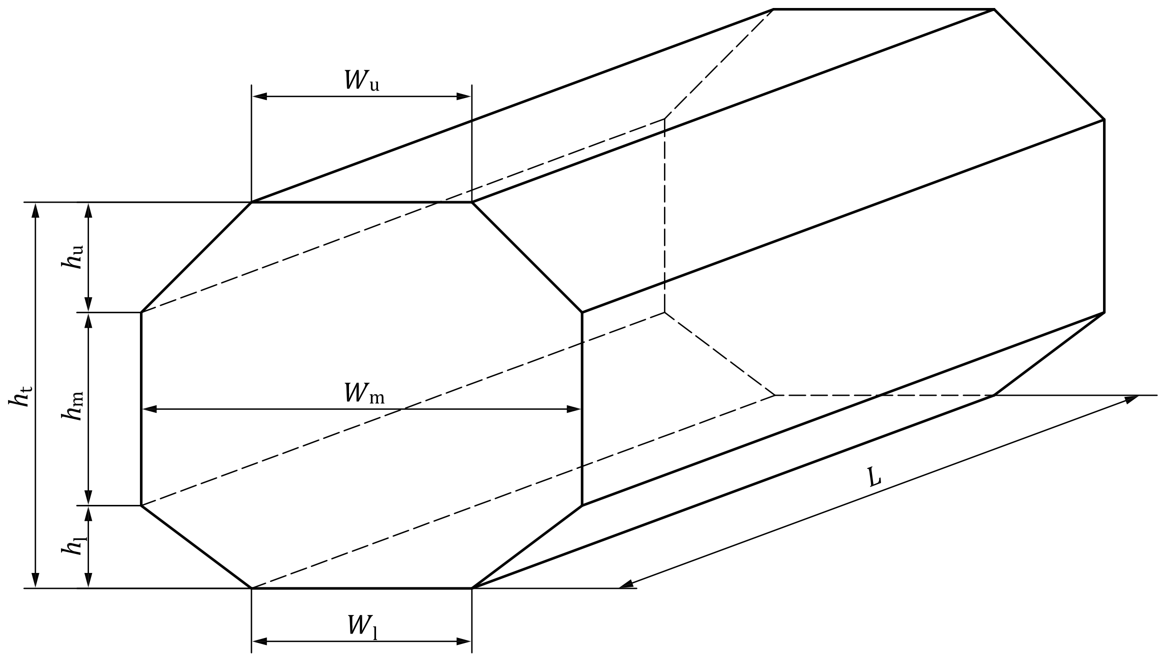


Figure 8 — Elements of tank volume calculation

Corrections shall be made in accordance with 10.5 to 10.8.

10.2 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.

10.3 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 7.5.5).

10.4 Area of chamfer portion

10.4.1 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 7.4.3 and 8.3.4) as well as horizontal areas at the top and the bottom of the chamfer.

$$A_x = A_l + \left(A_m - A_l\right) \times \frac{h_x}{h_l} \tag{25}$$

where

A_x	is the area at an arbitrary height in the lower chamfer portion;
A_m	is the horizontal area at the top of the lower chamfer;
A_l	is the horizontal area at the bottom of the lower chamfer;
h_x	is the arbitrary height in the lower chamfer;
h_l	is the height of lower chamfer.

10.4.2 For the middle part of the tank, one and the same area may be used for calculation.

10.4.3 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 7.4.4 and 8.3.4) as well as horizontal areas at the top and the bottom of the chamfer.

$$A_y = A_m - (A_m - A_u) \times \frac{h_y}{h_u} \tag{26}$$

where

A_y	is the area at an arbitrary height in the upper chamfer portion;
A_m	is the horizontal area at the bottom of the upper chamfer;
A_u	is the horizontal area at the top of the upper chamfer;
h_y	is the arbitrary height in the upper chamfer;
h_u	is the height of upper chamfer.

10.5 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.

10.6 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.

10.7 Combined trim and list corrections

The trim and list corrections compiled in accordance with 10.5 and 10.6 may be combined in one table.

10.8 Correction for tank shell expansion or contraction

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

In case of independent prismatic tank, correction of tank volume for cryogenic loaded condition shall be made by means of the coefficient of expansion of the material of the tank shell, using Formula (27):

$$F_v = 1 - 3\alpha_t(t_1 - t_2) \quad (27)$$

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 tank-calibration reference temperature for the tank table;
t_2	is the actual temperature of the liquid or vapour.

11 Report and tables

The following report and tables shall be bound into a book and kept on board the ship. In addition to the hard copies, the tables may be electronically stored in the ship's custody transfer measurement system.

a) The calibration report includes:

   1) name of calibrator;

   2) place of calibration;

   3) date of calibration;

   4) tank dimensions;

   5) measurement method;

   6) tank-calibration reference temperature;

   7) total tank capacity;

   8) uncertainty of measurement;

   9) directions for use of tables.

b) Tank capacity is tabulated against the gauge readings at suitable intervals. A second column may give the differences between the readings. An example of a tank capacity table is given in Annex B.

c) Trim correction tables 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. An example of a trim correction table is given in Annex C.

d) List correction tables to be applied to gauge readings are tabulated at suitable intervals of gauge reading for conditions of list at 0,5° intervals. An example of a list correction table is given in Annex D.

e) In the case of independent prismatic tanks, correction table for expansion/contraction of tank shell is to be applied for the difference between the tank-calibration reference temperature of the tank capacity table and the actual temperature of the liquid and vapour.

f) Thermal correction tables for ATG, which provide corrections for any effect of changes in temperature, pressure or cargo properties of the respective cargo components (see ISO 18132-1 and ISO 18132-3).

12 Recalibration

Tanks should be recalibrated as required by national regulations or if the calibration becomes suspect for any reason, e.g. deformation or modification. Change of ATGs may require reproduction of relevant correction tables.

Annex A
(informative)

Uncertainty associated with tank calibration

A.1 General

This annex describes calculations of uncertainty associated with tank calibration by the manual method (see Clause 7).

A.2 Symbols

a_1	Offset between string and aft end wall on port side wall, by rule	m
a_i	Offset between string and aft end wall, by rule	m
a_n	Offset between string and aft end wall on starboard side wall, by rule	m
A_{rule}	Uncertainty of rule	m
A_{tape}	Uncertainty of steel tape	m
A_{temp}	Uncertainty of thermometer	°C
b_1	Offset between string and fore end wall on port side wall, by rule	m
b_i	Offset between string and fore end wall, by rule	m
b_n	Offset between string and fore end wall on starboard side wall, by rule	m
c_i	Sensitivity coefficient	–
C_{ten}	Tension coefficient of steel tape	/N
D	Distance measured by steel tape	m
d	Distance measured by rule	m
D_{dir}	Distance obtained by direct method	m
d_i	Measurand by rule	m
D_i	Measurand by steel tape	m
D_{ref}	Distance obtained by reference line method	m
E_{ten}	Ratio of tension difference against T_{std}	–
h_i	Measurand of height	m
h_l	Height of lower chamfer	m
h_m	Height of side wall	m
h_t	Total tank height	m
h_u	Height of upper chamfer	m

k	Coverage factor	–
L	Tank length	m
L_i	Measurand of length	m
L_l	Averaged tank length on bottom plate	m
L_m	Averaged tank length of intermediate part	m
L_p	Tank length on port side wall measured by steel tape	m
L_{ref}	Tank length obtained by reference line method	m
L_s	Tank length on starboard side wall by steel tape	m
L_u	Averaged tank length on top plate	m
n	Number of measurement	–
P	Horizontal plane	–
R_{rule}	Resolution of rule	m
R_{tape}	Resolution of steel tape	m
T_{std}	Standard tension of steel tape	N
$u(D_{cal})$	Standard uncertainty of steel tape due to calibration	m
$u(d_{cal})$	Standard uncertainty of rule due to calibration	m
$u(D_{dev})$	Standard uncertainty of steel tape due to measurement deviation	m
$u(D_i)$	Standard uncertainty of steel tape due to a component $_i$.	m
$u(d_i)$	Standard uncertainty of rule due to a component $_i$.	m
$u(d_{dev})$	Standard uncertainty of rule due to measurement deviation	m
$u(D_{res})$	Standard uncertainty of steel tape due to resolution	m
$u(d_{res})$	Standard uncertainty of rule due to resolution	m
$u(D_{ten})$	Standard uncertainty of steel tape due to tension	m
$u(D_{th})$	Standard uncertainty of rule due to temperature	m
$u(d_{th})$	Standard uncertainty of steel tape due to temperature	m
$u(D_{va})$	Standard uncertainty of steel tape due to variation	m
$u(d_{va})$	Standard uncertainty of rule due to variation	m
$u(x_i)$	Standard uncertainty of a component x_i	–
$u_c(D)$	Combined uncertainty of steel tape	–
$u_c(d)$	Combined uncertainty of rule	–
$u_c(y)$	Combined uncertainty of y	–
$u_r(x)$	Standard uncertainty of x sorted with random component	–

$u_s(x)$	Standard uncertainty of *x* sorted with systematic component	–
V	Tank volume	m^3
V_D	Estimated variation of steel tape measurement	m
V_d	Estimated variation of rule measurement	m
w_i	Average width of a horizontal plane P_j	m
w_l	Tank width at lower part	m
w_m	Tank width at middle part	m
w_u	Tank width at upper part	m
δ	Deviation from the reference point	m
α	Temperature coefficient of steel tape	/°C
θ	Deviation in angle	°

A.3 Determination of combined standard uncertainty

The combined standard uncertainty, $u_c(y)$, is given by Formula (A.1) where all input quantities are independent.

$$u_c^2(y) = \sum_{i=1}^{n} \left[\left(\frac{\partial y}{\partial x_i} \right) \times u(x_i) \right]^2 \tag{A.1}$$

where $y = f(x_1, x_2, x_3, \ldots, x_n)$

A.4 Mathematical model

See Figure A.1.

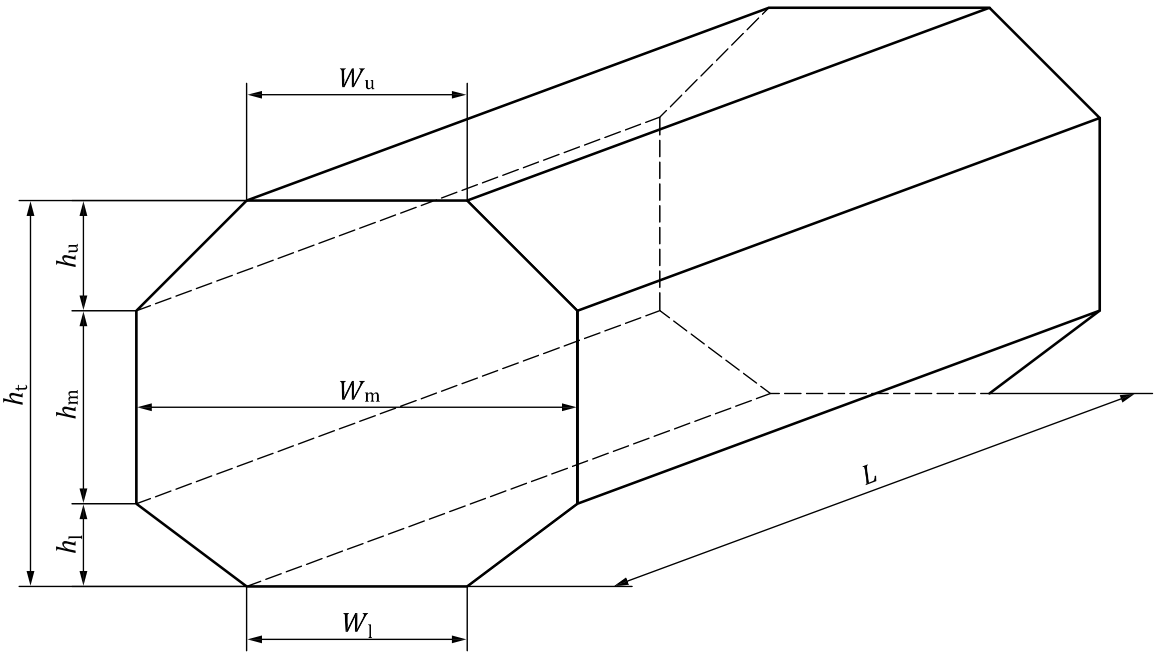


Figure A.1 — Typical membrane tank overview

From 10.1, the tank volume is given by Formula (A.2):

$$V = \left[\left(\frac{w_\mathrm{u} + w_\mathrm{m}}{2} \times h_\mathrm{u} \right) + w_\mathrm{m} \times h_\mathrm{m} + \left(\frac{w_\mathrm{m} + w_\mathrm{l}}{2} \times h_\mathrm{l} \right) \right] \times L \tag{A.2}$$

A.5 Contributory variance

The contributory variance is given by Formula (A.3):

$$u_\mathrm{c}^2(V) = c_\mathrm{L}^2 u^2(L) + c_{w_\mathrm{u}}^2 u^2(w_\mathrm{u}) + c_{w_\mathrm{m}}^2 u^2(w_\mathrm{m}) + c_{w_\mathrm{l}}^2 u^2(w_\mathrm{l}) + c_{h_\mathrm{u}}^2 u^2(h_\mathrm{u}) + c_{h_\mathrm{m}}^2 u^2(h_\mathrm{m}) + c_{h_\mathrm{l}}^2 u^2(h_\mathrm{l}) \tag{A.3}$$

h_u is given indirectly by the following formula:

$$h_\mathrm{u} = h_\mathrm{t} - (h_\mathrm{l} + h_\mathrm{m})$$

Therefore, it can be rewritten as:

$$u_\mathrm{c}^2(V) = c_\mathrm{L}^2 u^2(L) + c_{w_\mathrm{u}}^2 u^2(w_\mathrm{u}) + c_{w_\mathrm{m}}^2 u^2(w_\mathrm{m}) + c_{w_\mathrm{l}}^2 u^2(w_\mathrm{l}) + c_{h_\mathrm{u}}^2 \left[u^2(h_\mathrm{t}) + u^2(h_\mathrm{l}) + u^2(h_\mathrm{m}) \right]$$

$$+ c_{h_\mathrm{m}}^2 u^2(h_\mathrm{m}) + c_{h_\mathrm{l}}^2 u^2(h_\mathrm{l}) \tag{A.4}$$

A.6 Sensitivity coefficients

The sensitivity coefficients in Formula (A.4) can be obtained by Formula (A.5) to (A.11):

$$c_\mathrm{L} = \frac{\partial V}{\partial L} = \frac{(w_\mathrm{u} + w_\mathrm{m})h_\mathrm{u} + 2w_\mathrm{m}h_\mathrm{m} + (w_\mathrm{m} + w_\mathrm{l})h_\mathrm{l}}{2} \tag{A.5}$$

$$c_{h_\mathrm{u}} = \frac{\partial V}{\partial h_\mathrm{u}} = \frac{L(w_\mathrm{u} + w_\mathrm{m})}{2} \tag{A.6}$$

$$c_{h_\mathrm{m}} = \frac{\partial V}{\partial h_\mathrm{m}} = Lw_\mathrm{m} \tag{A.7}$$

$$c_{h_\mathrm{l}} = \frac{\partial V}{\partial h_\mathrm{l}} = \frac{L(w_\mathrm{m} + w_\mathrm{l})}{2} \tag{A.8}$$

$$c_{w_\mathrm{u}} = \frac{\partial V}{\partial w_\mathrm{u}} = \frac{Lh_\mathrm{u}}{2} \tag{A.9}$$

$$c_{w_\mathrm{m}} = \frac{\partial V}{\partial w_\mathrm{m}} = \frac{L(h_\mathrm{u} + 2h_\mathrm{m} + h_\mathrm{l})}{2} = \frac{L(h_\mathrm{t} + h_\mathrm{m})}{2} \tag{A.10}$$

$$c_{w_\mathrm{l}} = \frac{\partial V}{\partial w_\mathrm{l}} = \frac{Lh_\mathrm{l}}{2} \tag{A.11}$$

A.7 Cause of uncertainties

A.7.1 General

The causes of uncertainty associated with tank calibration are attributed to measurement method, source and effect, and each cause is classified into systematic and random effects.

A.7.2 Classification by method

A.7.2.1 General

The manual calibration of membrane tanks described in this standard includes direct method and reference line method.

A.7.2.2 Direct method

When measurements are taken directly by steel tape, the combined uncertainty, $u_c(D)$, is the sum of the uncertainty inherent in the steel tape.

$$u_c^2(D) = \sum_{i=1}^{n} u^2(D_i) \tag{A.12}$$

A.7.2.3 Reference line method

The combined uncertainty associated with the reference line method applied to the measurement of the averaged tank length of an intermediate part is derived from Formula (A.13):

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

$$L_{m,p} = \frac{L_P + L_S - (a_1 + a_n + b_1 + b_n)}{2} + \bar{a}_i + \bar{b}_i \tag{A.13}$$

The combined uncertainty, $u_c(L_m)$, is given as:

$$u_c^2(L_m) = c_{L_P}^2 u^2(L_P) + c_{L_S}^2 u^2(L_S) + c_{a_1}^2 u^2(a_1) + c_{a_n}^2 u^2(a_n) + c_{b_1}^2 u^2(b_1) + c_{b_n}^2 u^2(b_n) + c_{\bar{a}_i}^2 u^2(\bar{a}_i) + c_{\bar{b}_i}^2 u^2(\bar{b}_i)$$

(A.14)

And the sensitivity coefficients are as shown as follows:

$$c_{L_P} = c_{L_S} = c_{a_1} = c_{a_n} = c_{b_1} = c_{b_n} = \frac{\partial L}{\partial L_P} = \frac{1}{2} \tag{A.15}$$

$$c_{\bar{a}_i} = c_{\bar{b}_i} = \frac{\partial L}{\partial \bar{a}_i} = 1 \tag{A.16}$$

In addition,

$$u(L_P) = u(L_S) \tag{A.17}$$

$$u(a_1) = u(a_n) = u(b_1) = u(b_n) \tag{A.18}$$

$$u(\bar{a}_i) = u(\bar{b}_i) \tag{A.19}$$

Thus, the combined uncertainty, $u_c(L_{m,p})$, for length is given in Formula (A.20):

$$u_c^2(L_{m,p}) = \frac{u^2(L_P)}{2} + u^2(a_1) + 2u^2(\bar{a}_i) \tag{A.20}$$

Similarly, the combined uncertainty, $u_c(w_{m,p})$, for width is:

$$u_c^2(w_{m,p}) = \frac{u^2(w_F)}{2} + u^2(c_1) + 2u^2(\bar{c}_i) \tag{A.21}$$

A.7.3 Classification by source

A.7.3.1 General

Steel tapes and rule are used for the manual calibration of membrane tanks.

A.7.3.2 Measured by steel tape

See Formula (A.12).

A.7.3.3 Measured by rule

The combined uncertainty, $u_c(d)$, of the rule measurement is given as Formula (A.22):

$$u_c^2(d) = \sum_{i=1}^{n} u^2(d_i) \tag{A.22}$$

A.7.4 Classification by effect

The source of uncertainty comprised of random and systematic components. The random effect refers to the effect caused by a random component, which can be reduced by adopting an average of the measurement values. Systematic effects cannot be reduced by adopting an average of the measurement values.

In the manual measurement of membrane tanks, the combined uncertainty, $u_c(h_i)$, associated with the height measurement is described by Formula (23):

$$u_c^2(h_i) = \frac{u_r^2(h_i)}{n} + u_s^2(h_i) \tag{A.23}$$

For length and width measurements, the random effects are reduced in accordance with the number of horizontal planes.

$$u_c^2(L_i) = \frac{u_r^2(L_i)}{n \times p} + u_s^2(L_i) \tag{A.24}$$

$$u_c^2(w_i) = \frac{u_r^2(w_i)}{n \times p} + u_s^2(w_i) \tag{A.25}$$

NOTE Refer to Table A.1, A.7.7 and A.7.8.

A.7.5 Integration of uncertainties

A.7.5.1 General

The uncertainties classified in A.7.2 and A.7.3 are combined according to the measurement methods.

A.7.5.2 Combined uncertainty for direct method

For direct method, Formulae (A.12) and (A.23) are integrated as follows:

$$u_c^2(D_{dir}) = \sum_{i=1}^{n}\left(\frac{u_r^2(D_i)}{n} + u_s^2(D_i)\right) \tag{A.26}$$

A.7.5.3 Combined uncertainty for reference line method

For the reference line method, Formulae (A.12), (A.20), (A.21), (A.22), (A.24) and (A.25) are integrated as follows:

$$u_c^2(D_{ref}) = \frac{1}{2}\sum_{i=1}^{n}\left(\frac{u_r^2(D_i)}{n\times p} + u_s^2(D_i)\right) + \sum_{j=1}^{j}\left(\frac{u_r^2(d_j)}{n\times p} + u_s^2(d_j)\right) + 2\sum_{k=1}^{k}\left(\frac{u_r^2(d_k)}{n\times p} + u_s^2(d_k)\right) \tag{A.27}$$

A.7.6 Grouping of uncertainties

Components of uncertainty are grouped into random and systematic.

Table A.1 — Uncertainty grouping

Component of uncertainty		Reason
Random components		
	due to tension (only for steel tape)	Measurement value is varied by variance of giving standard tension to the tape. The giving tension varies every measurement around the standard tension.
	due to the resolution of tape or rule	Measurement value is varied by the resolution of the tape or rule. It varies at the half of the resolution.
	due to variation	This is estimation of the variance of the population.
	due to tank wall undulation	This is estimation of the variance of the population.
Systematic components		
	due to calibration or characteristic	Measurement value is always biased if the same tape or rule is used for series of measurement.
	due to temperature	Measurement value is always biased if the same thermometer is used for temperature correction.
	due to measurement deviation	Measurement value is always biased around the centre of ideal point.

A.7.7 Uncertainties associated with steel tape

A.7.7.1 Standard uncertainty of steel tape due to tension

In case that the tension applied to the tape deviates from the standard tension, the uncertainty is given by Formula (A.28).

$$u(D_{ten}) = D\times\frac{C_{ten}\times T_{std}\times E_{ten}}{\sqrt{3}} \tag{A.28}$$

A.7.7.2 Standard uncertainty of steel tape due to resolution

The probability distribution can be considered as a rectangular distribution. The uncertainty is given by Formula (A.29).

$$u\left(D_{\text{res}}\right)=\frac{R_{\text{tape}}}{2\times\sqrt{3}} \tag{A.29}$$

A.7.7.3 Standard uncertainty of steel tape due to variation

Variation can be found if multiple measurements are made. This variation can either be statistically analysed in accordance with the series of observations or be estimated from the repeatability described in 4.5. In the latter case, the uncertainty is given by Formula (A.30).

$$u\left(D_{\text{va}}\right)=\frac{V_{\text{D}}}{2\times\sqrt{3}} \tag{A.30}$$

A.7.7.4 Standard uncertainty due to tank wall undulation

Undulation of the tank walls can be the source of uncertainty. It can either be statistically analysed or be estimated from the experience. In the latter case, the uncertainty is given by the Formula (A.31).

$$u\left(D_{\text{ud}}\right)=\frac{V_{\text{uD}}}{2\times\sqrt{3}} \tag{A.31}$$

A.7.7.5 Standard uncertainty of steel tape due to calibration

In the case that an expanded calibration uncertainty is stated on the certificate, the standard uncertainty is calculated by dividing it by the coverage factor (k = 2):

$$u\left(D_{\text{cal}}\right)=\frac{A_{\text{tape}}}{2} \tag{A.32}$$

In the case that an expanded calibration uncertainty is not found on the certificate, but the steel tape is manufactured according to an industrial standard, the probability distribution can be considered as a rectangular distribution. In such case, the uncertainty is given by Formula (A.33).

$$u\left(D_{\text{cal}}\right)=D\times\frac{A_{\text{tape}}}{\sqrt{3}} \tag{A.33}$$

A.7.7.6 Standard uncertainty of steel tape due to temperature

The uncertainty of thermometer is stated on the calibration certificate or is declared by the manufacturer of the thermometer. In either case, the probability distribution can be considered as a rectangular distribution and the uncertainty is given by Formula (A.34):

$$u\left(D_{\text{th}}\right)=D\times\frac{\alpha\times A_{\text{temp}}}{\sqrt{3}} \tag{A.34}$$

A.7.7.7 Standard uncertainty of steel tape due to measurement deviation

If there is some deviation in angle from the point to the other, the probability distribution can be considered as a triangle distribution. The uncertainty is given by Formula (A.35):

$$u\left(D_{\text{dev}}\right)=\frac{D-D\times\cos\theta}{2\times\sqrt{6}} \tag{A.35}$$

A.7.8 Uncertainties associated with rule

A.7.8.1 Standard uncertainty of rule due to resolution

The probability distribution can be considered as a rectangular distribution. The uncertainty is given by Formula (A.36):

$$u(d_{\text{res}}) = \frac{R_{\text{rule}}}{2 \times \sqrt{3}} \tag{A.36}$$

A.7.8.2 Standard uncertainty of rule due to variation

Similar to A.7.7.3:

$$u(d_{\text{va}}) = \frac{V_{\text{d}}}{2 \times \sqrt{3}} \tag{A.37}$$

A.7.8.3 Standard uncertainty due to tank wall undulation

Similar to A.7.7.4:

$$u(d_{\text{ud}}) = \frac{V_{\text{ud}}}{2 \times \sqrt{3}} \tag{A.38}$$

A.7.8.4 Standard uncertainty of rule due to calibration

Similar to A.7.7.5:

$$u(d_{\text{cal}}) = d \times \frac{A_{\text{rule}}}{\sqrt{3}} \tag{A.39}$$

A.7.8.5 Standard uncertainty of rule due to temperature

Similar to A.7.7.6:

$$u(d_{\text{th}}) = d \times \frac{\alpha \times A_{\text{temp}}}{\sqrt{3}} \tag{A.40}$$

A.7.8.6 Standard uncertainty of rule due to measurement deviation

If there is some deviation from the point, the probability distribution can be considered as a triangle distribution. The uncertainty is given by Formula (A.41):

$$u(d_{\text{dev}}) = \frac{d - \sqrt{d^2 + \delta^2}}{\sqrt{6}} \tag{A.41}$$

A.8 Numerical example

The following tables (Tables A.2, A.3, A.4, A.5 and A.6) show uncertainty calculations of tank volume in relation to the manual measurement. In this example, a non-trapezoidal cargo tank on a 145 000 m^3 type LNG carrier is considered.

Table A.2 — Numerical example

Measurement distance by steel tape D, m		L	w	h
	upper	44,904	22,525	27,562
	middle		39,106	15,053
	lower		30,689	4,222
Accuracy of steel tape A_{tape}, m	The accuracy of strapping tape is prescribed in ISO 7507-1:2003, Annex A. $A_{tape} = \frac{1,5}{30\,000} = 0,000\,05$			
Temperature coefficient α, /°C	14×10^{-6}			
Accuracy of thermometer A_{temp}, °C	It is described in 5.7 as ± 0,5 °C.			
Standard tension of steel tape T_{std}, N	50			
Tension coefficient C_{ten}, /N	$3,01 \times 10^{-6}$			
Tension difference E_{ten}, %	10			
Minimum resolution of steel tape R_{tape}, m	0,001			
Deviation in angle θ, °	1,0			
Estimated limited value of variation of steel tape V_D, m	0,002 for measurement up to 25 m 0,003 for measurement over than 25 m			
Estimated limited value of variation due to tank wall undulation V_{uD}, m	0,030			
Number of measurement at same point n_D	2			
Measurement distance by rule d, m	0,150			
Accuracy of rule A_{rule}, m	It is prescribed in JIS B7516. $A_{rule} = \frac{0,10 + 0,05 \times (d/0,5)}{1\,000} = 0,000\,15$ Calculation result of the fraction less than 1 of d/0,5 shall round up to an integer.			
Minimum resolution of rule R_{rule}, m	0,001			
Deviation from measurement point δ, m	0,005			
Estimated limited value of variation of rule V_d, m	0,000 5			
Estimated limited value of variation due to tank wall undulation V_{ud}, m	0,030			
Number of measurement at same point n_d	2			

Table A.3 — Influence to volume due to uncertainty of length measurement

	Direct method L = 44,904 m		Reference line method d = 0,150 m		
			Middle part		
	Upper part	Lower part	L_p	a_1	a_i
n_D, n_d	2		2		
n	5	9	1	1	18
p	1	1	4		

Table A.3 *(continued)*

		Direct method L = 44,904 m		Reference line method d = 0,150 m		
		Upper part	Lower part	Middle part		
				L_p	a_1	a_i
$u_r(L_i)$	$u(D_{ten})$, m	0,000 39	0,000 39	0,000 39	-	-
	$u(D_{res})$ or $u(d_{res})$, m	0,000 29	0,000 29	0,000 29	0,000 29	0,000 29
	$u(D_{va})$ or $u(d_{va})$, m	0,001 73	0,001 73	0,001 73	0,000 29	0,000 29
	$u(D_{ud})$ or $u(d_{ud})$, m	0,008 66	0,008 66	0,008 66	0,001 44	0,001 44
$u_s(L_i)$	$u(D_{cal})$ or $u(d_{cal})$, m	0,001 30	0,001 30	0,001 30	0,000 07	0,000 07
	$u(D_{th})$ or $u(d_{th})$, m	0,000 18	0,000 18	0,000 18	0,000 00	0,000 00
	$u(D_{dev})$ or $u(d_{dev})$, m	0,001 40	0,001 40	0,001 40	0,000 02	0,000 02
$\Sigma u_r^2(L_i)$, m^2		$78,2 \times 10^{-6}$	$78,2 \times 10^{-6}$	$78,2 \times 10^{-6}$	$2,25 \times 10^{-6}$	$2,25 \times 10^{-6}$
$\Sigma u_s^2(L_i)$, m^2		$3,66 \times 10^{-6}$	$3,66 \times 10^{-6}$	$3,66 \times 10^{-6}$	$0,007\,9 \times 10^{-6}$	$0,007\,9 \times 10^{-6}$
Coefficient		1	1	0,5	1	2
Coeff. x $u_r^2(L)/(n \text{ x } p)$, m^2		$7,82 \times 10^{-6}$	$4,35 \times 10^{-6}$	$4,89 \times 10^{-6}$	$0,281 \times 10^{-6}$	$0,031\,3 \times 10^{-6}$
Coeff. x $u_s^2(L)$, m^2		$3,66 \times 10^{-6}$	$3,66 \times 10^{-6}$	$1,83 \times 10^{-6}$	$0,007\,8 \times 10^{-6}$	$0,015\,6 \times 10^{-6}$
$u^2(L)$, m^2		$11,5 \times 10^{-6}$	$8,01 \times 10^{-6}$	$6,72 \times 10^{-6}$	$0,289 \times 10^{-6}$	$0,046\,8 \times 10^{-6}$
$\Sigma u^2(L)$, m^2		$26,6 \times 10^{-6}$				
c_L^2, m^4		991^2				
$c_L^2\, u^2(L)$, m^6		26,1				

Table A.4 — Influence to volume due to uncertainty of width measurement

		Direct method	Reference line method 0,150 m					
		w_l = 30,689 m	w_u = 22,525 m			w_m = 39,106 m		
			w_f	c_1	c_i	w_f	c_1	c_i
n_D, n_d		2	2			2		
n		10	1	1	20	1	1	20
p		1	1			4		
$u_r(w)$	$u(D_{ten})$, m	0,000 27	0,000 20	-	-	0,000 34	-	-
	$u(D_{res})$ or $u(d_{res})$, m	0,000 29	0,000 29	0,000 29	0,000 29	0,000 29	0,000 29	0,000 29
	$u(D_{va})$ or $u(d_{va})$, m	0,001 73	0,001 15	0,000 29	0,000 29	0,001 15	0,000 29	0,000 29
	$u(D_{ud})$ or $u(d_{ud})$, m	0,008 66	0,008 66	0,001 44	0,001 44	0,008 66	0,001 44	0,001 44
$u_s(w)$	$u(D_{cal})$ or $u(d_{cal})$, m	0,000 89	0,000 65	0,000 07	0,000 07	0,001 13	0,000 07	0,000 07
	$u(D_{th})$ or $u(d_{th})$, m	0,000 12	0,000 09	0,000 00	0,000 00	0,000 16	0,000 00	0,000 00
	$u(D_{dev})$ or $u(d_{dev})$, m	0,000 95	0,000 70	0,000 02	0,000 02	0,001 22	0,000 02	0,000 02
$\Sigma u_r^2(w_i) \times 10^{-6}$, m^2		78,2	76,5	2,25	2,25	76,5	2,25	2,25
$\Sigma u_s^2(w_i) \times 10^{-6}$, m^2		1,71	0,921	0,007 8	0,007 8	2,78	0,007 8	0,007 8
Coefficient		1	0,5	1	2	0,5	1	2
Coeff. x $u_r^2(w)\,/(n \text{ x } p) \times 10^{-6}$, m^2		3,91	19,1	1,13	0,113	4,78	0,281	0,028 1
Coeff. x $u_s^2(w) \times 10^{-6}$, m^2		1,71	0,461	0,007 8	0,015 6	1,39	0,007 8	0,015 6
$u^2(w) \times 10^{-6}$, m^2		5,62	19,6	1,13	0,128	6,17	0,289	0,043 7
$\Sigma u^2(w) \times 10^{-6}$, m^2		5,62	20,8			6,50		

Table A.4 *(continued)*

	Direct method	Reference line method 0,150 m					
	w_l = 30,689 m	w_u = 22,525 m			w_m = 39,106 m		
		w_f	c_1	c_i	w_f	c_1	c_i
c_w^2, m^4	$94{,}8^2$	186^2			957^2		
$c_w^2\ u^2(w)$, m^6	0,050	0,721			5,955		
$\Sigma c_w^2\ u^2(w)$, m^6	6,7						

Table A.5 — Influence to volume due to uncertainty of height measurement

		h_t = 27,562 m	h_m = 15,053 m	h_l = 4,222 m	h_u = $h_t - h_m - h_l$ = 8,287 m
n_D, n_d		2			
n		35	20	12	-
$u_r(h)$	$u(D_{ten})$, m	0,000 24	0,000 13	0,000 04	-
	$u(D_{res})$ or $u(d_{res})$, m	0,000 29	0,000 29	0,000 29	-
	$u(D_{va})$ or $u(d_{va})$, m	0,001 73	0,001 15	0,001 15	-
	$u(D_{ud})$ or $u(d_{ud})$, m	0,008 66	0,008 66	0,008 66	
$u_s(h)$	$u(D_{cal})$ or $u(d_{cal})$, m	0,000 80	0,000 43	0,000 12	-
	$u(D_{th})$ or $u(d_{th})$, m	0,000 11	0,000 06	0,000 02	-
	$u(D_{dev})$ or $u(d_{dev})$, m	0,002 42	0,001 32	0,000 37	-
$\Sigma u_r^2(h_i)/n$, m^2		$1{,}12 \times 10^{-6}$	$1{,}91 \times 10^{-6}$	$3{,}18 \times 10^{-6}$	-
$\Sigma u_s^2(h_i)$, m^2		$6{,}52 \times 10^{-6}$	$1{,}94 \times 10^{-6}$	$0{,}153 \times 10^{-6}$	-
$u^2(h)$, m^2		$7{,}64 \times 10^{-6}$	$3{,}86 \times 10^{-6}$	$3{,}34 \times 10^{-6}$	$14{,}8 \times 10^{-6}$
c_h^2, m^4		-	$1\ 756^2$	$1\ 567^2$	$1\ 384^2$
$c_h^2\ u^2(h)$, m^6		-	11,9	8,2	28,4
$\Sigma c_h^2\ u^2(h)$, m^6		-	48,5		

Table A.6 — Uncertainty budget

Length	**Width**	**Height**	**Total**	
$c_L^2\ u^2(L)$	$c_w^2\ u^2(w)$	$c_h^2\ u^2(h)$	$u_c^2(V)$	$u_c(V)$
26,1 m^6	6,7 m^6	48,5 m^6	81,3 m^6	9,0 m^3
			Tank volume	44 516 m^3
			Relative combined uncertainty	0,020 3 %
			Coverage factor	2
			Relative expanded uncertainty	0,05 %

A.9 Conclusion

The relative expanded uncertainty (k = 2) of a non-trapezoidal tank on a typical LNG carrier is 0,05 %.

Annex B
(informative)

Example of tank capacity table (Tank No.3)

Gauge	Volume	Difference	Gauge	Volume	Difference	Gauge	Volume	Difference
cm	m³	m³	cm	m³	m³	cm	m³	m³
0	0,000	7,883	50	401,455	8,181	100	817,771	8,472
1	7,383	7,890	51	409,636	8,186	101	826,249	8,484
2	15,773	7,895	52	417,822	8,193	102	834,733	8,490
3	23,665	7,901	53	426,015	8,198	103	843,223	8,496
4	31,569	7,908	54	434,213	8,205	104	851,719	8,501
5	39,477	7,913	55	442,415	8,210	105	860,220	8,508
6	47,390	7,919	56	450,625	8,216	106	868,728	8,513
7	55,309	7,925	57	458,344	8,223	107	877,241	8,520
8	63,234	7,931	58	467,067	8,228	108	885,761	8,525
9	71,165	7,937	59	475,295	8,234	109	894,286	8,532
10	79,102	7,943	60	483,529	8,240	110	902,818	8,537
11	87,045	7,949	61	491,769	8,246	111	911,355	8,544
12	94,994	7,955	62	500,015	8,252	112	919,899	8,549
13	102,949	7,960	63	508,267	8,258	113	928,448	8,555
14	110,909	7,967	64	516,525	8,264	114	937,003	8,561
15	115,876	7,973	65	524,789	8,270	115	945,564	8,567
16	126,849	7,978	66	533,059	8,276	116	954,131	8,573
17	134,827	7,985	67	541,335	8,282	117	962,704	8,579
18	142,812	7,990	68	549,617	8,287	118	971,283	8,585
19	150,802	7,997	69	557,904	8,295	119	979,863	8,591
20	158,799	8,002	70	566,198	8,300	120	988,459	8,597
21	166,801	8,008	71	574,498	8,305	121	997,056	8,603
22	174,309	8,014	72	582,803	8,312	122	1 005,659	8,608
23	182,823	8,021	73	591,115	8,317	123	1 014,267	8,615
24	190,544	8,025	74	599,432	8,323	124	1 022,882	8,620
25	198,870	8,032	75	607,755	8,330	125	1 031,502	8,627
26	206,902	8,038	76	616,085	8,335	126	1 040,129	8,632
27	214,940	8,044	77	624,420	8,341	127	1 048,761	8,639
28	222,984	8,050	78	632,761	8,347	128	1 057,400	8,644
29	251,034	8,056	79	641,108	8,353	129	1 066,044	8,651
30	239,090	8,061	80	649,461	8,359	130	1 074,695	8,656
31	247,151	8,068	81	657,820	8,365	131	1 083,351	8,662
32	255,219	8,074	82	666,185	8,371	132	1 092,013	8,668

Gauge	Volume	Difference	Gauge	Volume	Difference	Gauge	Volume	Difference
cm	m^3	m^3	cm	m^3	m^3	cm	m^3	m^3
33	263,293	8,079	83	674,556	8,377	133	1 100,681	8,674
34	271,372	8,086	84	682,933	8,383	134	1 109,355	8,680
35	279,458	8,091	85	691,316	8,389	135	1 118,035	8,686
36	287,549	8,098	86	699,705	8,394	136	1 126,721	8,692
37	295,647	8,103	87	708,099	8,401	137	1 135,413	8,698
38	303,750	8,110	88	716,500	8,406	138	1 144,111	8,704
39	311,860	8,115	89	724,906	8,413	139	1 152,815	8,710
40	319,975	8,121	90	733,319	8,418	140	1 161,525	8,715
41	328,096	8,127	91	741,737	8,425	141	1 170,240	8,722
42	336,223	8,134	92	750,162	8,430	142	1 178,962	8,728
43	344,357	8,139	93	758,592	8,437	143	1 187,690	8,733
44	352,496	8,145	94	767,029	8,442	144	1 196,423	8,740
45	360,641	8,151	95	775,471	8,448	145	1 205,163	8,745
46	368,792	8,156	96	783,919	8,454	146	1 213,908	8,751
47	376,948	8,163	97	792,373	8,460	147	1 222,659	8,758
48	385,111	8,169	98	800,833	8,466	148	1 231,417	8,763
49	393,280	8,175	99	809,299	8,472	149	1 240,180	8,769

Annex C
(informative)

Example of trim correction table (Tank No. 1)

Gauge corrections in millimetres

	Trim												
Gauge	2,0 m	1,5 m	1,0 m	0,5 m	0,0 m	0,5 m	1,0 m	1,5 m	2,0 m	2,5 m	3,0 m	3,5 m	4,0 m
cm	B/H	B/H	B/H	B/H		B/S	B/S	B/S	B/S	B/S	B/S	B/S	B/S
0	64	48	32	16	0	0	1	1	1	2	2	2	3
5	63	47	31	16	0	−16	−26	−31	−33	−34	−35	−35	−36
10	63	47	31	16	0	−16	−31	−45	−53	−58	−62	−64	−66
15	63	47	31	16	0	−16	−31	−47	−61	−72	−79	−85	−89
20	63	47	31	16	0	−16	−31	−47	−62	−78	−89	−98	−106
30	63	47	32	16	0	−16	−31	−47	−63	−78	−94	−109	−123
40	64	48	32	16	0	−16	−32	−47	−63	−79	−94	−110	−125
50	64	48	32	16	0	−16	−32	−47	−63	−79	−94	−110	−126
60	64	48	32	16	0	−16	−32	−48	−63	−79	−95	−110	−126
70	64	48	32	16	0	−16	−32	−48	−63	−79	−95	−111	−126
80	64	48	32	16	0	−16	−32	−48	−64	−79	−95	−111	−127
90	64	48	32	16	0	−16	−32	−48	−64	−80	−95	−111	−127
100	65	48	32	16	0	−16	−32	−48	−64	−80	−96	−112	−127
120	65	49	32	16	0	−16	−32	−48	−64	−80	−96	−112	−128
140	65	49	33	16	0	−16	−32	−49	−65	−81	−97	−113	−129
160	65	49	33	16	0	−16	−33	−49	−65	−81	−97	−113	−129
180	66	49	33	16	0	−16	−33	−49	−65	−81	−98	−114	−130
200	66	49	33	16	0	−16	−33	−49	−65	−82	−98	−114	−130
300	67	50	34	17	0	−17	−33	−50	−67	−83	−100	−116	−133
400	68	51	34	17	0	−17	−34	−51	−68	−85	−101	−118	−135
600	68	51	34	17	0	−17	−34	−51	−68	−85	−101	−118	−135
800	68	51	34	17	0	−17	−34	−51	−68	−85	−101	−118	−135
1 000	68	51	34	17	0	−17	−34	−51	−68	−85	−101	−118	−135
1 200	68	51	34	17	0	−17	−34	−51	−68	−85	−101	−118	−135
1 400	68	51	34	17	0	−17	−34	−51	−68	−85	−101	−118	−135
1 500	68	51	34	17	0	−17	−34	−51	−68	−85	−101	−118	−135
1 600	68	51	34	17	0	−17	−34	−51	−68	−85	−101	−118	−135
1 700	68	51	34	17	0	−17	−34	−51	−68	−85	−101	−118	−135

	Trim												
Gauge	2,0 m	1,5 m	1,0 m	0,5 m	0,0 m	0,5 m	1,0 m	1,5 m	2,0 m	2,5 m	3,0 m	3,5 m	4,0 m
cm	B/H	B/H	B/H	B/H		B/S	B/S	B/S	B/S	B/S	B/S	B/S	B/S
1 800	68	51	34	17	0	−17	−34	−51	−68	−85	−101	−118	−135
1 900	68	51	34	17	0	−17	−34	−51	−68	−85	−101	−118	−135
2 000	67	51	34	17	0	−17	−34	−51	−68	−85	−102	−119	−135
2 100	66	50	33	17	0	−17	−33	−50	−67	−83	−100	−117	−134
2 120	66	50	33	17	0	−17	−33	−50	−66	−83	−100	−117	−133
2 140	66	49	33	16	0	−17	−33	−50	−66	−83	−100	−116	−133
2 160	65	49	33	16	0	−16	−33	−49	−66	−83	−99	−116	−132
2 180	65	49	33	16	0	−16	−33	−49	−66	−82	−99	−115	−132
2 200	65	49	33	16	0	−16	−33	−49	−65	−82	−98	−115	−131
2 220	65	48	32	16	0	−16	−33	−49	−65	−82	−98	−114	−131
2 240	64	48	32	16	0	−16	−32	−49	−65	−81	−97	−114	−130
2 260	64	48	32	16	0	−16	−32	−48	−65	−81	−97	−113	−130
2 280	64	48	32	16	0	−16	−32	−48	−64	−80	−97	−113	−129
2 300	56	46	32	16	0	−16	−32	−48	−64	−80	−96	−112	−128
B/H: by head; B/S: by stern													

Annex D
(informative)

Example of list correction table (Tank No. 1)

Gauge corrections in millimetres

Gauge	List to port						UP/R	List to starboard					
cm	3,0°	2,5°	2,0°	1,5°	1,0°	0,5°	0,0°	0,5°	1,0°	1,5°	2,0°	2,5°	3,0°
0	122	101	80	60	39	20	0	20	39	60	80	101	122
5	99	78	58	38	19	3	0	3	19	38	58	78	99
10	80	59	40	22	7	0	0	0	7	22	40	59	80
15	63	44	27	12	2	0	0	0	2	12	27	44	63
20	49	32	17	6	1	0	0	0	1	6	17	32	49
30	30	17	8	3	1	0	0	0	1	3	8	17	30
40	19	10	6	3	1	0	0	0	1	3	6	10	19
50	14	9	6	3	1	0	0	0	1	3	6	9	14
60	13	9	6	3	1	0	0	0	1	3	6	9	13
70	13	9	6	3	1	0	0	0	1	3	6	9	13
80	13	9	6	3	1	0	0	0	1	3	6	9	13
90	13	9	6	3	1	0	0	0	1	3	6	9	13
100	13	9	6	3	1	0	0	0	1	3	6	9	13
120	14	9	6	3	2	0	0	0	2	3	6	9	14
140	14	10	6	3	2	0	0	0	2	3	6	10	14
160	14	10	6	4	2	0	0	0	2	4	6	10	14
180	14	10	6	4	2	0	0	0	2	4	6	10	14
200	15	10	7	4	2	0	0	0	2	4	7	10	15
300	16	11	7	4	2	0	0	0	2	4	7	11	16
400	3	1	1	0	0	0	0	0	0	0	1	1	3
600	0	0	0	0	0	0	0	0	0	0	0	0	0
800	0	0	0	0	0	0	0	0	0	0	0	0	0
1 000	0	0	0	0	0	0	0	0	0	0	0	0	0
1 200	0	0	0	0	0	0	0	0	0	0	0	0	0
1 400	0	0	0	0	0	0	0	0	0	0	0	0	0
1 500	0	0	0	0	0	0	0	0	0	0	0	0	0
1 600	0	0	0	0	0	0	0	0	0	0	0	0	0
1 700	0	0	0	0	0	0	0	0	0	0	0	0	0
1 800	0	0	0	0	0	0	0	0	0	0	0	0	0

Gauge	List to port						UP/R	List to starboard					
cm	3,0°	2,5°	2,0°	1,5°	1,0°	0,5°	0,0°	0,5°	1,0°	1,5°	2,0°	2,5°	3,0°
1 900	0	0	0	0	0	0	0	0	0	0	0	0	0
2 000	−11	−8	−5	−3	−2	0	0	0	−2	−3	−5	−8	−11
2 100	−16	−11	−7	−4	−2	0	0	0	−2	−4	−7	−11	−16
2 120	−15	−11	−7	−4	−2	0	0	0	−2	−4	−7	−11	−15
2 140	−15	−10	−7	−4	−2	0	0	0	−2	−4	−7	−10	−15
2 160	−15	−10	−7	−4	−2	0	0	0	−2	−4	−7	−10	−15
2 180	−15	−10	−6	−4	−2	0	0	0	−2	−4	−6	−10	−15
2 200	−14	−10	−6	−4	−2	0	0	0	−2	−4	−6	−10	−14
2 220	−14	−10	−6	−4	−2	0	0	0	−2	−4	−6	−10	−14
2 240	−14	−10	−6	−3	−2	0	0	0	−2	−3	−6	−10	−14
2 260	−15	−9	−6	−3	−2	0	0	0	−2	−3	−6	−9	−15
2 280	−32	−18	−8	−3	−1	0	0	0	−1	−3	−8	−18	−32
2 300	−82	−61	−41	−22	−7	0	0	0	−7	−22	−41	−61	−82
UP/R: Upright													

Bibliography

[1] ISO 1998-5, *Petroleum industry — Terminology — Part 5: Transport, storage, distribution*

[2] ISO 1998-6, *Petroleum industry — Terminology — Part 6: Measurement*

[3] ISO 4512, *Petroleum and liquid petroleum products — Equipment for measurement of liquid levels in storage tanks — Manual methods*

[4] ISO 10976, *Refrigerated light hydrocarbon fluids — Measurement of cargoes on board LNG carriers*

[5] ISO 12917-2, *Petroleum and liquid petroleum products — Calibration of horizontal cylindrical tanks — Part 2: Internal electro-optical distance-ranging method*

[6] ISO 18132-1, *Refrigerated hydrocarbon and non-petroleum based liquefied gaseous fuels — General requirements for automatic tank gauges — Part 1: Automatic tank gauges for liquefied natural gas on board marine carriers and floating storage*

[7] ISO 18132-3, *Refrigerated hydrocarbon and non-petroleum based liquefied gaseous fuels — General requirements for automatic tank gauges — Part 3: Automatic tank gauges for liquefied petroleum and chemical gases on board marine carriers and floating storage*

[8] ISO/IEC Guide 98-3:2008, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

[9] JIS B7516, *Metal rules*

This page deliberately left blank

This page deliberately left blank

British Standards Institution (BSI)

BSI is the national body responsible for preparing British Standards and other standards-related publications, information and services.

BSI is incorporated by Royal Charter. British Standards and other standardization products are published by BSI Standards Limited.

About us

We bring together business, industry, government, consumers, innovators and others to shape their combined experience and expertise into standards -based solutions.

The knowledge embodied in our standards has been carefully assembled in a dependable format and refined through our open consultation process. Organizations of all sizes and across all sectors choose standards to help them achieve their goals.

Information on standards

We can provide you with the knowledge that your organization needs to succeed. Find out more about British Standards by visiting our website at bsigroup.com/standards or contacting our Customer Services team or Knowledge Centre.

Buying standards

You can buy and download PDF versions of BSI publications, including British and adopted European and international standards, through our website at bsigroup.com/shop, where hard copies can also be purchased.

If you need international and foreign standards from other Standards Development Organizations, hard copies can be ordered from our Customer Services team.

Subscriptions

Our range of subscription services are designed to make using standards easier for you. For further information on our subscription products go to bsigroup.com/subscriptions.

With **British Standards Online (BSOL)** you'll have instant access to over 55,000 British and adopted European and international standards from your desktop. It's available 24/7 and is refreshed daily so you'll always be up to date.

You can keep in touch with standards developments and receive substantial discounts on the purchase price of standards, both in single copy and subscription format, by becoming a **BSI Subscribing Member**.

PLUS is an updating service exclusive to BSI Subscribing Members. You will automatically receive the latest hard copy of your standards when they're revised or replaced.

To find out more about becoming a BSI Subscribing Member and the benefits of membership, please visit bsigroup.com/shop.

With a **Multi-User Network Licence (MUNL)** you are able to host standards publications on your intranet. Licences can cover as few or as many users as you wish. With updates supplied as soon as they're available, you can be sure your documentation is current. For further information, email bsmusales@bsigroup.com.

Revisions

Our British Standards and other publications are updated by amendment or revision.

We continually improve the quality of our products and services to benefit your business. If you find an inaccuracy or ambiguity within a British Standard or other BSI publication please inform the Knowledge Centre.

Copyright

Useful Contacts:

Customer Services
Tel: +44 845 086 9001
Email (orders): orders@bsigroup.com
Email (enquiries): cservices@bsigroup.com

Subscriptions
Tel: +44 845 086 9001
Email: subscriptions@bsigroup.com

Knowledge Centre
Tel: +44 20 8996 7004
Email: knowledgecentre@bsigroup.com

Copyright & Licensing
Tel: +44 20 8996 7070
Email: copyright@bsigroup.com

BSI Group Headquarters

389 Chiswick High Road London W4 4AL UK

bsi.

...making excellence a habit.™