

ISO

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION

ISO RECOMMENDATION

R 831

RULES FOR CONSTRUCTION OF STATIONARY BOILERS

1st EDITION
September 1968

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BRIEF HISTORY

The ISO Recommendation R 831, *Rules for construction of stationary boilers*, was drawn up by Technical Committee ISO/TC 11, *Boilers and pressure vessels*, the Secretariat of which is held by the United States of America Standards Institute (USASI).

Work on this question by the Technical Committee began in 1952 and led, in 1964, to the adoption of a Draft ISO Recommendation.

In September 1965, this Draft ISO Recommendation (No. 851) was circulated to all the ISO Member Bodies for enquiry. It was approved, subject to a few modifications of an editorial nature, by the following Member Bodies:

Argentina	Hungary	South Africa, Rep. of
Australia	India	Spain
Austria	Ireland	Sweden
Belgium	Israel	Switzerland
Brazil	Italy	Turkey
Chile	Japan	United Kingdom
Czechoslovakia	Netherlands	U.S.A.
France	Norway	U.S.S.R.
Germany	Portugal	

No Member Body opposed the approval of the Draft.

The Draft ISO Recommendation was then submitted by correspondence to the ISO Council, which decided, in September 1968, to accept it as an ISO RECOMMENDATION.

FOREWORD

This ISO Recommendation has been formulated to afford reasonably certain protection of life and property and to provide a margin of deterioration in service so as to give a reasonably long, safe period of usefulness taking into consideration advancements in design and material and the evidence of experience. It will be revised when and as necessary.

The formulae in Part III apply to boilers constructed throughout under the conditions prescribed in this ISO Recommendation and working under average conditions of draught, good feedwater, and adequate supervision.

Where working conditions are adverse (bad feedwater, undue erosion, exposure to the elements, etc.) or where maintenance supervision will, of necessity, be inadequate, it is recommended that thicknesses found by calculation from the formulae should be specially considered.

Various sections of this ISO Recommendation require reference to national standards (see Part I, clause 1.3, for a definition of a national standard) where it has not been possible at the present time to consolidate all successful and proved practices into rules of international scope; the rules do, however, provide a broad outline of the necessary limits of practice.

The national standards which come within these limits of practice may be registered under the provisions of Part I and, after registration is effected, may be used to complete the requirements of this ISO Recommendation.

For the purpose of this ISO Recommendation, the following definitions apply:

Inspecting Authority. That body or association acting on behalf of the purchaser or the legal authority in the country of origin which ensures that the design, material and construction are in accordance with these rules and the relevant accepted national standard.

Certifying Authority. That authority in the country of installation which certifies the compliance of the installation with the legal requirements in force in that country.

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RULES FOR CONSTRUCTION OF STATIONARY BOILERS

INTRODUCTION

This ISO Recommendation applies to the construction of steam boilers for stationary service. A pressure vessel in which steam is generated for use external to itself by the application of heat resulting from the combustion of fuel (solid, liquid, gaseous, or waste heat) is classed as a steam boiler. It does not apply to boilers of less than 25 litres (5½ gal) capacity, or less than 1 kgf/cm² (14.2 psi*) design gauge pressure.

This ISO Recommendation applies to the boiler proper from the feedwater inlet connection to the steam outlet connection and to all other connections including required valves and fittings. If welded ends are used, the requirements specified herein begin or end at the weld where flanges, if used, would have been fitted.

Superheaters, economizers, and other pressure parts connected directly to the boiler without intervening valves, and also reheaters, are considered as parts of a boiler and their construction should conform to the requirements of this ISO Recommendation.

Forced-circulation boilers and boilers with no fixed steam and water line should conform to the requirements specified herein except for special features of construction in boilers of these types and except for accessories that are manifestly not needed in connection with such boilers, such as water gauges, water columns, and gauge cocks.

Economizers or superheaters which are separated from boilers by valves, air preheaters, mechanical stokers, fuel burning equipment, forced or induced draught equipment, or other accessories which may be required by the purchaser, are extraneous to this ISO Recommendation.

* psi = lbf/in²

PART I

REGISTRATION OF NATIONAL STANDARDS

1. GENERAL

- 1.1 Where it is permitted or necessary to use national standards, as authorized in the Foreword, in conjunction with or supplementary to the requirements stipulated herein, such standards should be registered in accordance with the procedure outlined in section 2.
- 1.2 The ISO Member Body of a country is the only organization qualified to appraise and apply for registration (see clause 4.1) and is hereinafter called the Sponsor Body.
- 1.3 *National standards* are defined as specific standards which have been proved to be satisfactory in use and which are acceptable to the certifying authorities for the intended purpose in the Sponsor Body country. The term "National Standard" refers to specifications or rules prepared by national standards bodies or similar authorities and also includes rules prescribed by government authorities and having the force of law.
- 1.4 The procedure which a Sponsor Body employs to appraise a national standard for compliance with these rules should be comparable to the methods used for the acceptance of national standards in that country.
- 1.5 The Secretariat of Technical Committee ISO/TC 11 may perform only the functions of recognizing and recording the registration of national standards as specifically provided in this Part of this ISO Recommendation.
- 1.6 The Secretariat should circulate, annually, to all (P) and (O) Member Bodies of Technical Committee ISO/TC 11 a list of all registered national standards.
- 1.7 It is recognized that registration of a national standard is not binding upon the certifying authority at the point of installation, regardless of whether or not the Sponsor Body of that country has questioned the registration. It is the duty of the certifying authority to ensure that the installation conforms to the relevant statutory requirements, which should be made known at the time of the order.
- 1.8 Applications for additional copies of registered national standards should be made directly to the Sponsor Body concerned.

2. PROCEDURE

2.1 Proposal

The Sponsor Body should prepare a national standard for registration after appraisal to determine that it meets the requirements and intent of this ISO Recommendation applicable to the proposed standard.

- 2.1.1 The Sponsor Body should send the proposal form (see clause 4.1) to the Secretariat with two copies of the proposed national standard in French and in English, properly numbered in accordance with section 3 and clearly marked "Proposal".
- 2.1.2 At the same time, the Sponsor Body should send two copies of the form shown in clause 4.1 and two copies of the proposed national standard in French and in English to each Member Body of ISO/TC 11.
- 2.1.3 The Secretariat should record the date of receipt of the proposal form and acknowledge receipt to the Sponsor Body.

2.2 Consideration

Any Member Body which raises questions regarding the compliance of the proposed national standard should submit them directly to the Sponsor Body, with copies to the Secretariat, within 90 days of the receipt of the proposed national standard.

- 2.2.1 The Sponsor Body should attempt to resolve the questions directly with the Member Body which raises the question, with copies to the Secretariat.
- 2.2.2 In the event that the questions can be resolved without revision to the proposed national standard, the Member Body which raises the question should advise the Secretariat that such questions have been satisfactorily answered. If any Member Body takes no action within 90 days after receipt of the proposed national standard the Secretariat should assume that no comments are to be submitted.
- 2.2.3 In the event that the proposed national standard requires revisions to resolve the questions, it should be resubmitted in accordance with clause 2.1.
- 2.2.4 If a national standard is questioned after it has been registered under clause 2.3, these questions should be resolved directly with the Sponsor Body. In the event that they cannot be resolved, the Member Body raising the questions may inform the Secretariat, with copies to other Member Bodies. However, such comments should not be made a part of the registration form (see clause 4.2).

2.3 Registration

90 days after the receipt of the proposal form (see clause 2.1.3), the national standard will automatically be registered and the Secretariat will send the registration form (see clause 4.2) to all Member Bodies.

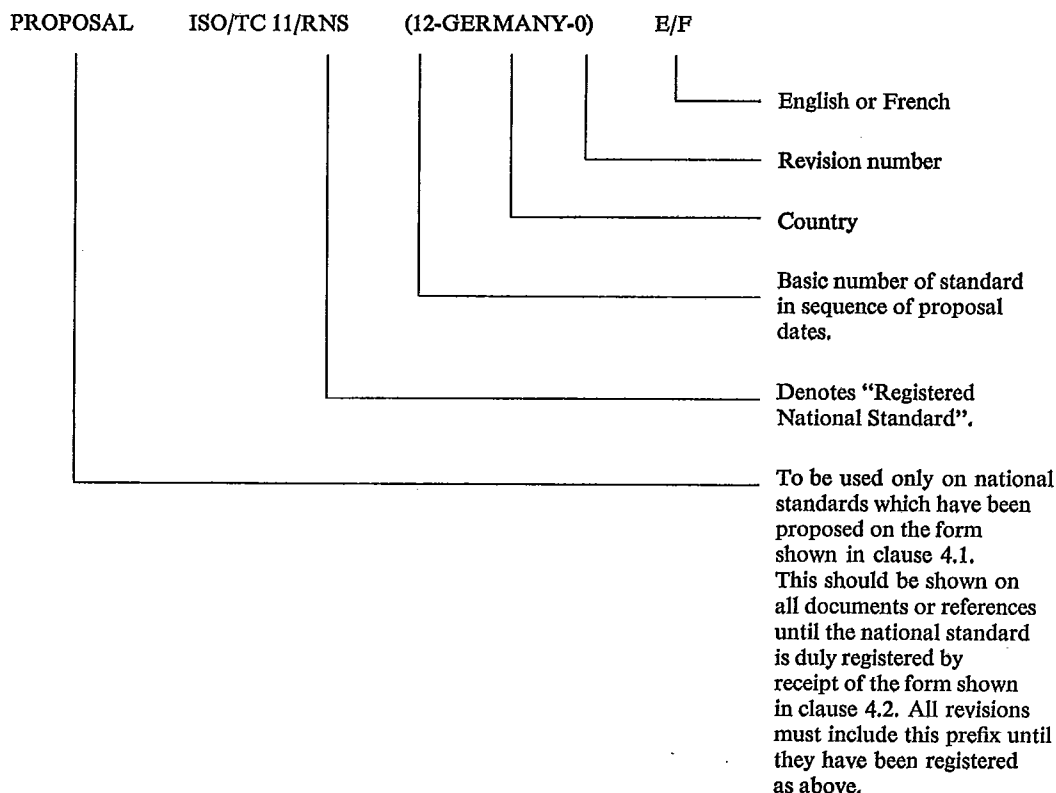
- 2.3.1 The Sponsor Body may, at its discretion, instruct the Secretariat to delay final registration until beyond the 90 day period in order to finalize discussion with other Member Bodies.
- 2.3.2 The Secretariat should forward a summary of any comments which are not resolved within the period of 90 days to all Member Bodies, together with a copy of the registration form (see clause 4.2).
- 2.3.3 A Sponsor Body may at any time cancel the registration of any of its national standards by notification to the Secretariat with copies to all Member Bodies.

- 2.3.4** A registered national standard which is subsequently revised should again be submitted in its entirety for registration in accordance with clause 2.1, with the number modified to indicate a revision (see section 3). The registered national standard remains valid until registration of the revised national standard is completed, at which time it should be cancelled.

NOTE. — It is suggested that for the convenience of other countries and for maximum speed in consideration, some method of identification of the revisions be used by the Sponsor Body.

3. NUMBERING

- 3.1** All national standards, either being proposed or after registration, used in compliance with this ISO Recommendation should be properly numbered in accordance with the Technical Committee ISO/TC 11 system and also with the normal national standard number.
- 3.2** The ISO/TC 11 number should be composed as follows:



4. FORMS

4.1 Proposal Form

To Secretariat ISO/TC 11:

cc: All (P) Member Bodies

APPLICATION FOR REGISTRATION

Proposed Standard Registration No. We have appraised our National Standard No., entitled, for compliance with ISO Recommendation R 831, section(s), and affirm that it meets all the requirements of that document. We attach two copies of this National Standard in French and in English. We request that this be registered in accordance with Part I of that document.

Signed

on behalf of (Sponsor Body)

4.2 Registration Form

To (Sponsor Body)

cc: All (P) and (O) Member Bodies

REGISTRATION

Your National Standard No., entitled, received with your Proposal Form 4.1 dated has been duly registered in accordance with the registration procedure of ISO Recommendation R 831. The Registration number allocated to this National Standard is ISO/TC 11/RNS (.....) E/F. The comments received on this National Standard are summarized on pages attached hereto.

Signed

on behalf of Secretariat of ISO/TC 11



Documents

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PART II

MATERIALS

FOREWORD

The provisions of Part II of this ISO Recommendation cover only boiler pressure parts of carbon steels, i.e. steels having a silicon specified content not greater than 0.60 %, a manganese specified content not greater than 1.40 % and with no other alloying addition.

For boilers to meet the requirements of this ISO Recommendation, materials should be ordered in accordance with national standards and specifications, provided the latter conform to the requirements of Part II and have been registered in accordance with Part I of this ISO Recommendation. If a national standard does not include figures for the characteristics at elevated temperatures, as required by Part II, then a list of these should accompany the application for registration. The boilermaker should certify that the applied specifications conform to the requirements of this ISO Recommendation.

Until applicable provisions are added, alloyed steels, as well as some materials used in the manufacture of valves and fittings, flanges, bolts, rivets, etc., not covered by the present provisions, should be ordered to comply with official regulations and/or national standards agreed between the purchaser of the boiler and the boilermaker.

For dimensions and tolerances, national standards may be used.

Methods of testing not covered by these provisions should conform to the requirements of ISO Standards or Recommendations where these apply. In cases where no such ISO Standards or Recommendations exist, the appropriate national standard should be used.

All acceptance test results required by these provisions should be certified by the inspecting authority (see Part VI).

1. BOILER PLATES OF CARBON STEEL

1.1 Scope

These provisions cover carbon steel plates used in the construction of welded or riveted pressure parts of boilers.

1.2 Manufacture

The steel for plates conforming to these provisions should be made by the open-hearth or the electric furnace process or by any other process which gives steel having equivalent properties. Rimmed steels are permitted only for riveted drums and then only for plates with a nominal thickness of up to 20 mm ($\frac{3}{4}$ in).

1.3 Chemical composition

The ladle analysis, which should be reported to the boilermaker, should conform to the following requirements:

Carbon	0.25 %* maximum
Silicon	0.40 % maximum
Manganese	1.40 % maximum
Phosphorus	0.05 % maximum
Sulphur	0.05 % maximum

1.3.1 The purchaser may, if he so wishes, order a check analysis.

1.4 Heat treatment

Plates not intended for hot forming should be supplied in the normalized condition unless otherwise agreed upon between the purchaser and the supplier. Normalizing may be omitted, if it is demonstrated that equivalent properties can be produced by the rolling and subsequent cooling.

1.5 Defects

The plates should have a workmanlike surface and should be free from injurious defects. Provided that the minimum specified thickness is maintained, minor surface defects may be admitted and other defects removed by mechanical means so as to achieve a smooth level surface. Surface defects may be repaired, by welding only, with the consent of the boiler-maker and the inspecting authority and provided that the plate is stress-relieved after welding where necessary.

1.6 Mechanical properties

1.6.1 These provisions cover one quality group of steels determined by the ratio of stress at proof limit 0.2 % at elevated temperatures to the specified minimum tensile strength at room temperature.

* A carbon content not exceeding 0.35 % may be permitted in accordance with registered national standards by agreement with the boilermaker, inspecting authority, and the purchaser of the boiler.

NOTE. — The term “stress at proof limit 0.2 %” (for definition see ISO Recommendation R 82, *Tensile testing of steel*) used herein means the stress for 0.2 % offset. For acceptance tests at room temperature, the upper yield point when it is clearly defined should be taken in place of stress at proof limit 0.2 %. The stress at proof limit 0.2 % for elevated temperatures should be determined according to ISO Recommendation R 205, *Determination of proof stress and proving test for steel at elevated temperatures*. At elevated temperatures where a distinct yield point occurs, ISO Recommendation R 205 is not applicable and reference should be made to ISO Recommendation R 783, *Mechanical testing of steel at elevated temperatures — Determination of lower yield stress and proof test and proving test*.

- 1.6.2 The specified minimum tensile strength of all steels should amount to at least 33 kgf/mm² (47 000 psi) and the maximum tensile strength to not more than 62 kgf/mm² (88 000 psi). Within this range the maximum tensile strength specified on a particular order should not exceed the specified minimum tensile strength on the order by more than 10 kgf/mm² (14 220 psi).
- 1.6.3 The upper yield point at room temperature should be not less than 50 % of the specified minimum tensile strength at room temperature. The actual value of the upper yield point at room temperature of the steel should be reported to the boilermaker for his information.
- 1.6.4 The breaking elongation in % should be greater than or equal to

$$\frac{100 - R_m}{2.2}$$

where

R_m = measured tensile strength at room temperature in kilogrammes-force per square millimetre,

$$\left(R \text{ kgf/mm}^2 = \frac{R \text{ psi}}{1422} \right)$$

100 = a quality index (see Note below),

2.2 = a constant which is valid only when $L_o = 5d_o$ or $L_o = 5.65 \sqrt{S_o}$

where

L_o = gauge length,

d_o = original diameter of round test piece,

S_o = original cross-section of rectangular test piece.

NOTE. — The quality index of 100 in the formula for the breaking elongation is valid only for plate thicknesses up to 50 mm (2 in); for greater plate thicknesses the quality index should be 95.

- 1.6.5 The minimum values of the stress at proof limit 0.2 % at elevated temperatures (symbol E_t , see Part III, clause 1.1) of the carbon steels covered by these provisions can be calculated by multiplying the minimum specified tensile strength at room temperature (R_{20}) by the ratio (E_t/R_{20}) given in Table 1.

For the stresses to rupture in 100 000 hours (symbol S_R , see Part III, clause 1.1), tentative figures are given in Table 2 only for information purposes. These values will be revised periodically.

NOTE. — Sufficient data have not yet been collected for giving values of stresses producing a creep of 1 % after 100 000 hours.

1.6.5.1 The plate manufacturer should satisfy the boilermaker and his representative that the steel supplied is capable of meeting the value E_t

- (1) (a) by producing adequate records of test results on the type of steel concerned, and
- (b) by showing that the steel supplied actually conforms to the requirements, by a ladle analysis and by a statement that the manufacturing processes have remained comparable;

or

- (2) in the absence of the data mentioned in (1) (a), by proof stress tests at the design temperature stated on the individual order.

NOTES

1. By special arrangement between the plate manufacturer and the boilermaker and/or his representative, proof stress tests may be required for the individual order.
2. For all steels (carbon or alloy),
 - (a) when the steelmaker has collected on the grade of steel used a sufficient number of tests for application to a statistical definition of E_t (see Part III, clause 1.1), E_t should be equal to the average value of the test results at temperature t less two standard deviations;
 - (b) when a sufficient number of tests is not available, E_t should be taken as a minimum value guaranteed by the steelmaker which should be checked at the time of acceptance. For carbon steels the value of the proof stress given by the ratio E_t/R_{20} (taken from Table 1) may be taken without verification at the time of acceptance.

1.6.5.2 If a registered national standard includes certified ratios E_t/R_{20} higher than those in Table 1, or minimum proof stress values higher than those calculated from Table 1, or higher values for S_R than are given in Table 2, these higher values may be applicable. Such higher values should be in accordance with the requirements of clause 1.6.5.1.

1.7 Tests

1.7.1 Each rolled plate should be tested separately. From each plate, strips sufficient for the required test pieces should be taken transversely to the final rolling direction. For all lengths of plates, one test strip should be taken from one end of the plate at a position midway between the edge and the centre. From plates having a length of 7 m (23 ft) or

more, or weighing 5 000 kg (11 000 lb) or more, a second test piece should be taken from one corner of the other end. If the plate is heat treated, the test strips generally should be separated from the plate only after the final heat treatment. If the strips are cut off beforehand, they should be heat treated together with the plates appertaining thereto and should rest on the corresponding plate ends.

TABLE 1 – Minimum values for the ratio of the stress at proof limit 0.2% at elevated temperatures (E_t) to the minimum specified tensile strength at room temperature (R_{20}) of carbon steel boiler plates

Temperature	250 °C* 482 °F	275 °C* 527 °F	300 °C 572 °F	325 °C 617 °F	350 °C 662 °F	375 °C 707 °F	400 °C 752 °F	425 °C 797 °F
E_t/R_{20}	0.40	0.38	0.36	0.34	0.33	0.32	0.31	0.30

* For temperatures lower than 300°C, any test required for acceptance purposes (in default of records of previous tests at these temperatures) should be made at 300°C, in which case the proof stress should be not less than the value obtained by calculation from the specified minimum tensile strength at room temperature and the above proof-ratio of 0.36 for 300 °C. This procedure should be used until a reliable method is standardized for proof stress determination at lower temperatures.

TABLE 2 – Tentative stresses for rupture, S_R , in 100 000 hours (see clause 1.6.5)

Temperature		Average values		Minimum values	
°C	°F	kgf/mm ²	psi	kgf/mm ²	psi
400	752	12.5	17 800	10.0	14 200
410	770	10.8	15 400	8.6	12 200
420	788	9.4	13 400	7.5	10 700
430	806	8.3	11 800	6.6	9 400
440	824	7.3	10 400	5.8	8 200
450	842	6.5	9 200	5.2	7 400
460	860	5.7	8 100	4.6	6 500
470	878	5.0	7 100	4.0	5 700
480	896	4.4	6 300	3.5	5 000
490	914	3.8	5 400	3.0	4 300
500	932	3.3	4 700	2.6	3 700

1.7.2 The gauge length should preferably be equal to $L_0 = 5.65 \sqrt{S_0}$ (see clause 1.6.4). Alternatively, other gauge lengths may be used, provided the elongation is expressed as the equivalent value on a gauge length of $5.65 \sqrt{S_0}$. In arbitration cases a test piece of gauge length equal to $5.65 \sqrt{S_0}$ should be used.

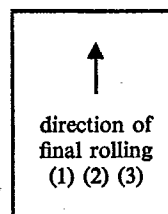
- 1.7.3 All data on the tensile properties apply for transverse test samples. The mechanical values given in clauses 1.6.2 to 1.6.5.2 should be verified on test pieces in the normalized condition. In the case of plates that are to be stress-relieved after fabrication, the test pieces representing the plates should be given a simulated stress-relieving treatment unless otherwise agreed. This treatment should be carried out at $600 \pm 10^\circ\text{C}$ ($1112 \pm 18^\circ\text{F}$) for 3 hours unless otherwise agreed.
- 1.7.4 If the result of the tensile test fails to meet the prescribed requirements, two retests should be made, both of which should satisfy the requirements.
- 1.7.5 In arbitration cases, round test bars with $L_0 = 5d_0$ should be used. For plate thicknesses exceeding 60 mm (2.36 in) these pieces should be taken from the exterior third of the plate cross-section.
- 1.7.6 If the unsatisfactory result of a test is obviously due to technical conditions of the testing method or to a closely limited defect of a test piece, then the failure can be left out of consideration in the decision on the fulfilment of the requirements and another test piece may be substituted.
- 1.7.7 If the unsatisfactory result of a test is due to an unfavourable heat treatment, the plate and the test strip may be heat treated again. Following this, the entire test should be repeated.

1.8 Marking

The plates should be marked legibly by stamping to show

- (1) the identification symbols for the type of steel as given in the applied national standard or specification,
- (2) the brand of the manufacturer,
- (3) symbols, letters, or numbers which relate the test certificates, test pieces, plates and heats to each other.

The location of the marking should be at one end of the plate, in the middle, so that the symbols, letters, or numbers may be read in the direction of final rolling, as shown below.



2. TUBES OF CARBON STEEL FOR BOILERS AND SUPERHEATERS

2.1 Scope

These provisions cover seamless and electric resistance welded tubes of carbon steel suitable for welding for use in the construction of boilers and superheaters subject to internal and external pressure.

NOTE. – In Part II the word “tube” also refers to “pipe”.

2.2 Manufacture

2.2.1 The steel for tubes conforming to these provisions should be made by the open-hearth or the electric furnace process or by any other process which gives steel having equivalent properties.

2.2.1.1 If rimmed steel is used in the manufacture of electric resistance welded tubes, the strips should be rolled in single widths and should not be slit longitudinally except to trim the edges.

2.2.2 The tubes may be seamless or electric resistance welded, hot finished or cold finished.

2.3 Chemical composition

The ladle analysis, which should be reported to the boilermaker, should conform to the following requirements:

Carbon	0.25 %* maximum
Silicon	0.40 % maximum
Manganese	1.40 % maximum
Phosphorus	0.05 % maximum
Sulphur	0.05 % maximum

When the ladle analysis is not available, the analysis of sample tubes selected at random may be used.

2.4 Heat treatment

2.4.1 Tubes which are hot finished at a temperature sufficient to soften the material need not be further heat treated except by arrangement with the boilermaker.

2.4.2 Tubes which are cold drawn should afterwards be suitably heat treated throughout their length.

2.4.3 Electric resistance welded tubes should be suitably heat treated throughout their length.

* A carbon content not exceeding 0.35 % may be permitted in accordance with registered national standards by agreement with the boilermaker, inspecting authority, and the purchaser of the boiler.

2.5 Defects

The tubes should have a workmanlike finish and be clean and free from injurious defects. The ends should be cut reasonably square and be free of burrs.

2.6 Mechanical properties

- 2.6.1 These provisions cover one quality group of steels determined by the ratio of stress at proof limit 0.2 % at elevated temperatures to the minimum specified tensile strength at room temperature.

NOTE. - The term "stress at proof limit 0.2 %" used herein means the stress for 0.2 % offset. (For definition see ISO Recommendation R 82, *Tensile testing of steel*). For acceptance tests at room temperature, the upper yield point when it is clearly defined should be taken in place of stress at proof limit 0.2 %. The stress at proof limit 0.2 % for elevated temperatures should be determined according to ISO Recommendation R 205, *Determination of proof stress and proving test for steel at elevated temperatures*. At elevated temperatures where a distinct yield point occurs, ISO Recommendation R 205 is not applicable and reference should be made to ISO Recommendation R 783, *Mechanical testing of steel at elevated temperatures - Determination of lower yield stress and proof test and proving test*.

- 2.6.2 The specified minimum tensile strength of material cut from finished tubes should be at least 31 kgf/mm² (44 000 psi). The minimum specified tensile strength should not exceed 50 kgf/mm² (71 000 psi). The tensile strength should not exceed 62 kgf/mm² (88 000 psi).
- 2.6.3 The upper yield point at room temperature should be not less than 50 % of the specified minimum tensile strength at room temperature. The actual value of the upper yield point at room temperature of the steel should be reported to the boilermaker for his information.

TABLE 3 - Minimum values for the ratio of the stress at proof limit 0.2 % at elevated temperatures (E_t) to the minimum specified tensile strength at room temperature (R_{20}) of carbon steel boiler tubes

Temperature	250 °C* 482 °F	275 °C* 527 °F	300 °C 572 °F	325 °C 617 °F	350 °C 662 °F	375 °C 707 °F	400 °C 752 °F	425 °C 797 °F
E_t/R_{20}	0.40	0.38	0.36	0.34	0.33	0.32	0.31	0.30

* For temperatures lower than 300 °C, any test required for acceptance purposes (in default of records of previous tests at these temperatures) should be made at 300 °C, in which case the proof stress should be not less than the value obtained by calculation from the specified minimum tensile strength at room temperature and the above ratio of 0.36 for 300 °C. This procedure should be used until a reliable method is standardized for proof stress determination at lower temperatures.



TABLE 4 - Tentative stresses for rupture, S_R , in 100 000 hours (see clause 2.6.5)

Temperature		Average values		Minimum values	
°C	°F	kgf/mm ²	psi	kgf/mm ²	psi
400	752	12.5	17 800	10.0	14 200
410	770	10.8	15 400	8.6	12 200
420	788	9.4	13 400	7.5	10 700
430	806	8.3	11 800	6.6	9 400
440	824	7.3	10 400	5.8	8 200
450	842	6.5	9 200	5.2	7 400
460	860	5.7	8 100	4.6	6 500
470	878	5.0	7 100	4.0	5 700
480	896	4.4	6 300	3.5	5 000
490	914	3.8	5 400	3.0	4 300
500	932	3.3	4 700	2.6	3 700

2.6.4 The breaking elongation in % should be greater than or equal to

$$\frac{100 - R_m}{2.2}$$

where

R_m = measured tensile strength at room temperature in kilogrammes-force per square millimetre,

$$\left(R \text{ kgf/mm}^2 = \frac{R \text{ psi}}{1422} \right)$$

100 = a quality index,

2.2 = a constant which is valid only when $L_0 = 5.65 \sqrt{S_0}$

where

L_0 = gauge length,

S_0 = original cross-section of test piece.

2.6.5 The minimum values of the stress at proof limit 0.2 % at elevated temperatures (symbol E_t , see Part III, clause 1.1) of the steels covered by these provisions can be calculated by multiplying the specified minimum tensile strength at room temperature (R_{20}) by the ratio (E_t/R_{20}) given in Table 3.

For the stresses to rupture in 100 000 hours, S_R (see Part III, clause 1.1), tentative figures are given in Table 4, only for information purposes. These values will be revised periodically.

NOTE. - Sufficient data have not yet been collected for giving values of stresses producing a creep of 1 % after 100 000 hours.

2.6.5.1 The tube manufacturer should satisfy the boilermaker and his representative that the steel supplied is capable of meeting the value E_t

- (1) (a) by producing adequate records of test results on the type of steel concerned, and
- (b) by showing that the steel supplied actually conforms to requirements by a ladle analysis and a statement that the manufacturing processes have remained comparable;

OR

- (2) in the absence of the data mentioned in (1) (a), by proof stress tests at the design temperature stated on the individual order.

NOTES

1. By special arrangement between the tube manufacturer and the boilermaker and/or his representative, proof stress tests may be required for the individual order.
2. For all steels (carbon or alloy),
 - (a) when the steelmaker has collected on the grade of steel used a sufficient number of tests for application to a statistical definition of E_t (see Part III, clause 1.1), E_t should be equal to the average value of the test results at temperature t less two standard deviations;
 - (b) when a sufficient number of tests is not available, E_t should be taken as a minimum value guaranteed by the steelmaker which should be checked at the time of acceptance. For carbon steels, the value of the proof stress given by ratio E_t/R_{20} (taken from Table 3) may be taken without verification at the time of acceptance.

2.6.5.2 If a registered national standard includes certified ratios E_t/R_{20} higher than those shown in Table 3, or minimum proof stress values higher than those calculated from Table 3, or higher values for S_R than are given in Table 4, these higher values may be applicable. Such higher values should be in accordance with the requirements of clause 2.6.5.1 above.

2.7 Tests

2.7.1 *Number of tests.* For batches of 400 or less than 400 tubes, one tube per lot of 50 tubes, or 2 % of the total number of tubes, at the option of the manufacturer, should be submitted to a tensile test, a flattening test, and a drift-expanding test or flanging test. For batches of more than 400 tubes, one additional tube out of each 100 tubes or part thereof above 400 tubes should be tested.

The drift expanding and flanging tests apply only for tubes of outside diameter not greater than 150 mm (6 in) and a thickness not greater than 9 mm (3/8 in).

NOTE. — By "batch" is meant a group of tubes of the same diameter and thickness manufactured from metal of the same specifications and of the same manufacture.

2.7.2 Tensile test. The test shall be carried out in accordance with ISO Recommendation R 375, *Tensile testing of steel tubes*. The test pieces should, at the option of the manufacturer, be cut from the tube in the longitudinal direction, of the full cross-section of the tube or, where it is practicable, be taken transversely. The test piece should not be further heat treated or straightened within the gauge length. The gauge length should preferably be equal to $L_0 = 5.65 \sqrt{S_0}$ (see clause 2.6.4). Alternatively, other gauge lengths may be used, provided the elongation is expressed as the equivalent value on a gauge length of $5.65 \sqrt{S_0}$. In arbitration cases a test piece of gauge length equal to $5.65 \sqrt{S_0}$ should be used.

2.7.3 Flanging and drift-expanding test. At the option of the manufacturer one of the following tests should be carried out:

- (1) Flanging test according to ISO Recommendation R 165, *Flanging test on steel tubes*. The test consists in forming on the end of a tube, or on the end of a test piece cut from a tube, a flange in a plane perpendicular to the axis of the tube. The outside diameter of the flange should exceed the specified outside diameter of the tube by the amount shown in Table 5, and after flanging the tube should show no crack or flaw.
- (2) Drift-expanding test according to ISO Recommendation R 166, *Drift expanding test on steel tubes*. The test piece should, without cracking, be expanded by a mandrel having an included angle of 30°, 45° or 60°, at the option of the manufacturer, to increase the outside diameter according to Table 5.

TABLE 5 – Minimum increase of outside diameter of tubes in flanging and drift-expanding tests

Type of test	Minimum specified tensile strength (R)		Outside diameter of the tube (D)	Increase of outside diameter of the tube
	kgf/mm ²	psi		
Flanging test	$R < 42$	$R < 60\ 000$	A: $D \leq 63.5$ mm (2½ in) B: 63.5 mm (2½ in) $< D \leq 150$ mm (5.9 in)	%
			A	17
	$R \geq 42$	$R \geq 60\ 000$	B	11
			A	14
Drift-expanding test			B	8
			A	17
			B	11



- 2.7.4 *Flattening test.* The test shall be carried out in accordance with ISO Recommendation R 202, *Flattening test on steel tubes.*

The test piece should show no crack or flaw when the distance H , expressed in millimetres, between the plates has reached the value given by the formula

$$H = \frac{(1 + c) a}{c + \frac{a}{D}}$$

where

a = thickness of the tube, expressed in millimetres,

D = outside diameter of the tube, expressed in millimetres,

c = constant as given below.

c = 0.09 for steel having a specified minimum tensile strength from 31 kgf/mm² (44 000 psi) up to and including 35 kgf/mm² (49 800 psi).

c = 0.07 for steel having a specified minimum tensile strength over 35 kgf/mm² (49 800 psi) up to and including 42 kgf/mm² (60 000 psi).

c = 0.05 for steel having a specified minimum tensile strength over 42 kgf/mm² (60 000 psi) up to and including 50 kgf/mm² (71 000 psi).

For electric resistance welded tubes, the weld should be placed in the line of maximum bend.

- 2.7.5 *Hydraulic test.* Each tube should be tested by hydraulic pressure on completion of manufacture. The test pressure should be one and a half times the design pressure, but in any case should not be less than 0.70 kgf/mm² (1000 psi) nor greater than the pressure calculated from the formula

$$P = \frac{2 S e}{D}$$

where

P = test pressure,

D = outside diameter of the tube,

e = nominal wall thickness of the tube,

S = stress, which should be taken as 40 % of the minimum tensile strength at room temperature as specified in the order.

- 2.7.6 If the result of one of the tests fails to meet the prescribed requirements, two retests should be made both of which should satisfy the requirements. If the results of the tests do not satisfy the requirements, the lot of tubes represented by the test samples should be rejected.

2.7.7 If the unsatisfactory result of a test is obviously due to technical conditions of the testing method or to a closely limited defect of a test piece, then the failure can be left out of consideration in the decision on the fulfilment of the requirements and another test piece may be substituted.

2.7.8 If the unsatisfactory result of a test is due to an unfavourable heat treatment, the tubes may be heat treated again. Following this, the entire test should be repeated.

2.8 Marking

2.8.1 Tubes which are both over 50 mm (2 in) outside diameter and over 1000 mm (39.37 in) in length should be marked legibly to show

- (1) the identification symbols for the type of steel as given in the applied national standard or specification,
- (2) the brand of the manufacturer,
- (3) whether seamless or electric resistance welded.

2.8.2 For tubes less than 50 mm (2 in) outside diameter and for tubes less than 1000 mm (39.37 in) in length, the information in clause 2.8.1 above may be marked on a tag securely attached to the bundle or box in which they are shipped.

2.8.3 For each shipment, the information to be provided to the purchaser should be such as is required by the relevant national specification.

3. SEAMLESS BOILER DRUMS OF CARBON STEEL

3.1 Scope

These provisions cover seamless drums having an internal diameter of at least 600 mm (23.62 in), of carbon steel suitable for welding. They apply to hollow bodies having

- integral ends,
- ends closed by means of dished plates,
- open ends for multi-part drums, or
- any combination of the above.

3.2 Manufacture

3.2.1 The steel for boiler drums conforming to these provisions should be made by the open-hearth or electric furnace process or by any other process which gives steel having equivalent properties.

3.2.2 The forging should be made from a solid cast ingot, which is punched, bored or trepanned, or from a hollow cast ingot. The wall thickness should be reduced during forging by at least one half.

3.3 Chemical composition

The ladle analysis, which should be reported to the boilermaker, should conform to the following requirements:

Carbon	0.25 %* maximum
Silicon	0.15 to 0.50 %
Manganese	1.40 % maximum
Phosphorus	0.05 % maximum
Sulphur	0.05 % maximum

3.4 Heat treatment

All drums should be suitably heat treated.

3.5 Defects

3.5.1 Where not machined, the forgings should have workmanlike surfaces as normally obtained by hot working. Provided that the minimum specified thickness is maintained, minor surface defects may be admitted and other defects removed by mechanical means so as to achieve a smooth level surface. Surface defects may be repaired, by welding only, with the consent of the boilermaker and the inspecting authority and provided that the drum is stress-relieved after welding where necessary.

* A carbon content not exceeding 0.35 % may be permitted in accordance with registered national standards by agreement with the boilermaker, inspecting authority, and the purchaser of the boiler.

- 3.5.2 The deviation from circularity in any section (see clause 3.7.7) should, in the case of normalized drums, not exceed 2 % and, in the case of stress-relieved drums, 1 %. The deviation from a straight line should not amount to more than 0.3 % of the cylindrical length.

3.6 Mechanical properties

- 3.6.1 These provisions cover one quality group of steels determined by the ratio of stress at proof limit 0.2 % at elevated temperatures to the minimum specified tensile strength at room temperature.

NOTE. — The term "stress at proof limit 0.2 %" (for definition see ISO Recommendation R 82, *Tensile testing of steel*) used herein means the stress for 0.2 % offset. For acceptance tests at room temperature, the upper yield point when it is clearly defined should be taken in place of stress at proof limit 0.2 %. The stress at proof limit 0.2 % for elevated temperatures should be determined according to ISO Recommendation R 205, *Determination of proof stress and proving test for steel at elevated temperatures*. At elevated temperatures where a distinct yield point occurs, ISO Recommendation R 205 is not applicable and reference should be made to ISO Recommendation R 783, *Mechanical testing of steel at elevated temperatures — Determination of lower yield stress and proof test and proving test*.

- 3.6.2 The specified minimum tensile strength of all steels should amount to at least 41 kgf/mm² (58 000 psi) and the maximum tensile strength to not more than 65 kgf/mm² (92 000 psi). Within this range, the maximum tensile strength specified on a particular order should not exceed the minimum specified tensile strength on the order by more than 10 kgf/mm² (14 220 psi).

- 3.6.3 The upper yield point at room temperature should be not less than 50 % of the specified minimum tensile strength at room temperature. The actual value of the upper yield point at room temperature of the steel should be reported to the boilermaker, for his information.

TABLE 6 — Minimum values for the ratio of the stress at proof limit 0.2 % at elevated temperatures (E_t) to the minimum specified tensile strength at room temperature (R_{20}) of forged boiler drums of carbon steel

Temperature	250 °C* 482 °F	275 °C* 527 °F	300 °C 572 °F	325 °C 617 °F	350 °C 662 °F	375 °C 707 °F	400 °C 752 °F	425 °C 797 °F
E_t/R_{20}	0.40	0.38	0.36	0.34	0.33	0.32	0.31	0.30

* For temperatures lower than 300 °C, any test required for acceptance purposes (in default of records of previous tests at these temperatures) should be made at 300 °C, in which case the proof stress should be not less than the value obtained by calculation from the specified minimum tensile strength at room temperature and the above proof-ratio of 0.36 for 300 °C. This procedure should be used until a reliable method is standardized for proof stress determination at lower temperatures.

TABLE 7 - Tentative stresses for rupture, S_R , in 100 000 hours (see clause 3.6.5)

Temperature		Average values		Minimum values	
°C	°F	kgf/mm ²	psi	kgf/mm ²	psi
400	752	12.5	17 800	10.0	14 200
410	770	10.8	15 400	8.6	12 200
420	788	9.4	13 400	7.5	10 700
430	806	8.3	11 800	6.6	9 400
440	824	7.3	10 400	5.8	8 200
450	842	6.5	9 200	5.2	7 400
460	860	5.7	8 100	4.6	6 500
470	878	5.0	7 100	4.0	5 700
480	896	4.4	6 300	3.5	5 000
490	914	3.8	5 400	3.0	4 300
500	932	3.3	4 700	2.6	3 700

3.6.4 The breaking elongation in % should be greater than or equal to

$$\frac{100 - R_m}{2.2}$$

where

R_m = measured tensile strength at room temperature, in kilogrammes-force per square millimetre,

$$\left(R \text{ kgf/mm}^2 = \frac{R \text{ psi}}{1422} \right)$$

100 = quality index,

2.2 = a constant which is valid only when $L_o = 5 d_o$

where

L_o = gauge length,

d_o = original diameter of round test piece.

3.6.5 The minimum values of the stress at proof limit 0.2 % at elevated temperatures (symbol E_t , see Part III, clause 1.1) of the steels covered by these provisions can be calculated by multiplying the specified minimum tensile strength at room temperature (R_{20}) by the ratio (E_t/R_{20}) given in Table 6.

For the stresses to rupture in 100 000 hours (symbol S_R , see Part III, clause 1.1) tentative figures are given in Table 7 only for information purposes. These values will be revised periodically.

NOTE. - Sufficient data have not yet been collected for giving values of stresses producing a creep of 1 % after 100 000 hours.

3.6.5.1 The drum manufacturer should satisfy the boilermaker and his representative that the steel supplied is capable of meeting the value E_t

- (1) (a) by producing adequate records of test results on the type of steel concerned, and
- (b) by showing that the steel supplied actually conforms to the requirements by a ladle analysis and a statement that the manufacturing processes have remained comparable;

or

- (2) in the absence of the data mentioned in (1) (a), by proof stress tests at the design temperature stated on the individual order.

NOTES

1. By special arrangement between the drum manufacturer and the boilermaker and/or his representative, proof stress tests may be required for the individual order.
2. For all steels (carbon or alloy),
 - (a) when the steelmaker has collected on the grade of steel used a sufficient number of tests for application to a statistical definition of E_t (see Part III, clause 1.1), E_t should be equal to the average value of the test results at temperature t less two standard deviations;
 - (a) when a sufficient number of tests is not available, E_t should be taken as a minimum value guaranteed by the steelmaker which should be checked at the time of acceptance. For carbon steels the value of the proof stress given by ratio E_t/R_{20} (taken from Table 6) may be taken without verification at the time of acceptance.

3.6.5.2 If a registered national standard includes certified ratios E_t/R_{20} higher than those shown in Table 6, or minimum proof stress values higher than those calculated from Table 6, or higher values for S_R than are given in Table 7, these higher values may be applicable. Such higher values are to be in accordance with the requirements of clause 3.6.5.1 above.

3.7 Tests

3.7.1 Each drum should be tested separately, that is, on test rings or prolongations of a minimum width of 50 mm (2 in) taken from both ends or from the open end in the case of a solid-ended drum.

These test pieces should be cut off in the case of closed hollow bodies before closing and they should be subjected to the same heat treatment as the drums themselves. In the case of open hollow bodies, the test pieces should be cut off after the completion of the heat treatment.

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- 3.7.2 A proportional test piece with $L_0 = 5 d_0$ should be used as test specimen.
- 3.7.3 All data on the tensile properties apply for tangential test samples in the condition in which the drum is delivered (see Part III, clause 1.1).
- 3.7.4 If the result of the tensile test fails to meet the prescribed requirements, two retests may be made, both of which should satisfy the requirements.
- 3.7.5 If the unsatisfactory result of a test is obviously due to technical conditions of the testing method or to a closely limited defect of a test piece, then the failure can be left out of consideration in the decision on the fulfilment of the requirements and another test piece may be substituted.
- 3.7.6 If the unsatisfactory result of a test is due to an unfavourable heat treatment, the forging may be heat treated again. Following this the entire test should be repeated.
- 3.7.7 In order to determine the deviation from circularity of the drums, the maximum and minimum internal diameter at one cross-section should be measured. From these measured values the percentage deviation from circularity should be calculated according to the formula

$$C = \frac{2 (d_{\max} - d_{\min})}{d_{\max} + d_{\min}} \times 100$$

where

C = percentage deviation from circularity of the drums,

$d_{\max}$ and $d_{\min}$ = maximum and minimum internal diameter at one cross-section.

In order to determine the deviation from a straight line, a stretched line should be placed longitudinally against the sides and its largest distance from the shell line concerned should be measured. From this distance, and from the length of the cylindrical shell, the deviation from the straight line should be calculated (see clause 3.5.2).

- 3.7.8 If specified in the order, a hydraulic test should be made in accordance with Part VI of this ISO Recommendation.

3.8 Marking

The drums should be marked legibly by stamping to show

- (1) the identification symbols for the type of steel as given in the applied national standard or specification,
- (2) the brand of the manufacturer,
- (3) symbols, letters, or numbers which relate the test certificates, test pieces, drums and heats to each other.

4. OTHER FORGED OR ROLLED PRESSURE PARTS FOR BOILER CONSTRUCTION OF CARBON STEEL

4.1 Scope

These provisions cover parts for boiler construction of carbon steel suitable for welding not included in the scope of Part II, sections 1, 2 and 3, of this ISO Recommendation.

They include, for example, flanges and welding fittings, as well as seamless headers (forged, rolled, or drawn) having an internal diameter of less than 600 mm (23.62 in).

4.2 Manufacture

4.2.1 The steel used for the parts to which these provisions apply should be made by the open-hearth or electric furnace process or by any other process which gives steel having equivalent properties.

4.2.2 In forging the parts, a reduction in thickness of at least 2 to 1 should be made.

4.3 Chemical composition

The ladle analysis, which should be reported to the boilermaker, should conform to the following requirements:

Carbon	0.25 %* maximum
Silicon	0.15 to 0.50 %
Manganese	1.40 % maximum
Phosphorus	0.05 % maximum
Sulphur	0.05 % maximum

4.4 Heat treatment

Unless otherwise agreed between the purchaser and manufacturer, all parts should be heat treated (see clause 1.4).

4.5 Defects

4.5.1 Where not machined, the pieces should have workmanlike surfaces as normally obtained by rolling, forging, or drawing. Provided that the minimum specified thickness is maintained, minor surface defects may be admitted and other defects removed by mechanical means so as to achieve a smooth level surface. Surface defects may be repaired, by welding only, with the consent of the boilermaker and the inspecting authority and provided that the part is stress-relieved after welding where necessary.

* A carbon content not exceeding 0.35 % may be permitted in accordance with registered national standards by agreement with the boilermaker, inspecting authority, and the purchaser of the boiler.

- 4.5.2 Round headers should be reasonably straight, smooth and circular. When the internal diameter is greater than 375 mm (15 in), the deviation from circularity (see Part II, clause 4.7.8) should not exceed 2 % and the deviation from the straight should not amount to more than 0.3 % of the cylindrical length. Headers of sections other than round should conform reasonably to the designed section.

4.6 Mechanical properties

- 4.6.1 These provisions cover one quality group of steels determined by the ratio of stress at proof limit 0.2 % at elevated temperatures to the specified minimum tensile strength at room temperature.

NOTE. - The term "stress at proof limit 0.2 %" (for definition see ISO Recommendation R 82, *Tensile testing of steel*) used herein means the stress for 0.2 % offset. For acceptance tests at room temperature, the upper yield point when it is clearly defined should be taken in place of stress at proof limit 0.2 %. The stress at proof limit 0.2 % for elevated temperatures should be determined according to ISO Recommendation R 205, *Determination of proof stress and proving test for steel at elevated temperatures*. At elevated temperatures where a distinct yield point occurs, ISO Recommendation R 205 is not applicable and reference should be made to ISO Recommendation R 783, *Mechanical testing of steel at elevated temperatures - Determination of lower yield stress and proof test and proving test*.

- 4.6.2 The specified minimum tensile strength of all steels should amount to at least 41 kgf/mm² (58 000 psi) and the maximum tensile strength to not more than 60 kgf/mm² (85 000 psi). Within this range, the maximum tensile strength specified on a particular order should not exceed the specified minimum tensile strength on the order by more than 10 kgf/mm² (14 220 psi).
- 4.6.3 The upper yield point at room temperature should not be less than 50 % of the minimum specified tensile strength at room temperature. The actual value of the upper yield point at room temperature of the steel must be reported to the boilermaker for his information.

TABLE 8 - Minimum values for the ratio of the stress at proof limit 0.2 % at elevated temperatures (E_t) to the minimum specified tensile strength at room temperature (R_{20}) of carbon steel forgings

Temperature	250 °C* 482 °F	275 °C* 527 °F	300 °C 572 °F	325 °C 617 °F	350 °C 662 °F	375 °C 707 °F	400 °C 752 °F	425 °C 797 °F
E_t/R_{20}	0.40	0.38	0.36	0.34	0.33	0.32	0.31	0.30

* For temperatures lower than 300 °C, any test required for acceptance purposes (in default of records of previous tests at these temperatures) should be made at 300 °C, in which case the proof stress should be not less than the value obtained by calculation from the minimum specified tensile strength at room temperature and the above proof-ratio. This procedure should be used until a reliable method is standardized for proof stress determination at lower temperatures.

TABLE 9 - Tentative stresses for rupture, S_R , in 100 000 hours (see clause 4.6.5)

Temperature		Average values		Minimum values	
°C	°F	kgf/mm ²	psi	kgf/mm ²	psi
400	752	12.5	17 800	10.0	14 200
410	770	10.8	15 400	8.6	12 200
420	788	9.4	13 400	7.5	10 700
430	806	8.3	11 800	6.6	9 400
440	824	7.3	10 400	5.8	8 200
450	842	6.5	9 200	5.2	7 400
460	860	5.7	8 100	4.6	6 500
470	878	5.0	7 100	4.0	5 700
480	896	4.4	6 300	3.5	5 000
490	914	3.8	5 400	3.0	4 300
500	932	3.3	4 700	2.6	3 700

4.6.4 The breaking elongation in % should be greater than or equal to

$$\frac{93 - R_m}{2.2}$$

where

R_m = measured tensile strength at room temperature, in kilogrammes-force per square millimetre,

$$\left(R \text{ kgf/mm}^2 = \frac{R \text{ psi}}{1422} \right)$$

93 = quality index (see Note below),

2.2 = a constant which is valid only when $L_o = 5d_o$

where

L_o = gauge length,

d_o = original diameter of round test piece.

NOTE. - The quality index 93 in the formula should be replaced by 100 for non-proportional test pieces.

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- 4.6.5 The minimum values of the stress at proof limit 0.2 % at elevated temperatures (symbol E_t , see Part III, clause 1.1) of the steels covered by these provisions can be calculated by multiplying the specified minimum tensile strength at room temperature (R_{20}) by the ratio (E_t/R_{20}) given in Table 8.

For the stresses to rupture in 100 000 hours (symbol S_R , see Part III, clause 1.1) tentative figures are given in Table 9 only for information purposes. These values will be revised periodically.

NOTE. - Sufficient data have not yet been collected for giving values of stresses producing a creep of 1 % after 100 000 hours.

- 4.6.5.1 The manufacturer should satisfy the boilermaker and his representative that the steel supplied is capable of meeting the value E_t

- (1) (a) by producing adequate records of test results on the type of steel concerned, and
- (b) by showing that the steel supplied actually conforms to the requirements, by ladle analysis and a statement that the manufacturing processes have remained comparable;

or

- (2) in the absence of the data mentioned in (1) (a), by proof stress tests at the design temperature stated on the individual order.

NOTES

1. By special arrangement between the manufacturer and the boilermaker and/or his representative, proof stress tests may be required for the individual order.
2. For all steels (carbon or alloy),
 - (a) when the steelmaker has collected on the grade of steel used a sufficient number of tests for application to a statistical definition of E_t (see Part III, clause 1.1), E_t should be equal to the average value of the test results at temperature t less two standard deviations;
 - (b) when a sufficient number of tests is not available, E_t should be taken as a minimum value guaranteed by the steelmaker which should be checked at the time of acceptance. For carbon steels the value of the proof stress given by ratio E_t/R_{20} (taken from Table 8) may be taken without verification at the time of acceptance.

- 4.6.5.2 If a registered national standard includes certified ratios E_t/R_{20} higher than those in Table 8, or minimum proof stress values higher than those calculated from Table 8, or higher values for S_R than are given in Table 9, these higher values may be applicable. Such higher values are to be in accordance with the requirements of clause 4.6.5.1 above.

4.7 Tests

- 4.7.1 For testing, either the parts themselves should be used or additional material of sufficient size for test pieces should be available. In the case of headers, for example, surplus lengths for test rings may be used. In the case of flanges swaged in dies, the punchings produced may be used as test pieces, in which case the identity of the material of the punching with that of the flange should be evidenced in an adequate manner. The test may be performed also on the semi-finished material, for example, a bar or a billet, provided it is given approximately the same reduction and heat treatment as the finished forging. For headers with closed ends, the test rings should be cut off before dishing or reducing and should be subjected to the same heat treatment as the headers themselves. In the case of headers which are closed by special covers, the test ring should be cut off after the heat treatment. Similar procedures should be used with the test pieces of other forgings.
- 4.7.2 For testing, pieces of one and the same cast and of the same heat treatment batch as well as of similar dimensions may be gathered into one group. At least one test piece should be made from each group.
- 4.7.3 A proportional test piece with $L_0 = 5d_0$ should be used as test specimen.
- 4.7.4 Tangential test pieces should be used for headers where possible. Generally, on headers with outside diameter less than 200 mm (7.87 in), longitudinal test pieces are allowed.
- 4.7.5 If the result of the tensile test fails to meet the prescribed requirements, two retests may be made, both of which should satisfy the requirements.
- 4.7.6 If the unsatisfactory result of a test is obviously due to technical conditions of the testing method or to a closely limited defect of a test piece, then the failure can be left out of consideration in the decision on the fulfilment of the requirements and another test piece may be substituted.
- 4.7.7 If the unsatisfactory result of a test is due to an unfavourable heat treatment, the part may be heat treated again. Following this the entire test should be repeated.
- 4.7.8 In order to determine the deviation from circularity of the headers, the maximum and the minimum external diameter at one cross-section should be measured. For these measured values the percentage deviation from circularity should be calculated according to the formula:

$$C = \frac{2(d_{\max} - d_{\min})}{d_{\max} + d_{\min}} \times 100$$

where

C = deviation from circularity of the headers,

$d_{\max}$ and $d_{\min}$ = maximum and minimum external diameter at one cross-section.

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In order to determine the deviation from a straight line, a stretched line should be placed longitudinally against the sides and its largest distance from the shell line concerned should be measured. From this distance, and from the length of the cylindrical shell, the deviation from the straight should be calculated (see clause 4.5.2 above).

- 4.7.9 If specified in the order, a hydraulic test should be made in accordance with Part VI of this ISO Recommendation.

4.8 Marking

The parts should be marked legibly by stamping to show

- (1) the identification symbols for the type of steel as given in the applied national standard or specification,
- (2) the brand of the manufacturer,
- (3) symbols, letters, or numbers which relate the test certificates, test pieces, parts and heats to each other.

5. CARBON STEEL CASTINGS FOR PRESSURE PARTS FOR BOILER CONSTRUCTION

5.1 Scope

These provisions cover carbon steel castings used in the construction of boilers.

5.2 Manufacture

The steel used for castings to which these provisions apply should be made by the open-hearth or electric furnace process or by any other process which gives steel having equivalent properties.

5.3 Chemical composition

The ladle analysis, which should be reported to the boilermaker, should conform to the following requirements:

Carbon	0.25 %* maximum
Silicon	0.60 % maximum
Manganese	1.40 % maximum
Phosphorus	0.05 % maximum
Sulphur	0.05 % maximum

* A carbon content not exceeding 0.35 % may be permitted in accordance with registered national standards by agreement with the boilermaker, inspecting authority, and the purchaser of the boiler.

5.4 Heat treatment

All steel castings should be heat treated by annealing, normalizing, or normalizing and tempering.

5.5 Defects

The steel castings should have clean surfaces and should be free from injurious defects. The specified permissible variations in size or thickness should not be exceeded. Defects may be repaired, by welding only, with the consent of the boilermaker and the inspecting authority, and provided that the castings are stress-relieved after welding where necessary.

5.6 Mechanical properties

- 5.6.1 These provisions cover one quality group of steels determined by the ratio of stress at proof limit 0.2 % at elevated temperatures to the minimum specified tensile strength at room temperature.

NOTE. — The term "stress at proof limit 0.2 %" used herein means the stress for 0.2 % offset. (For definition see ISO Recommendation R 82, *Tensile testing of steel*.) For acceptance tests at room temperature, the upper yield point when it is clearly defined should be taken in place of stress at proof limit 0.2 %. The stress at proof limit 0.2 % for elevated temperatures should be determined according to ISO Recommendation R 205, *Determination of proof stress and proving test for steel at elevated temperatures*. At elevated temperatures where a distinct yield point occurs, ISO Recommendation R 205 is not applicable and reference should be made to ISO Recommendation R 783, *Mechanical testing of steel at elevated temperatures — Determination of lower yield stress and proof test and proving test*.

- 5.6.2 For all types of steel castings conforming to these provisions, only minimum values for the tensile strength are fixed. These minimum values should be between 40 and 50 kgf/mm² (57 000 and 71 000 psi).

- 5.6.3 The upper yield point at room temperature should be not less than 50 % of the specified minimum tensile strength at room temperature. The actual value of the upper yield point at room temperature of the steel should be reported to the boilermaker for his information.

TABLE 10 — Minimum values for the ratio of the stress at proof limit 0.2 % at elevated temperatures (E_t) to the minimum specified tensile strength at room temperature (R_{20}) of carbon steel castings

Temperature	250 °C* 482 °F	275 °C* 527 °F	300 °C 572 °F	325 °C 617 °F	350 °C 662 °F	375 °C 707 °F	400 °C 752 °F	425 °C 797 °F
E_t/R_{20}	0.40	0.38	0.36	0.34	0.33	0.32	0.31	0.30

* For temperatures lower than 300 °C, any test required for acceptance purposes (in default of records of previous tests at these temperatures) should be made at 300 °C, in which case the proof stress should be not less than the value obtained by calculation from the minimum specified tensile strength at room temperature and the above proof-ratio of 0.36 % at 300 °C. This procedure should be used until a reliable method is standardized for proof stress determination at lower temperatures.

TABLE 11 - Tentative stresses for rupture, S_R , in 100 000 hours (see clause 5.6.5)

Temperature		Average values		Minimum values	
°C	°F	kgf/mm ²	psi	kgf/mm ²	psi
400	752	12.5	17 800	10.0	14 200
410	770	10.8	15 400	8.6	12 200
420	788	9.4	13 400	7.5	10 700
430	806	8.3	11 800	6.6	9 400
440	824	7.3	10 400	5.8	8 200
450	842	6.5	9 200	5.2	7 400
460	860	5.7	8 100	4.6	6 500
470	878	5.0	7 100	4.0	5 700
480	896	4.4	6 300	3.5	5 000
490	914	3.8	5 400	3.0	4 300
500	932	3.3	4 700	2.6	3 700

5.6.4 The breaking elongation in % should be greater than or equal to

$$\frac{93 - R_m}{2.2}$$

where

R_m = measured tensile strength at room temperature, in kilogrammes-force per square millimetre,

$$\left(R \text{ kgf/mm}^2 = \frac{R \text{ psi}}{1422} \right)$$

93 = a quality index,

2.2 = a constant which is valid only when $L_o = 5d_o$

where

L_o = gauge length,

d_o = original diameter of round test piece.

5.6.5 The minimum values of the stress at proof limit 0.2 % at elevated temperatures (symbol E_t , see Part III, clause 1.1) of the steels covered by these provisions can be calculated by multiplying the minimum specified tensile strength at room temperature (R_{20}) by the ratio (E_t/R_{20}) given in Table 10.

For the stresses to rupture in 100 000 hours (symbol S_R , see Part III, clause 1.1), tentative figures are given in Table 11 only for information purposes. These values will be revised periodically.

NOTE. — Sufficient data have not yet been collected for giving values of stresses producing a creep of 1 % after 100 000 hours.

5.6.5.1 The casting manufacturer should satisfy the boilermaker and his representative that the steel supplied is capable of meeting the value E_t

- (1) (a) by producing adequate records of the test results on the type of steel concerned, and
- (b) by showing that the steel supplied actually conforms to the requirements by ladle analysis and a statement that the manufacturing processes have remained comparable;

or

- (2) in the absence of the data mentioned in (1) (a), by proof stress tests at the design temperature stated on the individual order.

NOTES

1. By special arrangement between the casting manufacturer and the boilermaker and/or his representative, proof stress tests may be required for the individual order.
2. For all steels (carbon or alloy),
 - (a) when the steelmaker has collected on the grade of steel used a sufficient number of tests for application to a statistical definition of E_t (see Part III, clause 1.1), E_t should be equal to the average value of the test results at temperature t less two standard deviations;
 - (b) when a sufficient number of tests is not available, E_t should be taken as a minimum value guaranteed by the steelmaker which should be checked at the time of acceptance. For carbon steels the value of the proof stress given by ratio E_t/R_{20} (taken from Table 10) may be taken without verification at the time of acceptance.

5.6.5.2 If a registered national standard includes certified ratios E_t/R_{20} higher than those shown in Table 10 or minimum proof stress values higher than those calculated from Table 10 or higher values for S_R than are given in Table 11, these higher values may be applicable. Such higher values are to be in accordance with the requirements of clause 5.6.5.1 above.

5.7 Tests

5.7.1 Steel castings should be tested on test pieces which have been cast attached to the casting with a thickness corresponding to the controlling wall thickness. These test pieces should be cut off only after the final heat treatment. If it is inadequate or impossible to cast the test pieces attached to the casting, the test pieces may be taken from the casting itself or from test blocks of the same heat of steel which are cast separately. These test pieces should be heat treated together with the casting. If necessary, the location of the cast-on test pieces or the position of the test pieces as taken from the castings should be determined by agreement between purchaser and manufacturer.

- 5.7.2 Each heat of steel should be tested by at least one test piece. In special cases additional testing may be agreed upon.
- 5.7.3 A proportional test piece with $L_0 = 5d_0$ should be used as test specimen.
- 5.7.4 If the result of the tensile test fails to meet the prescribed requirements, two retests may be made, both of which should satisfy the requirements.
- 5.7.5 If the unsatisfactory result of a test is obviously due to technical conditions of the testing methods or to a closely limited defect of a test piece, then the failure can be left out of consideration in the decision on the fulfilment of the requirements and another test piece may be substituted.
- 5.7.6 If the unsatisfactory result of a test is due to an unfavourable heat treatment, the castings may be heat treated again. Following this, the entire test should be repeated.
- 5.7.7 The castings should be submitted to such tests for soundness as may be appropriate to the particular quality and design of the casting. This may include such tests as hydraulic test of at least one and a half times the design pressure, drop test, hammering test, drilling test, radiographic and other forms of non-destructive testing. The particular type of tests, the test conditions and the interpretation of the results should be agreed between purchaser and manufacturer.

5.8 Marking

A legible mark should be cast or stamped on the castings to show

- (1) the identification symbols for the type of steel as given in the applied national standard or specification,
- (2) the brand of the manufacturer,
- (3) symbols, letters, or numbers which relate the test certificates, test pieces, castings and heats to each other.

PART III

DESIGN - STRENGTH OF PRESSURE PARTS

FOREWORD

Part III of this ISO Recommendation does not cover all details of design. Where complete details are not given, it is intended that the manufacturer should be in a position to justify, upon the request of the inspecting authority, details of design which will be as safe as otherwise provided by this ISO Recommendation.

Part III applies without restriction to all steels (carbon steels and alloy steels).

1. ALLOWABLE STRESS

1.1 Definitions

Allowable stress (designated by the symbol f). The stress to be used in the formulae for the calculation of pressure parts.

NOTE. - The designer should determine this allowable stress from the material properties as defined below and the values given in clause 1.3.

t = metal temperature.

R_{20} = minimum tensile strength specified for the grade of steel concerned, at room temperature. (Test to be in accordance with ISO Recommendation R 82, *Tensile testing of steel*).

E_{20} = minimum yield strength specified for the grade of steel concerned, at room temperature. (Test to be in accordance with ISO Recommendation R 82).

E_t = minimum yield point stress at proof limit 0.2 % for the grade of steel concerned, at temperature t . (Test to be in accordance with ISO Recommendation R 205, *Determination of proof stress and proving test for steel at elevated temperatures*).

S_R = average stress for the grade of steel concerned to produce rupture in 100 000 hours at temperature t or, if the width of the end of the scatter band of results exceeds ± 20 % of the average value, 1.25 times the minimum stress at temperature t to produce rupture in 100 000 hours. (Test to be in accordance with ISO Recommendation R 206, *Creep stress rupture testing of steel at elevated temperatures*).

S_C = average stress to produce an elongation (creep), for the grade of steel concerned, of 1 % in 100 000 hours at temperature t . (Test to be in accordance with ISO Recommendations R 203, *Interrupted creep testing of steel at elevated temperatures (Load and temperature interrupted)*, and R 204, *Non-interrupted creep testing of steel at elevated temperatures*).

The above characteristics of the materials correspond to their properties under service conditions.

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- 1.2 The material specifications registered in accordance with Part I of this ISO Recommendation should use the values given in Part II or should give values for the above material properties at the various temperatures for which the grade of steel concerned may be used.

NOTE. - Where values for S_C and S_R have not been established in an ISO Recommendation, the national standards in force should be used.

- 1.3 The allowable stress f is the lowest of the four following values:

$$f = \frac{E_t}{1.6} \qquad f = \frac{R_{20}}{2.7}$$

$$f = \frac{S_R}{1.6} \qquad f = \frac{S_C}{1.0}$$

At temperatures below 250 °C (482 °F), the value of f for 250 °C should be used.

- 1.4 The allowable stress for cast steels should be 80 % of that obtained from clause 1.3.
- 1.5 The allowable stress used in the calculation of riveted joints should not exceed one quarter of the specified minimum tensile strength at room temperature.

2. CALCULATIONS OF STRENGTH OF PRESSURE PARTS

2.1 Design pressure and calculation pressure

For natural or assisted circulation boilers, the design pressure is the maximum allowable working pressure in the steam drum of the boiler.

For once-through forced-circulation boilers, the design pressure is the maximum allowable working pressure at the final superheater steam outlet.

For all boilers the calculation pressure of any part is the design pressure adjusted to take into account the pressure drops corresponding to the most severe conditions of pressure drop and hydraulic head.

2.2 Units used

All formulae in Part III of this ISO Recommendation are dimensionally consistent. Consequently, the same units should be used for thicknesses, radii, and diameters on the one hand, and for stresses and pressures on the other hand.

The unit of surface to be used should be the surface of a square whose side is equal to the unit of length.

2.3 Cylindrical shells, drums and headers under internal pressure

2.3.1 Calculation formula. The minimum thickness of a cylindrical shell is given by the following formula:

$$e = \frac{PR}{fz - 0.5P} + e_1$$

where

- e = minimum thickness of the shell or shell section,
- P = calculation pressure (defined in clause 2.1),
- R = inside radius of the shell or shell section,
- f = allowable stress, defined in section 1, for the service temperature of the metal t (defined in clause 2.3.2),
- z = efficiency (expressed as a fraction) of longitudinal welded or riveted joints or of ligaments between tube holes or other openings in the shell, whichever applies and gives the lowest value,
- e_1 = additive thickness equal to 0.75 mm (0.03 in) in order to take corrosion into account.

The minimum thickness should be not less than

5 mm (0.197 in) for welded construction,
7 mm (0.276 in) for riveted construction.

2.3.1.1 CONDITIONS FOR APPLICATION OF FORMULA. The formula in clause 2.3.1 applies under the following conditions only:

- (a) where the ratio of the outside radius to inside radius does not exceed 1.5;
- (b) in the case of a shell consisting of several sections of different thicknesses (see Fig. 1), median lines of sections shall be an extension of each other at each longitudinal joint within the limits of the tolerances specified in clause 2.3.1.3.

2.3.1.2 INFLUENCE OF WEIGHT ON A CYLINDRICAL SHELL. In addition to the application of these requirements in respect to circumferential stresses in drums, the design of all drums should be investigated from the point of view of longitudinal stresses.

The investigation should include stresses due to weight, to pressure on the ends, and to bending caused by each.

The thicknesses of the shell should be determined in such a manner that in any line of holes whether longitudinal, circumferential or diagonal, the resultant stress (being the sum of the stresses due to the pressure and the stresses due to the weight) does not exceed the allowable stress.

2.3.1.3 INFLUENCE OF OUT-OF-ROUNDNESS ON A CYLINDRICAL SHELL. In the calculation of thickness of cylindrical shells, stresses due to out-of-roundness up to 1 % are not taken into consideration, and cylindrical shells should conform to the tolerances shown elsewhere in this ISO Recommendation.

2.3.1.4 INFLUENCE OF THERMAL STRESSES. Drums and headers of thickness greater than 30 mm (1.18 in) should not be exposed to combustion gases having an anticipated temperature in excess of 650 °C (1202 °F), unless they are efficiently cooled by closely arranged tubes accommodated therein.

2.3.1.5 INFLUENCE OF OTHER STRESS FACTORS. In addition to the requirements in clauses 2.3.1.2, 2.3.1.3 and 2.3.1.4, consideration should also be given to stresses such as those due to nozzle loadings, local membrane stresses, cyclic loadings, etc.

2.3.2 *Metal temperature t .* The metal temperature t , to be used in determining the allowable stress f , should be the temperature of the metal at the middle of the wall of the shell.

2.3.2.1 For nonfired elements and those adequately protected by insulation from the hot gases, the metal temperature t should be equal to the maximum temperature of the interior fluid.

2.3.2.2 For fired elements, the temperature of the metal t should be determined by the manufacturer; it should be not less than the maximum temperature of the interior fluid increased by 25 °C (45 °F).

2.3.3 *Efficiency of longitudinal welded joints.* For butt-welded joints conforming to the construction and control requirements stipulated in Part IV, section 1, the coefficient e should be equal to 1.

2.3.4 Efficiency of riveted joints

2.3.4.1 EFFICIENCY OF LONGITUDINAL RIVETED JOINTS. The efficiency of a longitudinal riveted joint is the lowest of the values given by the following formulae:

$$(1) \quad z = \frac{p - d}{p} = \text{strength of the plate along the outer row of rivets in relation to the solid plate;}$$

$$(2) \quad z = \frac{T_r}{R_{20}} \times \frac{1.875 B + C}{p e} = \text{shearing strength of all the rivets in relation to the solid plate;}$$

$$(3) \quad z = \frac{p - 2d}{p} + \left(\frac{T_r}{R_{20}} \times \frac{AK}{p e} \right) = \text{combined strength of rivets along the outer row and of the plate along the inner row of rivets in relation to the solid plate.}$$

NOTE. - Formula (3) applies only to joints in which the number of rivets along the inner row or rows is double that of those in the outer row (see Fig. 2).

In these formulae

A = cross-sectional area of one rivet hole in the outer row of rivets,

B = total cross-sectional area of rivet holes in pitch p where the rivets are in double shear,

C = total cross-sectional area of rivet holes in pitch p where the rivets are in single shear,

d = diameter of the rivet hole,

NOTE. - When rivets have different diameters in different rows, the diameter of a rivet hole in the outer row is taken as d in formula (1) and the diameter of a rivet hole in the inner row is taken as d in formula (3).

e = thickness of the plate,

K = 1 for rivets in single shear,

K = 1.875 for rivets in double shear,

p = pitch of rivet holes in the outer row,

R_{20} = specified minimum tensile strength of the shell material,

T_r = shear strength of rivets (= 0.8 of the specified minimum tensile strength of the rivets).

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Longitudinal lap and longitudinal single butt joints are not recommended and in any case should not be used above 750 mm (30 in) diameter, and for pressures exceeding 5 kgf/cm² (70 psi).

2.3.4.2 RIVETED CIRCUMFERENTIAL AND DRUM END SEAMS. The joint efficiency of circumferential seams including the seams joining drum heads to drum shells should be equal to or greater than one-half the joint efficiency on the longitudinal axis, except in Lancashire and Cornish boilers where the strength of the seams joining the drum heads with the cylindrical shells should be not less than 38 % of the calculated thickness of the plate (see clause 2.3.1). The strength of the intermediate seams should be not less than 50 % of that of the longitudinal seams and in no case less than 42 % of the strength of the calculated thickness of the plate (see clause 2.3.1). Where the shell plate thickness exceeds 17.5 mm (11/16 in), the intermediate circumferential seams should be double riveted.

2.3.4.3 THICKNESS OF BUTT STRAPS. Where the thickness of the shell plates does not exceed 19 mm (3/4 in), the thickness of both the inner and outer butt straps should be equal to the thickness of the shell plate. Where the thickness of the shell plates exceeds 19 mm (3/4 in), the outer butt strap may be made 0.875 of the thickness of the shell, but not less than 19 mm (3/4 in). The inner butt strap in such cases should be made 3 mm (1/8 in) thicker than the outer butt straps or the same thickness as the shell plate, whichever is less.

2.3.4.4 SIZE OF RIVET HOLES. The diameter of the holes in longitudinal and circumferential seams should be not less than the thickness of the shell plate.

2.3.4.5 MAXIMUM PITCH OF RIVETS OF LONGITUDINAL JOINTS. The maximum pitch of rivets in longitudinal joints should be

$$eK' + 41 \text{ mm (1 5/8 in)}$$

where e = thickness of the plate.

The value of K' is given in Table 12.

TABLE 12 - Values of coefficient K' for riveted joints

Number of rivets in the exterior pitch p	K' for double-strap joints
1	1.75
2	3.50
3	4.63
4	5.52
5	6.00

- 2.3.4.6** DISTANCE BETWEEN RIVET ROWS AND BETWEEN RIVETS AND THE EDGE OF THE OUTER SURFACE OF THE PLATE. The clear space between a rivet hole and the nearest edge of the plate should be not less than the diameter of the rivet hole; i.e. the centre of the rivet hole should be at a distance not less than one and one-half diameters from the nearest edge of the plate.

The distance between the rows of rivets in joints whether lapped or fitted with butt straps should be not less than that given in the following rules:

(a) *Staggered riveting*

- (1) If adjacent rows have an equal number of rivets, the distance between the rows should be not less than $0.33 p + 0.67 d$.
- (2) If the number of rivets in one row is one-half of the number of rivets in the adjacent row, the distance between the rows should be not less than $3 d$, and not less than $0.2 p + 1.15 d$.
- (3) If the number of rivets in the inner rows is double that in the outer rows, the distance between two adjacent inner rows having a complete number of rivets should be not less than $0.165 p + 0.67 d$.

(b) *Chain riveting (in line)*

- (1) If adjacent rows have an equal number of rivets, the distance between the rows should be not less than $2 d$.
- (2) If the number of rivets in one row is one-half of the number of rivets in an adjacent row, the distance between the rows should be not less than $3 d$.
- (3) If the number of rivets in the inner rows is double the number of rivets in the outer row, the distance between the adjacent inner rows having the full number of rivets should be not less than $2 d$.

where

d = diameter of rivet holes,

p = pitch of rivet holes.

NOTE. — If the number of rivets in the outer row is less than the number of rivets in the inner row, p should be taken as the pitch of the rivets in the outer row.

2.3.5 Efficiency of ligaments between tube holes

2.3.5.1 DRILLING PARALLEL TO THE AXIS. When tube holes are drilled in a cylindrical shell parallel to its axis, the efficiency z of ligaments should be determined as follows:

- (a) *Regular drilling.* When the holes are regularly spaced along the line in question, the following formula should apply:

$$z = \frac{p - d}{p}$$

where

p = pitch of tube holes,

d = diameter of tube holes.

- (b) *Irregular drilling* (see Fig. 3). When the pitch of holes along the line in question is unequal, the following formula should apply:

$$z = \frac{p - n d}{p}$$

where

p = total length between centres corresponding to n consecutive ligaments,

NOTE. - This length should conform to conditions specified in clause 2.3.5.4.

n = number of tube holes in length p ,

d = diameter of tube holes.

2.3.5.2 CIRCUMFERENTIAL DRILLING. When bending stresses due to weight are negligible, the efficiency of ligaments between holes in the case of a circumferential drilling should not be used in the calculation of thickness of a cylindrical shell, provided that the efficiency of circumferential ligaments calculated according to clause 2.3.5.1 (a) or 2.3.5.1 (b) is at least one-half of the efficiency of longitudinal ligaments.

If this condition is not complied with, clause 2.3.1 should be used with z equal to twice the efficiency of circumferential ligaments calculated according to clause 2.3.5.1 (a) or 2.3.5.1 (b). For application of clauses 2.3.5.1 (a) and 2.3.5.1 (b), the pitch of tubes should be measured either on the flat plate before rolling or along the median line after rolling.

2.3.5.3 DRILLING ALONG A DIAGONAL LINE

- (a) When bending stresses due to weight are negligible and the tube holes are arranged along a diagonal line with respect to the longitudinal axis, the efficiency z of corresponding ligaments is given in Figure 4, with the ratio $\frac{b}{a}$ on the abscissa and the ratio

$$\frac{2a-d}{2a} \text{ or } \frac{d}{a} \text{ used as a parameter,}$$

where

a and b are measured as shown in Figures 5 and 6,

d = diameter of the tube holes.

NOTES

1. The dimension b should be measured either on the flat plate before rolling or on the median line after rolling.
2. The data given on Figure 4 are based on the following formula:

$$z = \frac{2}{A + B + \sqrt{(A - B)^2 + 4C^2}}$$

where

$$A = \frac{\cos^2 \alpha + 1}{2 \left(1 - \frac{d \cos \alpha}{a} \right)}$$

$$B = \frac{1}{2} \left(1 - \frac{d \cos \alpha}{a} \right) (\sin^2 \alpha + 1)$$

$$C = \frac{\sin \alpha \cos \alpha}{2 \left(1 - \frac{d \cos \alpha}{a} \right)}$$

$$\cos \alpha = \frac{1}{\sqrt{1 + \frac{b^2}{a^2}}}$$

$$\sin \alpha = \frac{1}{\sqrt{1 + \frac{a^2}{b^2}}}$$

(α = angle of centreline of cylinder to centreline of diagonal holes)



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- (b) The same rule as in clause 2.3.5.3 (a) should apply for the case of drilling holes to a regular saw-tooth pattern as shown in Figure 7.
- (c) In the case of a regular staggered spacing of tube holes, (see Fig. 5), the smallest value of the efficiency z of all the ligaments, longitudinal, circumferential, and diagonal, is given in Figure 8 by the ratio $\frac{P_c}{P_L}$ on the abscissa, and the ratio

$$\frac{P_L - d}{P_L} \text{ or } \frac{d}{a}$$

where

d = diameter of the tube holes,

P_c = $2b$ = twice the distance between circumferential rows of holes,

P_L = $2a$ = twice the distance between axial rows of holes.

NOTE. – The dimension P_c should be measured either on the flat plate before rolling or on the median line after rolling. The data on Figure 8 are based on the same formulae as Figure 4.

2.3.5.4 LENGTH WHICH CAN BE TAKEN INTO CONSIDERATION FOR DRILLING OF UNEQUALLY SPACED HOLES. Where holes are unequally spaced, the average ligament efficiency z (used in the formula in clause 2.3.1) should be not more than can be calculated (using the formula in clause 2.3.5.1 (b)) at any part over a length equal to the inside diameter of the shell (1524 mm (60 in) maximum), or not more than 1.25 times that obtained over a length equal to the inside radius (762 mm (30 in) maximum) taken at the least favourable part.

A lower efficiency calculated over a shorter length need not be considered

If the unequally spaced holes form a symmetrical pattern over a length greater than the inside diameter of the shell with a maximum of 1524 mm (60 in) to give a greater efficiency over such length than is obtained above, then this greater efficiency may be used.

When holes spaced longitudinally along a drum are not in a straight line, the equivalent longitudinal pitch for each spacing may be used in the application of the above rules. This equivalent pitch is obtained by multiplying the actual longitudinal pitch by the equivalent efficiency obtained from Figure 4 for each spacing.

2.3.6 Openings in cylindrical shells

2.3.6.1 MAXIMUM DIAMETER FOR AN UNREINFORCED OPENING

- (a) Openings in a definite pattern, such as tube holes, may be designed in accordance with the rules for ligaments (clause 2.3.5), provided the diameter of the largest hole in the group does not exceed that permitted in (b) below.
- (b) The maximum diameter d of any unreinforced opening should not exceed that permitted by Figures 9 and 10 with a maximum of 203 mm (8 in).

The notations in Figures 9 and 10 are defined as follows:

$$K = \frac{P \cdot D}{1.82fe}$$

where

P = calculation pressure as defined in clause 2.1,

d = maximum allowable diameter of opening (in the case of an opening of elliptical or obround form, the mean value of the two axes of the opening shall be taken for d),

D = outer diameter of the shell,

e = actual thickness of the shell,

f = allowable stress (see clause 2.3.1).

When K has a value of unity or greater, the maximum size of an unreinforced opening should be 51 mm (2 in).

- (c) For a riveted non-watertube boiler, the maximum diameter of an unreinforced opening should be 2 1/2 times the thickness of the plate plus 70 mm (2 3/4 in).

2.3.6.2 REINFORCEMENT OF OPENINGS IN WELDED CONSTRUCTION. For openings in welded construction requiring reinforcement, compensation should be considered adequate when the area X to be compensated is less than the compensating area Y (see Fig. 11 and 12).

The sectional area X should be calculated as the product of the inside diameter of the nozzle and the thickness of a seamless shell of similar material unpierced by tube holes or nozzles and designed for the same conditions of pressure and temperature as the shell in question.

The compensating area Y should be measured in a plane through the axis of the nozzle parallel to the longitudinal axis of the drum and should be calculated as the sum of the following areas:

- (a) The sectional area of the nozzle minus the sectional area of a nozzle of the same bore having a thickness calculated by the formula in clause 2.3.1 (with $e_1 = 0$) for the same design pressure and temperature. This area should be measured up to a point at a distance from the applicable surface of the shell equal to the smaller of the following:
 - (1) $2 \frac{1}{2}$ times the thickness of the shell;
 - (2) $2 \frac{1}{2}$ times the nozzle-wall thickness, plus the thickness of any added reinforcement, exclusive of weld metal, on the side of the shell under consideration.
- (b) The cross-sectional area of the welding fillets on the same side of the drum shell.
- (c) The area obtained by multiplying the difference between the actual shell thickness and the minimum thickness of an equivalent seamless unpierced shell by the greater of the following:
 - (1) $2 [e_s + 76 \text{ mm (3 in)}]$
where e_s = the thickness of the shell plate,
 - (2) the inside diameter d of the nozzle in the plane of sections X and Y (see Fig. 11 and 12).

Where the material of the nozzle has an allowable stress lower than that of the shell, the compensating sectional area of the nozzle should be multiplied by the ratio

$$\frac{\text{allowable stress of nozzle material}^*}{\text{allowable stress of shell material}}$$

* With proper reduction in the case of castings.