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PART UG
GENERAL REQUIREMENTS FOR ALL METHODS OF CONSTRUCTION AND ALL MATERIALS

UG-1 SCOPE

The requirements of Part UG are applicable to all pressure vessels and vessel parts and shall be used in conjunction with the specific requirements in Subsections B and C and the Mandatory Appendices that pertain to the method of fabrication and the material used.

MATERIALS

UG-4 GENERAL

(a) Material subject to stress due to pressure shall conform to one of the specifications given in Section II and shall be limited to those that are permitted in the applicable Part of Subsection C, except as otherwise permitted in UG-9, UG-10, UG-11, UG-15, and the Mandatory Appendices. Material may be identified as meeting more than one material specification and/or grade provided the material meets all requirements of the identified material specification(s) and/or grade(s) [see UG-23(a)].

(b) Material for nonpressure parts, such as skirts, supports, baffles, lugs, clips, and extended heat transfer surfaces, need not conform to the specifications for the material to which they are attached or to a material specification permitted in this Division, but if attached to the vessel by welding shall be of weldable quality [see UW-5(b)]. The allowable stress values for material not identified in accordance with UG-93 shall not exceed 80% of the maximum allowable stress value permitted for similar material in Subsection C.

(c) Material covered by specifications in Section II is not restricted as to the method of production unless so stated in the specification, and so long as the product complies with the requirements of the specification. (See UG-85.)

(d) Materials other than those allowed by this Division may not be used, unless data thereon are submitted to and approved by the Boiler and Pressure Vessel Committee in accordance with Appendix 5 in Section II, Part D.

(e) Materials outside the limits of size and/or thickness given in the title or scope clause of the specifications given in Section II, and permitted by the applicable part of Subsection C, may be used if the material is in compliance with the other requirements of the specification,[1] and no size or thickness limitation is given in the stress tables. In those specifications in which chemical composition or mechanical properties vary with size or thickness, materials outside the range shall be required to conform to the composition and mechanical properties shown for the nearest specified range.

(f) It is recommended that the user or his designated agent assure himself that materials used for the construction of the vessels will be suitable for the intended service with respect to retention of satisfactory mechanical properties, and resistance to corrosion, erosion, oxidation, and other deterioration during their intended service life. See also informative and nonmandatory guidance regarding metallurgical phenomena in Appendix 6 of Section II, Part D.

UG-5 PLATE[2]

Plate used in the construction of pressure parts of pressure vessels shall conform to one of the speci-

[1] In some instances the limitations of the scope clause in the material specifications are based on a very realistic maximum. It is recommended that the designer and/or fabricator confer with the material manufacturer or supplier before proceeding, thus assuring himself that except for size or thickness, all requirements of the material specification will be met and so certified.

[2] The term "plate" for the purpose of this usage includes sheet and strip also.

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fications in Section II for which allowable stress values are given in the tables referenced in UG-23, except as otherwise provided in UG-4, UG-10, UG-11, and UG-15.

UG-6 FORGINGS

Forged material may be used in pressure vessel construction provided the material has been worked sufficiently to remove the coarse ingot structure. Specifications and maximum allowable stress values for acceptable forging materials are given in the tables referenced in UG-23. (See Part UF for forged vessels.)

UG-7 CASTINGS

Cast material may be used in the construction of pressure vessels and vessel parts. Specifications and maximum allowable stress values for acceptable casting materials are given in the tables referenced in UG-23. These allowable stress values shall be multiplied by the applicable casting quality factor given in UG-24 for all materials except cast iron.

UG-8 PIPE AND TUBES

(a) Pipe and tubes of seamless or welded[3] construction conforming to one of the specifications given in Section II may be used for shells and other parts of pressure vessels. Allowable stress values for the materials used in pipe and tubes are given in the tables referenced in UG-23.

(b) Integrally finned tubes may be made from tubes that conform in every respect with one of the specifications given in Section II. These tubes may be used under the following conditions.

(1) The tubes, after finning, shall have a temper or condition which conforms to one of those provided in the governing specifications, or, when specified, they may be furnished in the "as-fabricated condition" where the finned portions of the tube are in the cold worked temper (as-finned) resulting from the finning operation, and the unfinned portions in the temper of the tube prior to finning.

(2) The maximum allowable stress value for the finned tube shall be that given in the tables referenced in UG-23 for the tube before finning except as permitted in (3) below.

(3) The maximum allowable stress value for a temper or condition that has a higher stress value than that of the tube before finning may be used provided that qualifying mechanical property tests demonstrate that such a temper or condition is obtained and conforms to one of those provided in the governing specifications in Section II, and provided that allowable stress values have been established in the tables referenced in UG-23 for the tube material used. The qualifying mechanical property tests shall be made on specimens of finned tube from which the fins have been removed by machining. The frequency of tests shall be as required in the unfinned tube specification.

(4) The maximum allowable internal or external working pressure of the tube shall be based on the root diameter and the minimum wall of the finned section, or the outside diameter and wall of the unfinned section together with appropriate stress values, whichever results in the lower maximum allowable working pressure. Alternatively, the maximum allowable external pressure for tubes with integral fins may be established under the rules of Appendix 23.

(5) In addition to the tests required by the governing specifications, each tube after finning shall be subjected to one of the following tests:

(a) an internal pneumatic test of not less than 250 psi (1720 kPa) for 5 sec without evidence of leakage. The test method shall permit easy visual detection of any leakage such as immersion of the tube under water or a pressure differential method.[4]

(b) an individual tube hydrostatic test in accordance with UG-99 which permits complete examination of the tube for leakage.

UG-9 WELDING MATERIALS

Welding materials used for production shall comply with the requirements of this Division, those of Section IX, and the applicable qualified welding procedure specification. When the welding materials comply with one of the specifications in Section II, Part C, the marking or tagging of the material, containers, or packages as required by the applicable Section II specification may be accepted for identification in lieu of a Certified Test Report or a Certificate of Compliance. When the welding materials do not comply with one of the specifications of Section II, the marking or

[3] Pipe and tubing fabricated by fusion welding, with filler metal added, may not be used in Code construction unless it is fabricated in accordance with Code rules as a pressure part.

[4] The pressure differential method is described in "Materials Research Standards," Vol. 1, No. 7, July 1961, published by ASTM.

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tagging shall be identifiable with the welding materials set forth in the welding procedure specification, and may be accepted in lieu of a Certified Test Report or a Certificate of Compliance.

UG-10 MATERIAL IDENTIFIED WITH OR PRODUCED TO A SPECIFICATION NOT PERMITTED BY THIS DIVISION, AND MATERIAL NOT FULLY IDENTIFIED

(a) Identified Material With Complete Certification From the Material Manufacturer. Material identified with a specification not permitted by this Division, or procured to chemical composition requirements, and identified to a single production lot as required by a permitted specification may be accepted as satisfying the requirements of a specification permitted by this Division provided the conditions set forth in (1) or (2) below are satisfied.

(1) Recertification by an Organization Other Than the Vessel or Part Manufacturer

(a) All requirements, including but not limited to, melting method, melting practice, deoxidation, quality, and heat treatment, of the specification permitted by this Division, to which the material is to be recertified, have been demonstrated to have been met.

(b) A copy of the certification by the material manufacturer of the chemical analysis required by the permitted specification, with documentation showing the requirements to which the material was produced and purchased, and which demonstrates that there is no conflict with the requirements of the permitted specification, has been furnished to the vessel or part Manufacturer.

(c) A certification that the material was manufactured and tested in accordance with the requirements of the specification to which the material is recertified, excluding the specific marking requirements, has been furnished to the vessel or part Manufacturer, together with copies of all documents and test reports pertinent to the demonstration of conformance to the requirements of the permitted specification.

(d) The material and the Certificate of Compliance or the Material Test Report have been identified with the designation of the specification to which the material is recertified and with the notation "Certified per UG-10."

(2) Recertification by the Vessel or Part Manufacturer

(a) A copy of the certification by the material manufacturer of the chemical analysis required by the permitted specification, with documentation showing the requirements to which the material was produced and purchased, and which demonstrates that there is no conflict with the requirements of the permitted specification, is available to the Inspector.

(b) For applications in which the maximum allowable stresses are subject to a cautionary note, documentation is available to the Inspector which establishes what deoxidation was performed during the material manufacture, to the degree necessary for the vessel or part Manufacturer to make a decision with regard to the cautionary note.

(c) Documentation is available to the Inspector which demonstrates that the metallurgical structure, mechanical property, and hardness requirements of the permitted specification have been met.

(d) For material recertified to a permitted specification which requires a fine austenitic grain size or which requires that a fine grain practice be used during melting, documentation is available to the Inspector which demonstrates that the heat treatment requirements of the permitted specification have been met, or will be met during fabrication.

(e) The material has marking, acceptable to the Inspector, for identification to the documentation.

(f) When the conformance of the material with the permitted specification has been established, the material has been marked as required by the permitted specification.

(b) Material Identified to a Particular Production Lot as Required by a Specification Permitted by This Division but Which Cannot Be Qualified Under UG-10(a). Any material identified to a particular production lot as required by a specification permitted by this Division, but for which the documentation required in UG-10(a) is not available, may be accepted as satisfying the requirements of the specification permitted by this Division provided that the conditions set forth below are satisfied.

(1) Recertification by an Organization Other Than the Vessel or Part Manufacturer. Not permitted.

(2) Recertification by the Vessel or Part Manufacturer

(a) Chemical analyses are made on different pieces from the lot to establish a mean analysis which is to be accepted as representative of the lot. The pieces chosen for analysis shall be selected at random from the lot. The number of pieces selected shall be at least 10% of the number of pieces in the lot, but not less than three. For lots of three pieces or less, each piece shall be analyzed. Each individual analysis for an element shall conform to the limits for product

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analysis in the permitted specification, and the mean for each element shall conform to the heat analysis limits of that specification. Analyses need only be made for those elements required by the permitted specification. However, consideration should be given to making analyses for elements not specified in the specification but which would be deleterious if present in excessive amounts.

(b) Mechanical property tests are made in accordance with the requirements of the permitted specification, and the results of the tests conform to the specified requirements.

(c) For applications in which the maximum allowable stresses are subject to a cautionary note, chemical analysis results are obtained which are sufficient to establish what deoxidation was used during the material manufacture, to the degree necessary for making a decision with regard to the cautionary note.

(d) When the requirements of the permitted specification include metallurgical structure requirements (i.e., fine austenitic grain size), tests are made and the results are sufficient to establish that those requirements of the specification have been met.

(e) When the requirements of the permitted specification include heat treatment, the material is heat treated in accordance with those requirements, either prior to or during fabrication.

(f) When the conformance of the material with the permitted specification has been established, the material has been marked as required by the permitted specification.

(c) Material Not Fully Identified. Material which cannot be qualified under the provisions of either UG-10(a) or UG-10(b), such as material not fully identified as required by the permitted specification or unidentified material, may be accepted as satisfying the requirements of a specification permitted by this Division provided that the conditions set forth below are satisfied.

(1) Qualification by an Organization Other Than the Vessel or Part Manufacturer. Not permitted.

(2) Qualification by the Vessel or Part Manufacturer

(a) Each piece is tested to show that it meets the chemical composition for product analysis and the mechanical properties requirements of the permitted specification. Chemical analyses need only be made for those elements required by the permitted specification. However, consideration should be given to making analyses for elements not specified in the specification but which would be deleterious if present in excessive amounts. For plates, when the direction of final rolling is not known, both a transverse and a longitudinal tension test specimen shall be taken from each sampling location designated in the permitted specification. The results of both tests shall conform to the minimum requirements of the specification, but the tensile strength of only one of the two specimens need conform to the maximum requirement.

(b) The provisions of (b)(2)(c), (b)(2)(d), and (b)(2)(e) above are met.

(c) When the identity of the material with the permitted specification has been established in accordance with (a) and (b) above, each piece (or bundle, etc., if permitted in the specification) is marked with a marking giving the permitted specification number and grade, type, or class as applicable and a serial number identifying the particular lot of material. A suitable report, clearly marked as being a "Report on Tests of Nonidentified Material," shall be completed and certified by the vessel or part Manufacturer. This report, when accepted by the Inspector, shall constitute authority to use the material in lieu of material procured to the requirements of the permitted specification.

UG-11 PREFABRICATED OR PREFORMED PRESSURE PARTS

Prefabricated or preformed pressure parts for pressure vessels which are subject to allowable working stresses due to internal or external pressure in the vessel and which are furnished by other than the shop of the Manufacturer responsible for the vessel to be marked with the Code Symbol shall conform to all applicable requirements of this Division as related to the vessel, including service restrictions applicable to the material, inspection in the shop of the parts Manufacturer, and the furnishing of Partial Data Reports as provided for in UG-120(c) except as permitted in (a), (b), and (c) below. When the prefabricated or preformed parts are furnished with a nameplate and the nameplate interferes with further fabrication or service, and where stamping on the material is prohibited, the Manufacturer of the completed vessel, with the concurrence of the Authorized Inspector, may remove the nameplate. The removal of the nameplate shall be noted in the "Remarks" section of the vessel Manufacturer's Data Report. The nameplate shall be destroyed. The rules of (a), (b), and (c) below shall not be applied to quick-actuating closures [UG-35(b)].

(a) Cast, Forged, Rolled, or Die Formed Standard Pressure Parts

(1) Pressure parts, such as pipe fittings, flanges, nozzles, welding necks, welding caps, manhole frames and covers, that are wholly formed by casting, forging,

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rolling, or die forming shall not require inspection, identification in accordance with UG-93(a) or (b), or Partial Data Reports. Standard pressure parts which comply with some ASME/ANSI standard[5] shall be made of materials permitted by this Division or of materials specifically listed in an ASME/ANSI product standard listed elsewhere in this Division. Standard pressure parts which comply with a Manufacturer's standard[6,7] shall be made of materials permitted by this Division. Parts made to either an ASME/ANSI standard or Manufacturer's standard shall be marked with the name or trademark of the parts manufacturer and such other markings as are required by the standard. Such markings shall be considered as the parts Manufacturer's certification that the product complies with the material specifications and standards indicated and is suitable for service at the rating indicated. The intent of this paragraph will have been met if, in lieu of the detailed marking on the part itself, the parts described herein have been marked in any permanent or temporary manner that will serve to identify the part with the parts manufacturer's written listing of the particular items and such listings are available for examination by the Inspector.

(2) Flanges and flanged fittings may be used at the pressure–temperature ratings specified in the appropriate standard listed in this Division. Other pressure–temperature ratings may be used if the flange satisfies the requirements of UG-11(a)(1) and, using the specified gaskets and bolting, satisfies the design requirements of UG-34 or Appendix 2 of this Division.

(3) Parts of small size falling within this category for which it is difficult or impossible to obtain identified material or which may be stocked and for which identification in accordance with UG-93 cannot be economically obtained and are not customarily furnished, and which do not appreciably affect the safety of the vessel, may be used for relatively unimportant parts or parts stressed to not more than 50% of the stress value permitted by this Division provided they are suitable for the purpose intended and are acceptable to the Inspector [see (a)(1) above and UG-4(b)]. The Manufacturer of the vessel to be marked with the Code Symbol shall satisfy himself that the part is suitable for the design conditions specified for the vessel in accordance with the rules of this Division.

(b) Cast, Forged, Rolled, or Die Formed Nonstandard Pressure Parts. Pressure parts such as shells, heads, removable doors, and pipe coils that are wholly formed by casting, forging, rolling, or die forming may be supplied basically as materials. All such parts shall be made of materials permitted under this Division and the Manufacturer of the part shall furnish identification in accordance with UG-93. Such parts shall be marked with the name or trademark of the parts Manufacturer and with such other markings as will serve to identify the particular parts with accompanying material identification. The Manufacturer of the vessel to be marked with the Code Symbol shall satisfy himself that the part is suitable for the design conditions specified for the completed vessel in accordance with the rules of this Division.

(c) Welded Standard Pressure Parts for Use Other Than the Shell or Heads of a Vessel. Pressure parts, such as welded standard pipe fittings, welding caps, and flanges that are fabricated by one of the welding processes recognized by this Division shall not require inspection, identification in accordance with UG-93(a) or (b), or Partial Data Reports provided:

(1) standard pressure parts which comply with some ASME/ANSI product standard[5]shall be made of materials permitted by this Division or of materials specifically listed in an ASME/ANSI product standard listed elsewhere in this Division. Standard pressure parts which comply with a Manufacturer's standard[6,7]shall be made of materials permitted by this Division.

(2) welding for pressure parts which comply with a Manufacturer's standard[6,7]shall comply with the requirements of UW-26(a), (b), and (c) and UW-27 through UW-40. Welding for pressure parts which comply with some ASME/ANSI product standard[5]shall comply with the requirements of UW-26(a), (b), and (c) and UW-27 through UW-40, or with the welding requirements of SA-234. Markings, where applicable, or Certification by the parts Manufacturer where markings are not applicable, shall be accepted as evidence of compliance with the above welding requirements. Such parts shall be marked as required by UG-11(a)(1).

Such parts shall be marked with the name or trademark of the parts manufacturer and with such other markings as will serve to identify the materials of which the parts are made. Such markings shall be

[5] These are pressure parts which comply with some ASME/ANSI product standard accepted by reference in UG-44. The ASME/ANSI product standard establishes the basis for the pressure–temperature rating and marking unless modified in UG-44.

[6] These are pressure parts which comply with a parts Manufacturer's standard which defines the pressure–temperature rating marked on the part and described in the parts Manufacturer's literature. The Manufacturer of the completed vessel shall satisfy himself that the part is suitable for the design conditions of the completed vessel in accordance with the rules of this Division.

[7] Pressure parts may be in accordance with an ASME/ANSI product standard not covered by footnote 5, but such parts shall satisfy the requirements applicable to a parts Manufacturer's standard and footnote 6.

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considered as the parts Manufacturer's certification that the product complies with (1) above. A statement by the parts Manufacturer that all welding complies with Code requirements shall be accepted as evidence that the product complies with (2) above.

(3) if radiography or postweld heat treatment is required by the rules of this Division, it may be performed either in the plant of the parts Manufacturer or in the plant of the manufacturer of the vessel to be marked with the Code Symbol.

If the radiographing is done under the control of the parts manufacturer, the completed radiographs, properly identified, with a radiographic inspection report, shall be forwarded to the vessel Manufacturer and shall be available to the Inspector.

(4) if heat treatment is performed at the plant of the parts manufacturer, certification by the parts manufacturer that such treatment was performed shall be accepted as evidence of compliance with applicable Code paragraphs. This certification shall be available to the Inspector.

(d) Parts furnished under the provisions of (a), (b), and (c) above need not be manufactured by a Certificate of Authorization Holder.

UG-12 BOLTS AND STUDS

(a) Bolts and studs may be used for the attachment of removable parts. Specifications, supplementary rules, and maximum allowable stress values for acceptable bolting materials are given in the tables referenced in UG-23.

(b) Studs shall be threaded full length or shall be machined down to the root diameter of the thread in the unthreaded portion, provided that the threaded portions are at least $1\frac{1}{2}$ diameters in length.

Studs greater than eight diameters in length may have an unthreaded portion which has the nominal diameter of the thread, provided the following requirements are met:

(1) the threaded portions shall be at least $1\frac{1}{2}$ diameters in length;

(2) the stud shall be machined down to the root diameter of the thread for a minimum distance of 0.5 diameters adjacent to the threaded portion;

(3) a suitable transition shall be provided between the root diameter and the unthreaded portion; and

(4) particular consideration shall be given to any dynamic loadings.

UG-13 NUTS AND WASHERS

(a) Nuts shall conform to the requirements in the applicable Part of Subsection C (see UCS-11 and UNF-13). They shall engage the threads for the full depth of the nut.

(b) The use of washers is optional. When used, they shall be of wrought materials.

UG-14 RODS AND BARS

Rod and bar stock may be used in pressure vessel construction for pressure parts such as flange rings, stiffening rings, frames for reinforced openings, stays and staybolts, and similar parts. Rod and bar materials shall conform to the requirements for bars or bolting in the applicable part of Subsection C.

UG-15 PRODUCT SPECIFICATION

When there is no material specification listed in Subsection C covering a particular wrought product of a grade, but there is an approved specification listed in Subsection C covering some other wrought product of that grade, the product for which there is no specification may be used provided:

(a) the chemical and physical properties, heat treating requirements, and requirements for deoxidation, or grain size requirements conform to the approved specification listed in Subsection C. The stress values for that specification given in the tables referenced in UG-23 shall be used.

(b) the manufacturing procedures, tolerances, tests, and marking are in accordance with a Section II specification covering the same product form of a similar material;

(c) for the case of welded tubing made of plate, sheet, or strip, without the addition of filler metal, the appropriate stress values are multiplied by a factor of 0.85;

(d) the product is not pipe or tubing fabricated by fusion welding with the addition of filler metal unless it is fabricated in accordance with the rules of this Division as a pressure part;

(e) mill test reports reference the specifications used in producing the material and in addition make reference to this paragraph.

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DESIGN

UG-16 GENERAL

(a) The design of pressure vessels and vessel parts shall conform to the general design requirements in the following paragraphs and in addition to the specific requirements for *Design* given in the applicable Parts of Subsections B and C.

(b) Minimum Thickness of Pressure Retaining Components. Except for the special provisions listed below, the minimum thickness permitted for shells and heads, after forming and regardless of product form and material, shall be $\frac{1}{16}$ in. (1.6 mm) exclusive of any corrosion allowance. Exceptions are:

(1) the minimum thickness does not apply to heat transfer plates of plate-type heat exchangers;

(2) this minimum thickness does not apply to the inner pipe of double pipe heat exchangers nor to tubes in shell-and-tube heat exchangers, where such pipes or tubes are NPS 6 (DN 150) and less. This exemption applies whether or not the outer pipe or shell is constructed to Code rules. All other pressure parts of these heat exchangers which are constructed to Code rules must meet the $\frac{1}{16}$ in. (1.6 mm) minimum thickness requirements.

(3) the minimum thickness of shells and heads of unfired steam boilers shall be $\frac{1}{4}$ in. (6 mm) exclusive of any corrosion allowance;

(4) the minimum thickness of shells and heads used in compressed air service, steam service, and water service, made from materials listed in Table UCS-23, shall be $\frac{3}{32}$ in. (2.4 mm) exclusive of any corrosion allowance.

(5) this minimum thickness does not apply to the tubes in air cooled and cooling tower heat exchangers if all the following provisions are met:

(a) the tubes shall not be used for lethal UW-2(a) service applications;

(b) the tubes shall be protected by fins or other mechanical means;

(c) the tube outside diameter shall be a minimum of $\frac{3}{8}$ in. and a maximum of $1\frac{1}{2}$ in.;

(d) the minimum thickness used shall not be less than that calculated by the formulas given in UG-27 or 1-1 and in no case less than the greater of the minimum thickness calculated using a design pressure of 500 psi at 70°F or 0.022 in.

(c) Mill Undertolerance. Plate material shall be ordered not thinner than the design thickness. Vessels made of plate furnished with an undertolerance of not more than the smaller value of 0.01 in. (0.3 mm) or 6% of the ordered thickness may be used at the full design pressure for the thickness ordered. If the specification to which the plate is ordered allows a greater undertolerance, the ordered thickness of the materials shall be sufficiently greater than the design thickness so that the thickness of the material furnished is not more than the smaller of 0.01 in. (0.3 mm) or 6% under the design thickness.

(d) Pipe Undertolerance. If pipe or tube is ordered by its nominal wall thickness, the manufacturing undertolerance on wall thickness shall be taken into account except for nozzle wall reinforcement area requirements in accordance with UG-37 and UG-40. The manufacturing undertolerances are given in the several pipe and tube specifications listed in the applicable Tables in Subsection C. After the minimum wall thickness is determined, it shall be increased by an amount sufficient to provide the manufacturing undertolerance allowed in the pipe or tube specification.

(e) Corrosion Allowance in Design Formulas. The dimensional symbols used in all design formulas throughout this Division represent dimensions in the corroded condition.

UG-17 METHODS OF FABRICATION IN COMBINATION

A vessel may be designed and constructed by a combination of the methods of fabrication given in this Division, provided the rules applying to the respective methods of fabrication are followed and the vessel is limited to the service permitted by the method of fabrication having the most restrictive requirements (see UG-116).

UG-18 MATERIALS IN COMBINATION

Except as specifically prohibited by other rules of this Division, a vessel may be designed and constructed of any combination of materials permitted in Subsection C, provided the applicable rules are followed and the requirements in Section IX for welding dissimilar metals are met.

The requirements for the base metals, HAZ's, and weld metal(s) of a dissimilar metal weldment shall each be applied in accordance with the rules of this Division. (For example, if a carbon steel base metal is joined to a stainless steel base metal with a nickel filler metal, the rules of Part UCS apply to the carbon steel base metal and its HAZ; Part UHA to the stainless steel base metal and its HAZ; and Part UNF to the weld metal.)

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NOTE: Because of the different thermal coefficients of expansion of dissimilar materials, caution should be exercised in design and construction under the provisions of this paragraph in order to avoid difficulties in service under extreme temperature conditions, or with unusual restraint of parts such as may occur at points of stress concentration and also because of metallurgical changes occurring at elevated temperatures. [See also *Galvanic Corrosion* in Appendix 6, 6-440(c), of Section II, Part D.]

UG-19 SPECIAL CONSTRUCTIONS

(a) Combination Units. When a pressure vessel unit consists of more than one independent pressure chamber, operating at the same or different pressures and temperatures, each such pressure chamber (vessel) shall be designed and constructed to withstand the most severe condition of coincident pressure and temperature expected in normal service. Only the parts of chambers which come within the scope of this Division, U-1, need be constructed in compliance with its provisions. Also, see 9-1(c) for jacketed vessels.

(b) Special Shapes. Vessels other than cylindrical and spherical and those for which no design rules are provided in this Division may be designed under the conditions set forth in U-2.

(c) When no design rules are given and the strength of a pressure vessel or vessel part cannot be calculated with a satisfactory assurance of accuracy, the maximum allowable working pressure of the completed vessel shall be established in accordance with the provisions of UG-101.

UG-20 DESIGN TEMPERATURE

(a) Maximum. Except as required in UW-2(d)(3), the maximum temperature used in design shall be not less than the mean metal temperature (through the thickness) expected under operating conditions for the part considered (see 3-2). If necessary, the metal temperature shall be determined by computation or by measurement from equipment in service under equivalent operating conditions.

(b) Minimum. The minimum metal temperature used in design shall be the lowest expected in service except when lower temperatures are permitted by the rules of this Division (see UCS-66 and UCS-160).[37] The minimum mean metal temperature shall be determined by the principles described in (a) above. Consideration shall include the lowest operating temperature, operational upsets, autorefrigeration, atmospheric temperature, and any other sources of cooling [except as permitted in (f)(3) below for vessels meeting the requirements of (f) below]. The MDMT marked on the nameplate shall correspond to a coincident pressure equal to the MAWP. When there are multiple MAWP's, the largest value shall be used to establish the MDMT marked on the nameplate. Additional MDMT's corresponding with other MAWP's may also be marked on the nameplate.[37]

(c) Design temperatures listed in excess of the maximum temperatures listed in the tables referenced in UG-23 are not permitted. In addition, design temperatures for vessels under external pressure shall not exceed the maximum temperatures given on the external pressure charts.

(d) The design of zones with different metal temperatures may be based on their determined temperatures.

(e) Suggested methods for obtaining the operating temperature of vessel walls in service are given in Appendix C.

(f) Impact testing per UG-84 is not mandatory for pressure vessel materials which satisfy all of the following.

(1) The material shall be limited to P-No. 1, Gr. No. 1 or 2, and the thickness, as defined in UCS-66(a), shall not exceed that given in (a) or (b) below:

(a) $\frac{1}{2}$ in. (13 mm) for materials listed in Curve A of Fig. UCS-66;

(b) 1 in. (25 mm) for materials listed in Curve B, C, or D of Fig. UCS-66.

(2) The completed vessel shall be hydrostatically tested per UG-99(b) or (c) or 27-3.

(3) Design temperature is no warmer than 650°F (343°C) nor colder than −20°F (−29°C). Occasional operating temperatures colder than −20°F (−29°C) are acceptable when due to lower seasonal atmospheric temperature.

(4) The thermal or mechanical shock loadings are not a controlling design requirement. (See UG-22.)

(5) Cyclical loading is not a controlling design requirement. (See UG-22.)

UG-21 DESIGN PRESSURE[8]

Vessels covered by this Division of Section VIII shall be designed for at least the most severe condition of coincident pressure and temperature expected in normal operation. For this condition and for test conditions, the maximum difference in pressure between the inside and outside of a vessel, or between any two

[8] It is recommended that a suitable margin be provided above the pressure at which the vessel will be normally operated to allow for probable pressure surges in the vessel up to the setting of the pressure relieving devices (see UG-134).

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chambers of a combination unit, shall be considered [see UG-98, UG-99(e), and 3-2].

UG-22 LOADINGS

The loadings to be considered in designing a vessel shall include those from:

(a) internal or external design pressure (as defined in UG-21);

(b) weight of the vessel and normal contents under operating or test conditions (this includes additional pressure due to static head of liquids);

(c) superimposed static reactions from weight of attached equipment, such as motors, machinery, other vessels, piping, linings, and insulation;

(d) the attachment of:

(1) internals (see Appendix D);

(2) vessel supports, such as lugs, rings, skirts, saddles, and legs (see Appendix G);

(e) cyclic and dynamic reactions due to pressure or thermal variations, or from equipment mounted on a vessel, and mechanical loadings;

(f) wind, snow, and seismic reactions, where required;

(g) impact reactions such as those due to fluid shock;

(h) temperature gradients and differential thermal expansion;

(i) abnormal pressures, such as those caused by deflagration.

UG-23 MAXIMUM ALLOWABLE STRESS VALUES[9]

(a) The maximum allowable stress value is the maximum unit stress permitted in a given material used in a vessel constructed under these rules. The maximum allowable tensile stress values permitted for different materials are given in Subpart 1 of Section II, Part D. A listing of these materials is given in the following tables, which are included in Subsection C. For material identified as meeting more than one material specification and/or grade, the maximum allowable tensile stress value for either material specification and/or grade may be used provided all requirements and limitations for the material specification and grade are met for the maximum allowable tensile stress value chosen.

Table UCS-23 Carbon and Low Alloy Steel (stress values in Section II, Part D, Table 3 for bolting, and Table 1A for other carbon steels)

Table UNF-23 Nonferrous Metals (stress values in Section II, Part D, Table 3 for bolting, and Table 1B for other nonferrous metals)

Table UHA-23 High Alloy Steel (stress values in Section II, Part D, Table 3 for bolting, and Table 1A for other high alloy steels)

Table UCI-23 Maximum Allowable Stress Values in Tension for Cast Iron

Table UCD-23 Maximum Allowable Stress Values in Tension for Cast Ductile Iron

Table UHT-23 Ferritic Steels with Properties Enhanced by Heat Treatment (stress values in Section II, Part D, Table 1A)

Table ULT-23 Maximum Allowable Stress Values in Tension for 5%, 8%, and 9% Nickel Steels and 5083-0 Aluminum Alloy at Cryogenic Temperatures for Welded and Nonwelded Construction

(b) The maximum allowable longitudinal compressive stress to be used in the design of cylindrical shells or tubes, either seamless or butt welded, subjected to loadings that produce longitudinal compression in the shell or tube shall be the smaller of the following values:

(1) the maximum allowable tensile stress value permitted in (a) above;

(2) the value of the factor B determined by the following procedure where

t = the minimum required thickness of the cylindrical shell or tube, in. (mm)

R_o = outside radius of cylindrical shell or tube, in. (mm)

E = modulus of elasticity of material at design temperature, psi (kPa). The modulus of elasticity to be used shall be taken from the applicable materials chart in Section II, Part D, Subpart 3.[10] (Interpolation may be made between lines for intermediate temperatures.)

The joint efficiency for butt welded joints shall be taken as unity.

The value of B shall be determined as follows.

Step 1. Using the selected values of t and R, calculate the value of factor A using the following formula:

$$A = \frac{0.125}{(R_o/t)}$$

[9] For the basis on which the tabulated stress values have been established, see Appendix 1 of Section II, Part D.

[10] Note that the modulus of elasticity values listed in UF-27 of this Division shall not be used for axial compression design.

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Step 2. Using the value of *A* calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the design temperature (see UG-20). Interpolation may be made between lines for intermediate temperatures.

In cases where the value at *A* falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of *A* falling to the left of the material/temperature line, see Step 4.

Step 3. From the intersection obtained in Step 2, move horizontally to the right and read the value of factor *B.* This is the maximum allowable compressive stress for the values of t and R_o used in Step 1.

Step 4. For values of *A* falling to the left of the applicable material/temperature line, the value of *B,* psi (kPa), shall be calculated using the following formula:

$$B = \frac{AE}{2}$$

Step 5. Compare the value of *B* determined in Steps 3 or 4 with the computed longitudinal compressive stress in the cylindrical shell or tube, using the selected values of t and R_o. If the value of *B* is smaller than the computed compressive stress, a greater value of t must be selected and the design procedure repeated until a value of *B* is obtained which is greater than the compressive stress computed for the loading on the cylindrical shell or tube.

(c) The wall thickness of a vessel computed by these rules shall be determined such that, for any combination of loadings listed in UG-22 that induce primary stress and are expected to occur simultaneously during normal operation[11] of the vessel, the induced maximum general primary membrane stress does not exceed the maximum allowable stress value in tension (see UG-23), except as provided in (d) below. Except where limited by special rules, such as those for cast iron in flanged joints, the above loads shall not induce a combined maximum primary membrane stress plus primary bending stress across the thickness which exceeds $1\frac{1}{2}$ times[12] the maximum allowable stress value in tension (see UG-23). It is recognized that high localized discontinuity stresses may exist in vessels designed and fabricated in accordance with these rules. Insofar as practical, design rules for details have been written to limit such stresses to a safe level consistent with experience.

The maximum allowable stress values that are to be used in the thickness calculations are to be taken from the tables at the temperature which is expected to be maintained in the metal under the conditions of loading being considered. Maximum stress values may be interpolated for intermediate temperatures.

(d) For the combination of earthquake loading, or wind loading with other loadings in UG-22, the wall thickness of a vessel computed by these rules shall be determined such that the general primary membrane stress shall not exceed 1.2 times the maximum allowable stress permitted in (a), (b), or (c) above. This rule is applicable to stresses caused by internal pressure, external pressure, and axial compressive load on a cylinder.

Earthquake loading and wind loading need not be considered to act simultaneously.

UG-24 CASTINGS

(a) Quality Factors. A casting quality factor as specified below shall be applied to the allowable stress values for cast materials given in Subsection C except for castings permitted by Part UCI. At a welded joint in a casting, only the lesser of the casting quality factor or the weld joint efficiency specified in UW-12 applies, but not both. NDE methods and acceptance standards are given in Appendix 7.

(1) A factor not to exceed 80% shall be applied to static castings which are examined in accordance with the minimum requirements of the material specification. In addition to the minimum requirements of the material specification, all surfaces of centrifugal castings shall be machined after heat treatment to a finish not coarser than 250 μin. (6.35 μm) arithmetical average deviation, and a factor not to exceed 85% shall be applied.

(2) For nonferrous and ductile cast iron materials, a factor not to exceed 90% shall be applied if in addition to the minimum requirements of UG-24(a)(1):

(a) each casting is subjected to a thorough examination of all surfaces, particularly such as are exposed by machining or drilling, without revealing any defects;

[11] See 3-2 Definition of Terms.

[12] The user of the Code is cautioned that for elevated metal temperatures when high membrane stress and/or high bending stress exist in the section, some inelastic straining due to creep in excess of the limits allowed by the criteria of Appendix 1 of Section II, Part D may occur.

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(b) at least three pilot castings[13] representing the first lot of five castings made from a new or altered design are sectioned or radiographed at all critical sections (see footnote 1, Appendix 7) without revealing any defects;

(c) one additional casting taken at random from every subsequent lot of five is sectioned or radiographed at all critical sections without revealing any defects; and

(d) all castings other than those which have been radiographed are examined at all critical sections by the magnetic particle or liquid penetrant methods in accordance with the requirements of Appendix 7.

(3) For nonferrous and ductile cast iron materials, a factor not to exceed 90% may be used for a single casting which has been radiographed at all critical sections and found free of defects.

(4) For nonferrous and ductile cast iron materials, a factor not to exceed 90% may be used for a casting which has been machined to the extent that all critical sections are exposed for examination for the full wall thickness; as in tubesheets drilled with holes spaced no farther apart than the wall thickness of the casting. The examination afforded may be taken in lieu of destructive or radiographic testing required in (2)(b) above.

(5) For carbon, low alloy, or high alloy steels, higher quality factors may be applied if in addition to the minimum requirements of (a)(1) above, additional examinations are made as follows.

(a) For centrifugal castings, a factor not to exceed 90% may be applied if the castings are examined by the magnetic particle or liquid penetrant methods in accordance with the requirements of Appendix 7.

(b) For static and centrifugal castings a factor not to exceed 100% may be applied if the castings are examined in accordance with all of the requirements of Appendix 7.

(6) The following additional requirements apply when castings (including those permitted in UG-11) are to be used in vessels to contain lethal substances (UW-2).

(a) Castings of cast iron (UCI-2) and cast ductile iron (UCD-2) are prohibited.

(b) Each casting of nonferrous material permitted by this Division shall be radiographed at all critical sections (see footnote 1, Appendix 7) without revealing any defects. The quality factor for nonferrous castings for lethal service shall not exceed 90%.

(c) Each casting of steel material permitted by this Division shall be examined per Appendix 7 for severe service applications [7-3(b)]. The quality factor for lethal service shall not exceed 100%.

(b) Defects. Imperfections defined as unacceptable by either the material specification or by Appendix 7, 7-3, whichever is more restrictive, are considered to be defects and shall be the basis for rejection of the casting. Where defects have been repaired by welding, the completed repair shall be subject to reexamination and, when required by either the rules of this Division or the requirements of the castings specification, the repaired casting shall be postweld heat treated and, to obtain a 90% or 100% quality factor, the repaired casting shall be stress relieved.

(c) Identification and Marking. Each casting to which a quality factor greater than 80% is applied shall be marked with the name, trademark, or other traceable identification of the manufacturer and the casting identification, including the casting quality factor and the material designation.

UG-25 CORROSION

(a) The user or his designated agent (see U-2) shall specify corrosion allowances other than those required by the rules of this Division. Where corrosion allowances are not provided, this fact shall be indicated on the Data Report.

(b) Vessels or parts of vessels subject to thinning by corrosion, erosion, or mechanical abrasion shall have provision made for the desired life of the vessel by a suitable increase in the thickness of the material over that determined by the design formulas, or by using some other suitable method of protection. (See Appendix E.)

NOTE: When using high alloys and nonferrous materials either for solid wall or clad or lined vessels, refer to UHA-6, UCL-3, and UNF-4, as appropriate.

(c) Material added for these purposes need not be of the same thickness for all parts of the vessel if different rates of attack are expected for the various parts.

(d) No additional thickness need be provided when previous experience in like service has shown that corrosion does not occur or is of only a superficial nature.

[13] *Pilot casting* — Any one casting, usually one of the first from a new pattern, poured of the same material and using the identical foundry procedure (risering, gating, pouring, and melting) as the castings it is intended to represent. Any pilot casting or castings taken to represent a lot and the castings of that lot shall be poured from a heat of metal from which the castings on the current order are poured.

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(e) Telltale Holes. Telltale holes may be used to provide some positive indication when the thickness has been reduced to a dangerous degree. Telltale holes shall not be used in vessels which are to contain lethal substances [see UW-2(a)], except as permitted by ULW-76 for vent holes in layered construction. When telltale holes are provided, they shall have a diameter of $\frac{1}{16}$ in. to $\frac{3}{16}$ in. (1.6 mm to 4.8 mm) and have a depth not less than 80% of the thickness required for a seamless shell of like dimensions. These holes shall be provided in the opposite surface to that where deterioration is expected. [For telltale holes in clad or lined vessels, see UCL-25(b).]

(f) Openings for Drain. Vessels subject to corrosion shall be supplied with a suitable drain opening at the lowest point practicable in the vessel; or a pipe may be used extending inward from any other location to within $\frac{1}{4}$ in. (6 mm) of the lowest point.

UG-26 LININGS

Corrosion resistant or abrasion resistant linings, whether or not attached to the wall of a vessel, shall not be considered as contributing to the strength of the wall except as permitted in Part UCL (see Appendix F).

UG-27 THICKNESS OF SHELLS UNDER INTERNAL PRESSURE

(a) The thickness of shells under internal pressure shall be not less than that computed by the following formulas.[14] In addition, provision shall be made for any of the other loadings listed in UG-22, when such loadings are expected. (See UG-16.)

(b) The symbols defined below are used in the formulas of this paragraph.

t = minimum required thickness of shell, in. (mm)
P = internal design pressure (see UG-21), psi (kPa)
R = inside radius of the shell course under consideration,[15] in. (mm)
S = maximum allowable stress value, psi (kPa) (see UG-23 and the stress limitations specified in UG-24)
E = joint efficiency for, or the efficiency of, appropriate joint in cylindrical or spherical shells, or the efficiency of ligaments between openings, whichever is less.

For welded vessels, use the efficiency specified in UW-12.

For ligaments between openings, use the efficiency calculated by the rules given in UG-53.

(c) Cylindrical Shells. The minimum thickness or maximum allowable working pressure of cylindrical shells shall be the greater thickness or lesser pressure as given by (1) or (2) below.

(1) Circumferential Stress (Longitudinal Joints). When the thickness does not exceed one-half of the inside radius, or P does not exceed $0.385SE$, the following formulas shall apply:

$$t = \frac{PR}{SE - 0.6P} \quad \text{or} \quad P = \frac{SEt}{R + 0.6t} \tag{1}$$

(2) Longitudinal Stress (Circumferential Joints).[16] When the thickness does not exceed one-half of the inside radius, or P does not exceed $1.25SE$, the following formulas shall apply:

$$t = \frac{PR}{2SE + 0.4P} \quad \text{or} \quad P = \frac{2SEt}{R - 0.4t} \tag{2}$$

(d) Spherical Shells. When the thickness of the shell of a wholly spherical vessel does not exceed $0.356R$, or P does not exceed $0.665SE$, the following formulas shall apply:

$$t = \frac{PR}{2SE - 0.2P} \quad \text{or} \quad P = \frac{2SEt}{R + 0.2t} \tag{3}$$

(e) When necessary, vessels shall be provided with stiffeners or other additional means of support to prevent overstress or large distortions under the external loadings listed in UG-22 other than pressure and temperature.

(f) A stayed jacket shell that extends completely around a cylindrical or spherical vessel shall also meet the requirements of UG-47(c).

(g) Any reduction in thickness within a shell course or spherical shell shall be in accordance with UW-9.

[14] Formulas in terms of the outside radius and for thicknesses and pressures beyond the limits fixed in this paragraph are given in 1-1 to 1-3.

[15] For pipe, the inside radius R is determined by the nominal outside radius minus the nominal wall thickness.

[16] These formulas will govern only when the circumferential joint efficiency is less than one-half the longitudinal joint efficiency, or when the effect of supplementary loadings (UG-22) causing longitudinal bending or tension in conjunction with internal pressure is being investigated. An example illustrating this investigation is given in L-2.1 and L-2.2.

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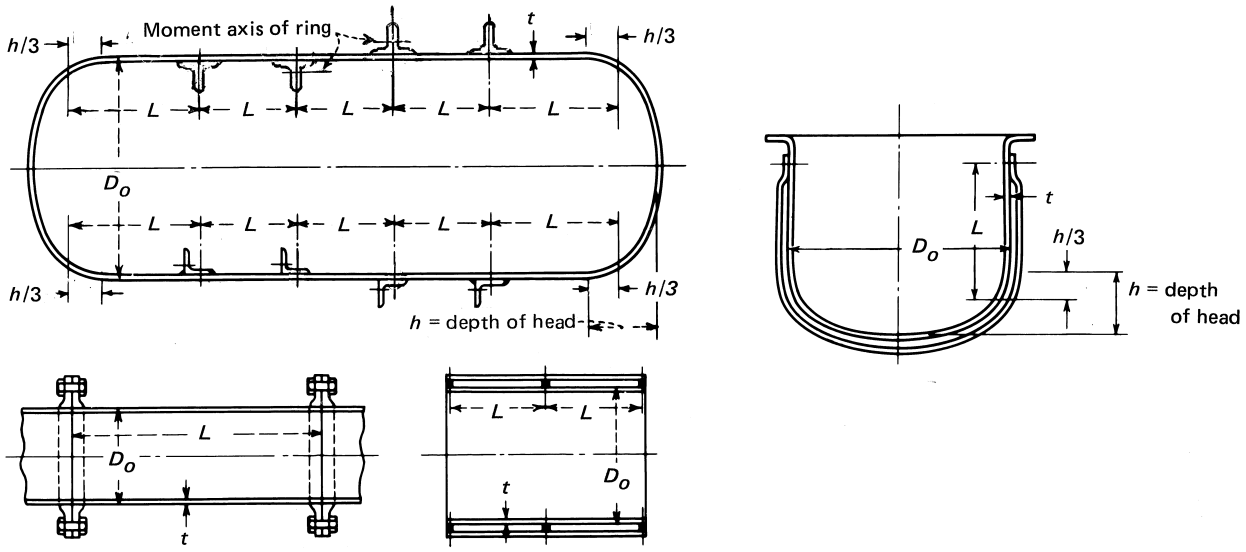


FIG. UG-28 DIAGRAMMATIC REPRESENTATION OF VARIABLES FOR DESIGN OF CYLINDRICAL VESSELS SUBJECTED TO EXTERNAL PRESSURE

UG-28 THICKNESS OF SHELLS AND TUBES UNDER EXTERNAL PRESSURE

(a) Rules for the design of shells and tubes under external pressure given in this Division are limited to cylindrical shells, with or without stiffening rings, tubes, and spherical shells. Three typical forms of cylindrical shells are shown in Fig. UG-28. Charts used in determining minimum required thicknesses of these components are given in Subpart 3 of Section II, Part D.

(b) The symbols defined below are used in the procedures of this paragraph:

A = factor determined from Fig. G in Subpart 3 of Section II, Part D and used to enter the applicable material chart in Subpart 3 of Section II, Part D. For the case of cylinders having D_o/t values less than 10, see UG-28(c)(2).

B = factor determined from the applicable material chart in Subpart 3 of Section II, Part D for maximum design metal temperature, psi (kPa) [see UG-20(c)]

D_o = outside diameter of cylindrical shell course or tube, in. (mm)

E = modulus of elasticity of material at design temperature, psi (kPa). For external pressure design in accordance with this Section, the modulus of elasticity to be used shall be taken from the applicable materials chart in Subpart 3 of Section II, Part D.[17] (Interpolation may be made between lines for intermediate temperatures.)

L = total length, in. (mm), of a tube between tubesheets, or design length of a vessel section between lines of support (see Fig. UG-28.1). A line of support is:

(1) a circumferential line on a head (excluding conical heads) at one-third the depth of the head from the head tangent line as shown on Fig. UG-28;

(2) a stiffening ring that meets the requirements of UG-29;

(3) a jacket closure of a jacketed vessel that meets the requirements of 9-5;

(4) a cone-to-cylinder junction or a knuckle-to-cylinder junction of a toriconical head or section which satisfies the moment of inertia requirement of 1-8.

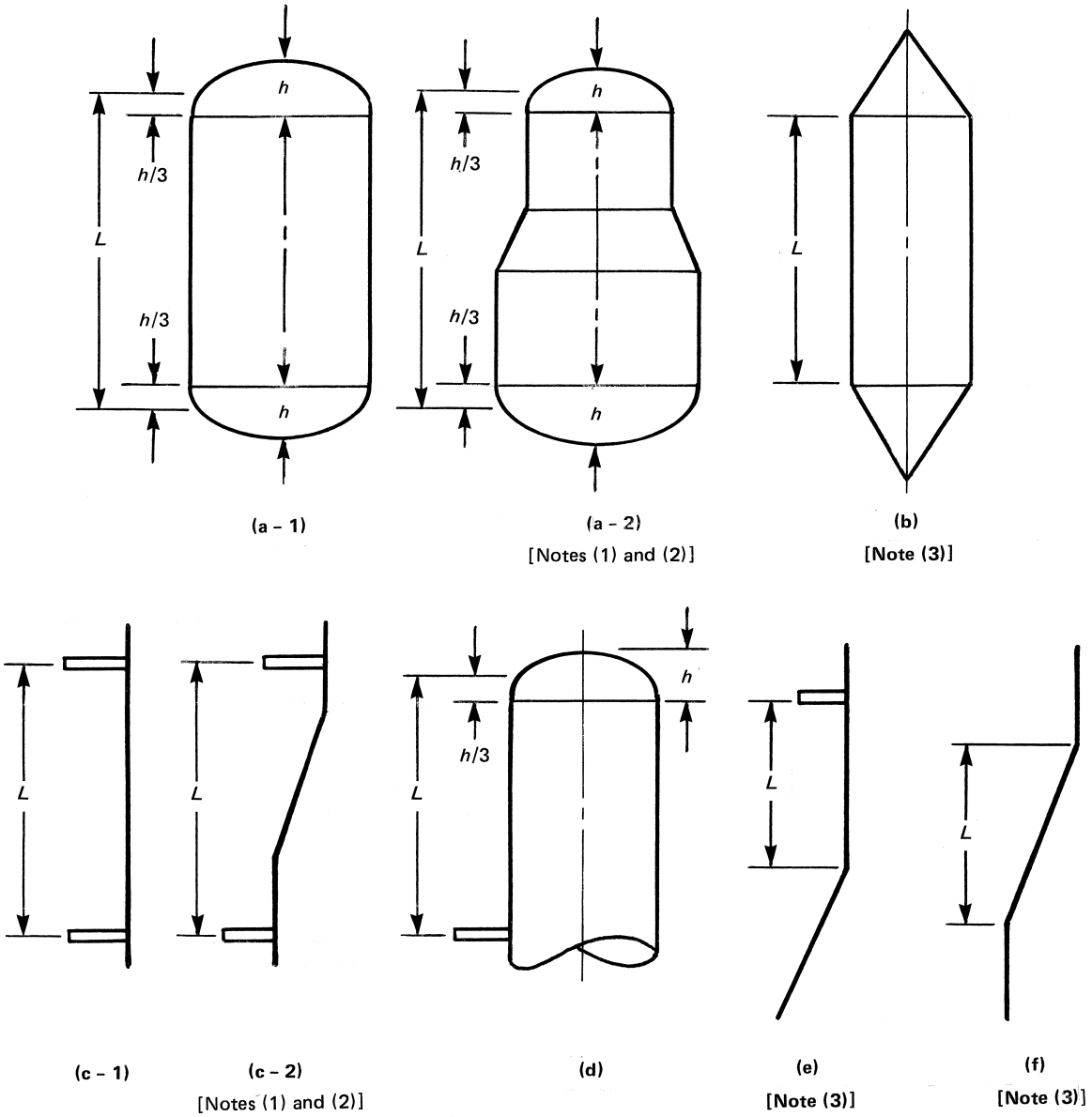
P = external design pressure, psi (kPa) [see Note in UG-28(f)]

P_a = calculated value of maximum allowable external working pressure for the assumed value of t, psi (kPa) [see Note in (f) below]

R_o = outside radius of spherical shell, in. (mm)

[17] Note that the modulus of elasticity values listed in UF-27 of this Division shall not be used for external pressure design.

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NOTES:
(1) When the cone-to-cylinder or the knuckle-to-cylinder junction is not a line of support, the nominal thickness of the cone, knuckle, or toriconical section shall not be less than the minimum required thickness of the adjacent cylindrical shell.
(2) Calculations shall be made using the diameter and corresponding thickness of each section with dimension *L* as shown.
(3) When the cone-to-cylinder or the knuckle-to-cylinder junction is a line of support, the moment of inertia shall be provided in accordance with 1-8.

FIG. UG-28.1 DIAGRAMMATIC REPRESENTATION OF LINES OF SUPPORT FOR DESIGN OF CYLINDRICAL VESSELS SUBJECTED TO EXTERNAL PRESSURE

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t = minimum required thickness of cylindrical shell or tube, or spherical shell, in. (mm)

t_s = nominal thickness of cylindrical shell or tube, in. (mm)

(c) Cylindrical Shells and Tubes. The required minimum thickness of a cylindrical shell or tube under external pressure, either seamless or with longitudinal butt joints, shall be determined by the following procedure.

(1) Cylinders having D_o/t values ≥ 10:

Step 1. Assume a value for t and determine the ratios L/D_o and D_o/t.

Step 2. Enter Fig. G in Subpart 3 of Section II, Part D at the value of L/D_o determined in Step 1. For values of L/D_o greater than 50, enter the chart at a value of $L/D_o = 50$. For values of L/D_o less than 0.05, enter the chart at a value of $L/D_o = 0.05$.

Step 3. Move horizontally to the line for the value of D_o/t determined in Step 1. Interpolation may be made for intermediate values of D_o/t. From this point of intersection move vertically downward to determine the value of factor A.

Step 4. Using the value of A calculated in Step 3, enter the applicable material chart in Subpart 3 of Section II, Part D for the material under consideration. Move vertically to an intersection with the material/temperature line for the design temperature (see UG-20). Interpolation may be made between lines for intermediate temperatures.

In cases where the value of A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material/temperature line, see Step 7.

Step 5. From the intersection obtained in Step 4, move horizontally to the right and read the value of factor B.

Step 6. Using this value of B, calculate the value of the maximum allowable external working pressure P_a using the following formula:

$$P_a = \frac{4B}{3(D_o/t)}$$

Step 7. For values of A falling to the left of the applicable material/temperature line, the value of P_a can be calculated using the following formula:

$$P_a = \frac{2AE}{3(D_o/t)}$$

Step 8. Compare the calculated value of P_a obtained in Steps 6 or 7 with P. If P_a is smaller than P, select a larger value for t and repeat the design procedure until a value of P_a is obtained that is equal to or greater than P. An example illustrating the use of this procedure is given in L-3(a).

(2) Cylinders having D_o/t values <10:

Step 1. Using the same procedure as given in UG-28(c)(1), obtain the value of B. For values of D_o/t less than 4, the value of factor A can be calculated using the following formula:

$$A = \frac{1.1}{(D_o/t)^2}$$

For values of A greater than 0.10, use a value of 0.10.

Step 2. Using the value of B obtained in Step 1, calculate a value P_{a1} using the following formula:

$$P_{a1} = \left[\frac{2.167}{(D_o/t)} - 0.0833\right] B$$

Step 3. Calculate a value P_{a2} using the following formula:

$$P_{a2} = \frac{2S}{D_o/t}\left[1 - \frac{1}{D_o/t}\right]$$

where S is the lesser of two times the maximum allowable stress value in tension at design metal temperature, from the applicable table referenced in UG-23, or 0.9 times the yield strength of the material at design temperature. Values of yield strength are obtained from the applicable external pressure chart as follows:

(a) For a given temperature curve, determine the B value that corresponds to the right hand side termination point of the curve.

(b) The yield strength is twice the B value obtained in (a) above.

Step 4. The smaller of the values of P_{a1} calculated in Step 2, or P_{a2} calculated in Step 3 shall be used for the maximum allowable external working pressure P_a. Compare P_a with P. If P_a is smaller than P, select a larger value for t and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P.

(d) Spherical Shells. The minimum required thickness of a spherical shell under external pressure, either seamless or of built-up construction with butt joints, shall be determined by the following procedure:

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Step 1. Assume a value for t and calculate the value of factor A using the following formula:

$$A = \frac{0.125}{(R_o/t)}$$

Step 2. Using the value of A calculated in Step 1, enter the applicable material chart in Subpart 3 of Section II, Part D for the material under consideration. Move vertically to an intersection with the material/temperature line for the design temperature (see UG-20). Interpolation may be made between lines for intermediate temperatures.

In cases where the value at A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values at A falling to the left of the material/temperature line, see Step 5.

Step 3. From the intersection obtained in Step 2, move horizontally to the right and read the value of factor B.

Step 4. Using the value of B obtained in Step 3, calculate the value of the maximum allowable external working pressure P_a using the following formula:

$$P_a = \frac{B}{(R_o/t)}$$

Step 5. For values of A falling to the left of the applicable material/temperature line, the value of P_a can be calculated using the following formula:

$$P_a = \frac{0.0625E}{(R_o/t)^2}$$

Step 6. Compare P_a obtained in Steps 4 or 5 with P. If P_a is smaller than P, select a larger value for t and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P. An example illustrating the use of this procedure is given in L-3(b).

(e) The external design pressure or maximum allowable external working pressure shall not be less than the maximum expected difference in operating pressure that may exist between the outside and the inside of the vessel at any time.

(f) Vessels intended for service under external working pressures of 15 psi (103 kPa) and less [see U-1(c)(2)(h)] may be stamped with the Code Symbol denoting compliance with the rules for external pressure provided all the applicable rules of this Division are satisfied. When the Code Symbol is to be applied, the user or his designated agent shall specify the required maximum allowable external working pressure.[18] The vessel shall be designed and stamped with the maximum allowable external working pressure.

(g) When there is a longitudinal lap joint in a cylindrical shell or any lap joint in a spherical shell under external pressure, the thickness of the shell shall be determined by the rules in this paragraph, except that $2P$ shall be used instead of P in the calculations for the required thickness.

(h) Circumferential joints in cylindrical shells may be of any type permitted by the Code and shall be designed for the imposed loads.

(i) Those portions of pressure chambers of vessels which are subject to a collapsing pressure and which have a shape other than that of a complete circular cylinder or formed head, and also jackets of cylindrical vessels which extend over only a portion of the circumference, shall be fully staybolted in accordance with the requirements of UG-47 through UG-50 or shall be proof tested in compliance with UG-101(p).

(j) When necessary, vessels shall be provided with stiffeners or other additional means of support to prevent overstress or large distortions under the external loadings listed in UG-22 other than pressure and temperature.

UG-29 STIFFENING RINGS FOR CYLINDRICAL SHELLS UNDER EXTERNAL PRESSURE

(a) Except as exempted in (f) below, the available moment of inertia of a circumferential stiffening ring shall be not less than that determined by one of the following two formulas:

$$I_s = [D_o^2 L_s (t + A_s/L_s)A]/14$$

$$I_s' = [D_o^2 L_s (t + A_s/L_s)A]/10.9$$

I_s = required moment of inertia of the stiffening ring cross section about its neutral axis parallel to the axis of the shell, in.^{4} (mm^4)

I_s' = required moment of inertia of the combined ring-shell cross section about its neutral axis parallel to the axis of the shell, in.^{4} (mm^4)

I = available moment of inertia of the stiffening ring cross section about its neutral axis parallel to the axis of the shell, in.^{4} (mm^4)

[18] It is recommended that a suitable margin be provided when establishing the maximum allowable external working pressure to allow for pressure variations in service.

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I' = available moment of inertia of combined ring-shell cross section about its neutral axis parallel to the axis of the shell, in.^{4} (mm^4). The nominal shell thickness t_s shall be used and the width of shell which is taken as contributing to the moment of inertia of the combined section shall not be greater than $1.10\sqrt{D_o t_s}$ and shall be taken as lying one-half on each side of the centroid of the ring. Portions of the shell plate shall not be considered as contributing area to more than one stiffening ring.

CAUTIONARY NOTE: Stiffening rings may be subject to lateral buckling. This should be considered in addition to the requirements for I_s and I'_s [see U-2(g)].

If the stiffeners should be so located that the maximum permissible effective shell sections overlap on either or both sides of a stiffener, the effective shell section for that stiffener shall be shortened by one-half of each overlap.

A_s = cross-sectional area of the stiffening ring, sq in. (mm^2)

A = factor determined from the applicable chart in Subpart 3 of Section II, Part D for the material used in the stiffening ring, corresponding to the factor B, below, and the design temperature for the shell under consideration

B = factor determined from the applicable chart in Subpart 3 of Section II, Part D for the material used for the stiffening ring, psi (kPa) [see UG-20(c)]

L_s = one-half of the distance from the center line of the stiffening ring to the next line of support on one side, plus one-half of the center line distance to the next line of support on the other side of the stiffening ring, both measured parallel to the axis of the cylinder, in. (mm). A line of support is:

(1) a stiffening ring that meets the requirements of this paragraph;

(2) a circumferential connection to a jacket for a jacketed section of a cylindrical shell;

(3) a circumferential line on a head at one-third the depth of the head from the head tangent line as shown on Fig. UG-28;

(4) a cone-to-cylinder junction.

P, D_o, E, t, and t_s are as defined in UG-28(b).

The adequacy of the moment of inertia for a stiffening ring shall be determined by the following procedure.

Step 1. Assuming that the shell has been designed and D_o, L_s, and t are known, select a member to be used for the stiffening ring and determine its cross-sectional area A_s. Then calculate factor B using the following formula:

$$B = \tfrac{3}{4}\left(\frac{PD_o}{t + A_s/L_s}\right)$$

Step 2. Enter the right-hand side of the applicable material chart in Subpart 3 of Section II, Part D for the material under consideration at the value of B determined by Step 1. If different materials are used for the shell and stiffening ring, use the material chart resulting in the larger value of A in Step 4, below.

Step 3. Move horizontally to the left to the material/temperature line for the design metal temperature. For values of B falling below the left end of the material/temperature line, see Step 5.

Step 4. Move vertically to the bottom of the chart and read the value of A.

Step 5. For values of B falling below the left end of the material/temperature line for the design temperature, the value of A can be calculated using the formula $A = 2B/E$.

Step 6a. In those cases where only the stiffening ring is considered, compute the required moment of inertia from the formula for I_s given above.

Step 6b. In those cases where the combined ring-shell is considered, compute the required moment of inertia from the formula for I_s' given above.

Step 7a. In those cases where only the stiffening ring is considered, determine the available moment of inertia I as given in the definitions.

Step 7b. In those cases where the combined ring-shell is considered, determine the available moment of inertia I' as given in the definitions.

NOTE: In those cases where the stiffening ring is not attached to the shell or where the stiffening ring is attached but the designer chooses to consider only the ring, Step 6a and Step 7a are considered. In those cases where the stiffening ring is attached to the shell and the combined moment of inertia is considered, Step 6b and Step 7b are considered.

Step 8. If the required moment of inertia is greater than the available moment of inertia for the section selected, for those cases where the stiffening ring is not attached or where the combined ring-shell stiffness was not considered, a new section with a larger moment of inertia must be selected; the ring must be attached to the shell and the combination shall be considered; or the ring-shell combination which was previously not considered together shall be considered together. If the required moment of inertia is greater than the available moment of inertia for those cases where the combined

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ring-shell was considered, a new ring section with a larger moment of inertia must be selected. In any case, when a new section is used, all of the calculations shall be repeated using the new section properties of the ring or ring-shell combination.

If the required moment of inertia is smaller than the actual moment of inertia of the ring or ring-shell combination, whichever is used, that ring section or combined section is satisfactory.

An example illustrating the use of this procedure is given in L-5.

(b) Stiffening rings shall extend completely around the circumference of the cylinder except as permitted in (c) below. Any joints between the ends or sections of such rings, such as shown in Fig. UG-29.1(A) and (B), and any connection between adjacent portions of a stiffening ring lying inside or outside the shell as shown in Fig. UG-29.1(C) shall be made so that the required moment of inertia of the combined ring-shell section is maintained.

(c) Stiffening rings placed on the inside of a vessel may be arranged as shown in Fig. UG-29.1(E) and (F) provided that the required moment of inertia of the ring in (E) or of the combined ring-shell section in (F) is maintained within the sections indicated. Where the gap at (A) or (E) does not exceed eight times the thickness of the shell plate, the combined moment of inertia of the shell and stiffener may be used.

Any gap in that portion of a stiffening ring supporting the shell, such as shown in Fig. UG-29.1(D) and (E), shall not exceed the length of arc given in Fig. UG-29.2 unless additional reinforcement is provided as shown in Fig. UG-29.1(C) or unless the following conditions are met:

(1) only one unsupported shell arc is permitted per ring; and

(2) the length of the unsupported shell arc does not exceed 90 deg.; and

(3) the unsupported arcs in adjacent stiffening rings are staggered 180 deg.; and

(4) the dimension L defined in UG-28(b) is taken as the larger of the following: the distance between alternate stiffening rings, or the distance from the head tangent line to the second stiffening ring plus one-third of the head depth.

(d) When internal plane structures perpendicular to the longitudinal axis of the cylinder (such as bubble trays or baffle plates) are used in a vessel, they may also be considered to act as stiffening rings provided they are designed to function as such.

(e) Any internal stays or supports used as stiffeners of the shell shall bear against the shell of the vessel through the medium of a substantially continuous ring.

NOTE: Attention is called to the objection to supporting vessels through the medium of legs or brackets, the arrangement of which may cause concentrated loads to be imposed on the shell. Vertical vessels should be supported through a substantial ring secured to the shell (see G-3). Horizontal vessels, unless supported at or close to the ends (heads) or at stiffening rings, should be supported through the medium of substantial members extending over at least one-third of the circumference, as shown at (K) in Fig. UG-29.1.

Attention is called also to the hazard of imposing highly concentrated loads by the improper support of one vessel on another or by the hanging or supporting of heavy weights directly on the shell of the vessel. (See Appendix G.)

(f) When closure bars or other rings are attached to both the inner shell and outer jacket of a vessel, with pressure in the space between the jacket and inner shell, this construction has adequate inherent stiffness, and therefore the rules of this paragraph do not apply.

UG-30 ATTACHMENT OF STIFFENING RINGS

(a) Stiffening rings may be placed on the inside or outside of a vessel, and shall be attached to the shell by welding or brazing. Brazing may be used if the vessel is not to be later stress relieved. The ring shall be essentially in contact with the shell and meet the rules in UG-29(b) and (c). Welding of stiffening rings shall comply with the requirements of this Division for the type of vessel under construction.

(b) Stiffening rings may be attached to the shell by continuous, intermittent, or a combination of continuous and intermittent welds or brazes. Some acceptable methods of attaching stiffening rings are illustrated in Fig. UG-30.

(c) Intermittent welding shall be placed on both sides of the stiffener and may be either staggered or in-line. Length of individual fillet weld segments shall not be less than 2 in. (51 mm) and shall have a maximum clear spacing between toes of adjacent weld segments of 8t for external rings and 12t for internal rings where t is the shell thickness at the attachment. The total length of weld on each side of the stiffening ring shall be:

(1) not less than one-half the outside circumference of the vessel for rings on the outside; and

(2) not less than one-third the circumference of the vessel for rings on the inside.

(d) A continuous full penetration weld is permitted as shown in sketch (e) of Fig. UG-30. Continuous fillet welding or brazing on one side of the stiffener with

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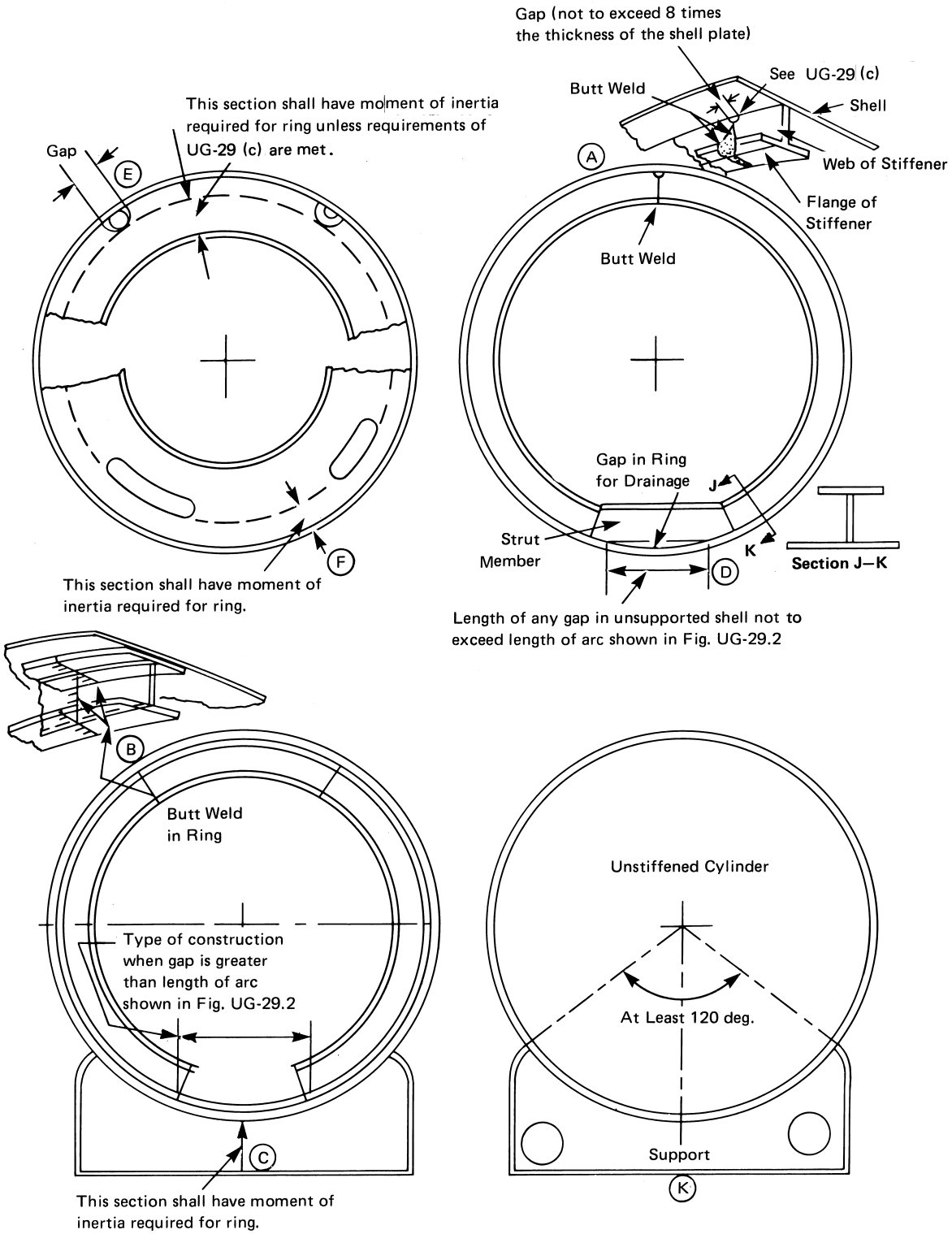


FIG. UG-29.1 VARIOUS ARRANGEMENTS OF STIFFENING RINGS FOR CYLINDRICAL VESSELS SUBJECTED TO EXTERNAL PRESSURE

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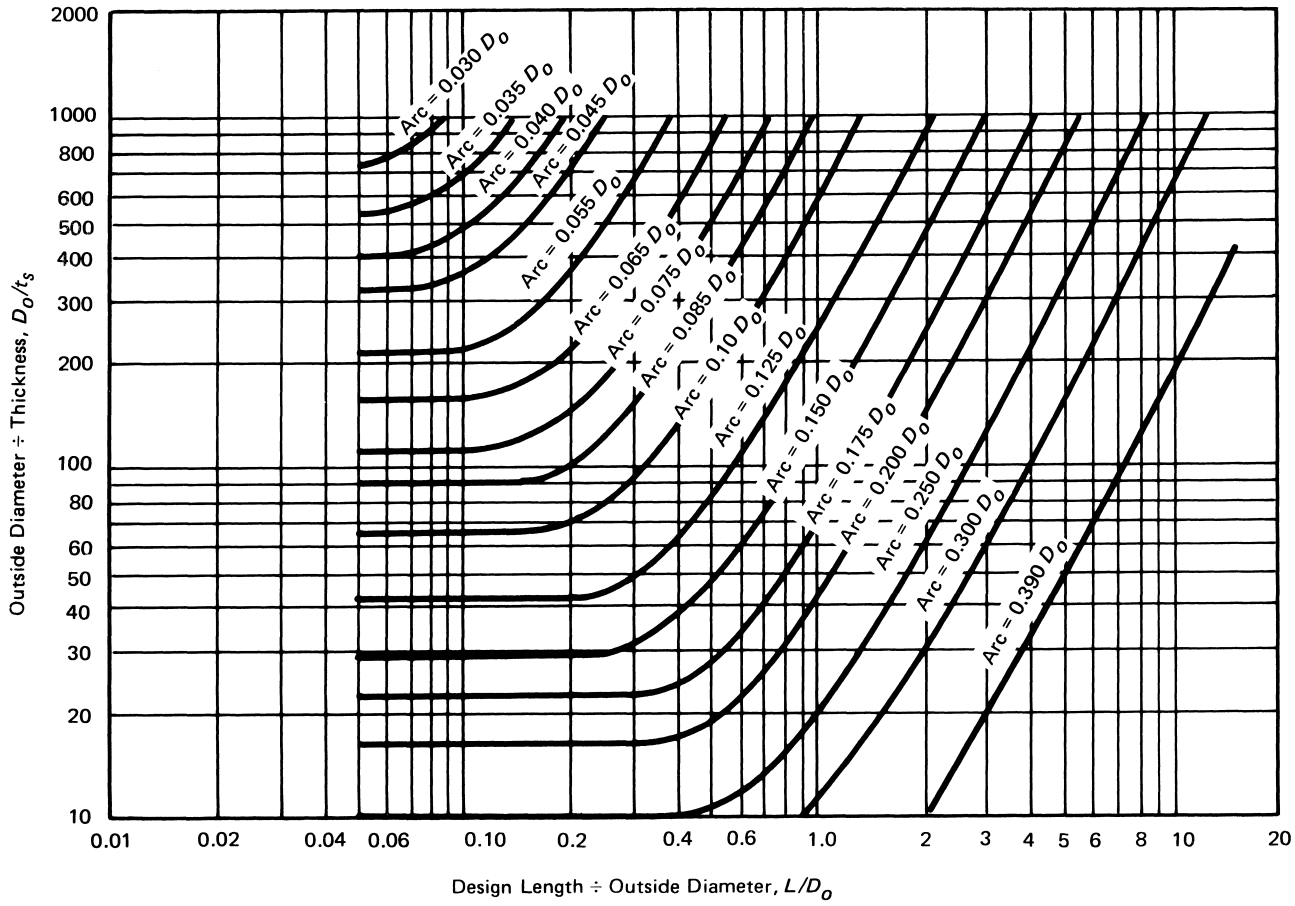


FIG. UG-29.2 MAXIMUM ARC OF SHELL LEFT UNSUPPORTED BECAUSE OF GAP IN STIFFENING RING OF CYLINDRICAL SHELL UNDER EXTERNAL PRESSURE

intermittent welding or brazing on the other side is permitted for sketches (a), (b), (c), and (d) of Fig. UG-30 when the thickness t_w of the outstanding stiffening element [sketches (a) and (c)] or width w of the stiffening element mating to the shell [sketches (b) and (d)] is not more than 1 in. (25 mm). The weld segments shall be not less than 2 in. (51 mm) long and shall have a maximum clear spacing between toes of adjacent weld segments of 24t.

(e) Strength of Attachment Welds. Stiffening ring attachment welds shall be sized to resist the full radial pressure load from the shell between stiffeners, and shear loads acting radially across the stiffener caused by external design loads carried by the stiffener (if any) and a computed radial shear equal to 2% of the stiffening ring's compressive load. See Example L-5 of Appendix L.

(1) The radial pressure load from shell, lb/in. (N/m), is equal to PL_s.

(2) The radial shear load, lb (kN), is equal to $0.01PL_sD_O$.

(3) P, L_s, and D_O are defined in UG-29.**

(f) Minimum Size of Attachment Welds. The fillet weld leg size shall be not less than the smallest of the following:

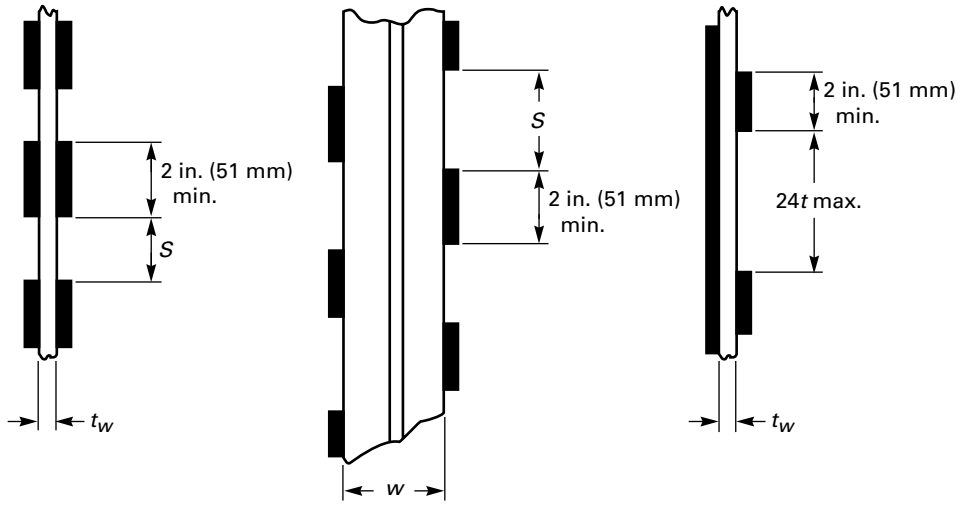
(1) $\frac{1}{4}$ in. (6 mm);

(2) vessel thickness at the weld location;

(3) stiffener thickness at weld location.

** For some of the terms of the above equation(s), it may be necessary to convert millimeters to meters to obtain a rational result in SI units.

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In-line Intermittent Weld | **Staggered Intermittent Weld** | **Continuous Fillet Weld One Side, Intermittent Other Side**

$S \leq 8t$ external stiffeners
$S \leq 12t$ internal stiffeners

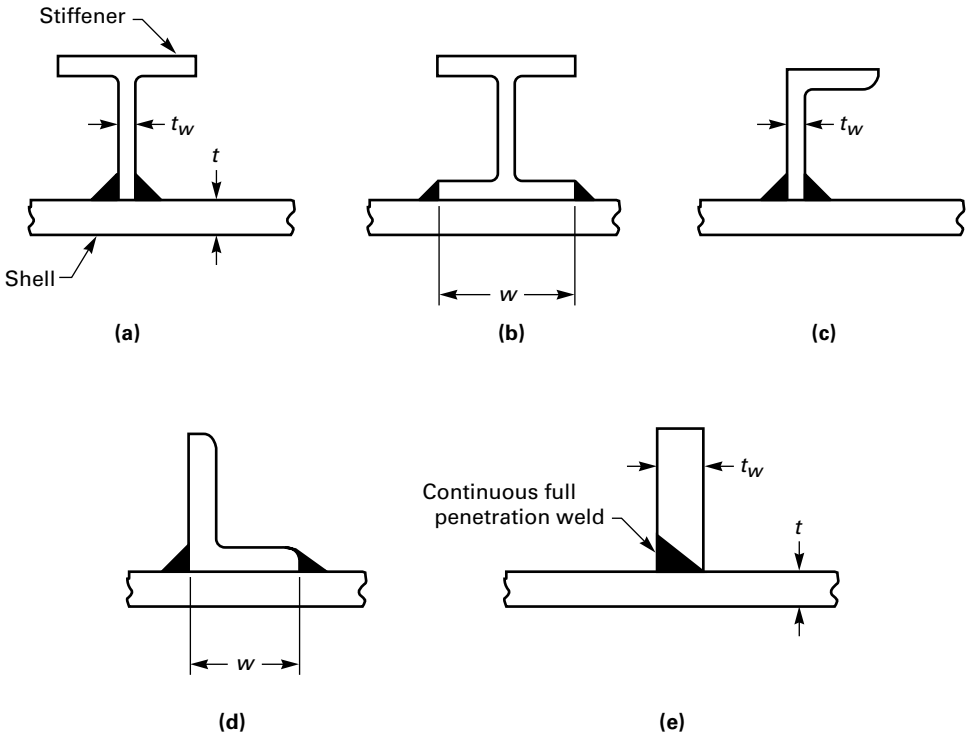


FIG. UG-30 SOME ACCEPTABLE METHODS OF ATTACHING STIFFENING RINGS

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01 UG-31 TUBES, AND PIPE WHEN USED AS TUBES OR SHELLS

(a) Internal Pressure. The required wall thickness for tubes and pipe under internal pressure shall be determined in accordance with the rules for shells in UG-27.

(b) External Pressure. The required wall thickness for tubes and pipe under external pressure shall be determined in accordance with the rules in UG-28.

(c) The thickness as determined under (a) or (b) above shall be increased when necessary to meet the following requirements.

(1) Additional wall thickness should be provided when corrosion, erosion, or wear due to cleaning operations is expected.

(2) Where ends are threaded, additional wall thickness is to be provided in the amount of $0.8/n$ in. ($20/n$ mm) [where n equals the number of threads per inch (25.4 mm)].

NOTE: The requirements for rolling, expanding, or otherwise seating tubes in tube plates may require additional wall thickness and careful choice of materials because of possible relaxation due to differential expansion stresses.

01 UG-32 FORMED HEADS, AND SECTIONS, PRESSURE ON CONCAVE SIDE

(a) The required thickness at the thinnest point after forming[19] of ellipsoidal, torispherical, hemispherical, conical, and toriconical heads under pressure on the concave side (plus heads) shall be computed by the appropriate formulas in this paragraph[20] (see UG-16). In addition, provision shall be made for any of the other loadings given in UG-22.

(b) The thickness of an unstayed ellipsoidal or torispherical head shall in no case be less than the required thickness of a seamless hemispherical head divided by the efficiency of the head-to-shell joint.

(c) The symbols defined below are used in the formulas of this paragraph:

t = minimum required thickness of head after forming, in. (mm)

P = internal design pressure (see UG-21), psi (kPa)

D = inside diameter of the head skirt; or inside length of the major axis of an ellipsoidal head; or inside diameter of a conical head at the point under consideration, measured perpendicular to the longitudinal axis, in. (mm)

D_i = inside diameter of the conical portion of a toriconical head at its point of tangency to the knuckle, measured perpendicular to the axis of the cone, in. (mm)
$= D - 2r(1 - \cos\alpha)$

r = inside knuckle radius, in. (mm)

S = maximum allowable stress value in tension as given in the tables referenced in UG-23, psi (kPa), except as limited in UG-24 and (e) below.

E = lowest efficiency of any joint in the head; for hemispherical heads this includes head-to-shell joint; for welded vessels, use the efficiency specified in UW-12

L = inside spherical or crown radius, in. (mm)

α = one-half of the included (apex) angle of the cone at the center line of the head (see Fig. 1-4)

(d) Ellipsoidal Heads. The required thickness of a dished head of semiellipsoidal form, in which half the minor axis (inside depth of the head minus the skirt) equals one-fourth of the inside diameter of the head skirt, shall be determined by

$$t = \frac{PD}{2SE - 0.2P} \quad \text{or} \quad P = \frac{2SEt}{D + 0.2t} \tag{1}$$

An acceptable approximation of a 2:1 ellipsoidal head is one with a knuckle radius of $0.17D$ and a spherical radius of $0.90D$.

(e) Torispherical Heads. The required thickness of a torispherical head for the case in which the knuckle radius is 6% of the inside crown radius and the inside crown radius equals the outside diameter of the skirt, [see (j) below], shall be determined by

$$t = \frac{0.885PL}{SE - 0.1P} \quad \text{or} \quad P = \frac{SEt}{0.885L + 0.1t} \tag{2}$$

Torispherical heads made of materials having a specified minimum tensile strength exceeding 70,000 psi (483 MPa) shall be designed using a value of S equal to 20,000 psi (138 000 kPa) at room temperature and reduced in proportion to the reduction in maximum allowable stress values at temperature for the material (see UG-23).

[19] In order to ensure that a finished head is not less than the minimum thickness required, it is customary to use a thicker plate to take care of possible thinning during the process of forming. The neck of an opening in a head with an integrally flanged opening will thin out due to the fluing operation. This is permissible provided the neck thickness is not less than the thickness required for a cylindrical shell subject to internal and/or external pressure, as applicable, and having an inside diameter equal to the maximum diameter of the opening [see UG-38(a) and UG-46(j)].

[20] Formulas in terms of outside dimensions and for heads of other proportions are given in 1-4 together with illustrative examples.

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(f) Hemispherical Heads. When the thickness of a hemispherical head does not exceed 0.356*L*, or *P* does not exceed 0.665*SE*, the following formulas shall apply:

$$t = \frac{PL}{2SE - 0.2P} \quad \text{or} \quad P = \frac{2SEt}{L + 0.2t} \tag{3}$$

(g) Conical Heads and Sections (Without Transition Knuckle). The required thickness of conical heads or conical shell sections that have a half apex-angle α not greater than 30 deg. shall be determined by

$$t = \frac{PD}{2\cos\alpha(SE - 0.6P)} \text{ or } P = \frac{2SEt\cos\alpha}{D + 1.2t\cos\alpha} \tag{4}$$

A reinforcing ring shall be provided when required by the rule in 1-5(d) and (e).

Conical heads or sections having a half apex-angle α greater than 30 deg. without a transition knuckle shall comply with Formula (4) and 1-5(g).

(h) Toriconical Heads and Sections. The required thickness of the conical portion of a toriconical head or section, in which the knuckle radius is neither less than 6% of the outside diameter of the head skirt nor less than three times the knuckle thickness, shall be determined by Formula (4) in (g) above, using D_i in place of *D*.

The required thickness of the knuckle shall be determined by Formula (3) of 1-4(d) in which

$$L = \frac{D_i}{2\cos\alpha}$$

Toriconical heads or sections may be used when the angle $\alpha \leq 30$ deg. and are mandatory for conical head designs when the angle α exceeds 30 deg., unless the design complies with 1-5(g).

(i) When an ellipsoidal, torispherical, hemispherical, conical, or toriconical head is of a lesser thickness than required by the rules of this paragraph, it shall be stayed as a flat surface according to the rules of UG-47 for braced and stayed flat plates.

(j) The inside crown radius to which an unstayed head is dished shall be not greater than the outside diameter of the skirt of the head. The inside knuckle radius of a torispherical head shall be not less than 6% of the outside diameter of the skirt of the head but in no case less than 3 times the head thickness.

(k) A dished head with a reversed skirt may be used in a pressure vessel provided the maximum allowable working pressure for the head is established in accordance with the requirements of UG-101.

(l) All formed heads, thicker than the shell and concave to pressure, intended for butt welded attachment, shall have a skirt length sufficient to meet the requirements of Fig. UW-13.1, when a tapered transition is required. All formed heads concave to pressure and intended for butt welded attachment need not have an integral skirt when the thickness of the head is equal to or less than the thickness of the shell. When a skirt is provided, its thickness shall be at least that required for a seamless shell of the same inside diameter.

(m) Heads concave to pressure, intended for attachment by brazing, shall have a skirt length sufficient to meet the requirements for circumferential joints in Part UB.

(n) Any taper at a welded joint within a formed head shall be in accordance with UW-9. The taper at a circumferential welded joint connecting a formed head to a main shell shall meet the requirements of UW-13 for the respective type of joint shown therein.

(o) If a torispherical, ellipsoidal, or hemispherical head is formed with a flattened spot or surface, the diameter of the flat spot shall not exceed that permitted for flat heads as given by Formula (1) in UG-34, using $C = 0.25$.

(p) Openings in formed heads under internal pressure shall comply with the requirements of UG-36 through UG-46.

(q) A stayed jacket that completely covers a formed inner head or any of the types included in this paragraph shall also meet the requirements of UG-47(c).

UG-33 FORMED HEADS, PRESSURE ON CONVEX SIDE

(a) General. The required thickness at the thinnest point after forming [see footnote 20, UG-32(a)] of ellipsoidal, torispherical, hemispherical, toriconical, and conical heads and conical segments under pressure on the convex side (minus heads) shall be computed by the appropriate formulas given in this paragraph (see UG-16). In addition, provisions shall be made for any other loading given in UG-22. The required thickness for heads due to pressure on the convex side shall be determined as follows.

(1) For ellipsoidal and torispherical heads, the required thickness shall be the greater of the following:

(a) the thickness computed by the procedure given in UG-32 for heads with pressure on the concave side (plus heads) using a design pressure 1.67 times the design pressure on the convex side, assuming a joint efficiency $E = 1.00$ for all cases; or

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TABLE UG-33.1
VALUES OF SPHERICAL RADIUS FACTOR K_o FOR ELLIPSOIDAL HEAD WITH PRESSURE ON CONVEX SIDE
Interpolation Permitted for Intermediate Values

$D_o/2h_o$	...	3.0	2.8	2.6	2.4	2.2
K_o	...	1.36	1.27	1.18	1.08	0.99
$D_o/2h_o$	2.0	1.8	1.6	1.4	1.2	1.0
K_o	0.90	0.81	0.73	0.65	0.57	0.50

(b) the thickness as computed by the appropriate procedure given in (d) or (e) below.

In determining the maximum allowable working pressure on the convex side of ellipsoidal or torispherical heads, reverse the procedures in (a)(1)(a) and (a)(1)(b) above, and use the smaller of the pressures obtained.

(2) For hemispherical heads, the required thickness shall be determined by the rules given in (c) below.

(3) For conical and toriconical heads and conical sections, the required thickness shall be determined by the rules given in (f) below.

(b) Nomenclature. The nomenclature defined below is used in this paragraph. Figure 1-4 shows principal dimensions of typical heads.

A, B, E, and P are as defined in UG-28(b)
D_o = outside diameter of the head skirt, in. (mm)
$D_o/2h_o$ = ratio of the major to the minor axis of ellipsoidal heads, which equals the outside diameter of the head skirt divided by twice the outside height of the head (see Table UG-33.1)
t_e = effective thickness of conical section, in. (mm)
$= t \cos \alpha$
L_c = axial length of conical section, excluding the knuckle, of a toriconical head or section (see Fig. UG-33.1), in. (mm)
L_e = equivalent length of conical section, in. (mm)
$= (L/2)(1 + D_s/D_L)$
L = axial length of cone or conical section (see Fig. UG-33.1), in. (mm) [for a toriconical head or section, see UG-33(g)].
D_s = outside diameter at small end of conical section under consideration, in. (mm)
D_L = outside diameter at large end of conical section under consideration, in. (mm)
h_o = one-half of the length of the outside minor axis of the ellipsoidal head, or the outside height of the ellipsoidal head measured from the tangent line (head-bend line), in. (mm)
K_o = factor depending on the ellipsoidal head proportions $D_o/2h_o$ (see Table UG-33.1)
R_o = for hemispherical heads, the outside radius, in. (mm)
R_o = for ellipsoidal heads, the equivalent outside spherical radius taken as $K_o D_o$, in. (mm)
R_o = for torispherical heads, the outside radius of the crown portion of the head, in. (mm)
t = minimum required thickness of head after forming, in. (mm)
α = one-half the apex angle in conical heads and sections, deg.

(c) Hemispherical Heads. The required thickness of a hemispherical head having pressure on the convex side shall be determined in the same manner as outlined in UG-28(d) for determining the thickness for a spherical shell. An example illustrating the use of this procedure is given in L-6.3.

(d) Ellipsoidal Heads. The required thickness of an ellipsoidal head having pressure on the convex side, either seamless or of built-up construction with butt joints, shall not be less than that determined by the following procedure.

Step 1. Assume a value for t and calculate the value of factor A using the following formula:

$$A = \frac{0.125}{R_o/t}$$

Step 2. Using the value of A calculated in Step 1, follow the same procedure as that given for spherical shells in UG-28(d), Steps 2 through 6. An example illustrating the use of this procedure is given in L-6.1.

(e) Torispherical Heads. The required thickness of a torispherical head having pressure on the convex side, either seamless or of built-up construction with butt joints, shall not be less than that determined by the same design procedure as is used for ellipsoidal heads given in (d) above, using the appropriate value for R_o. An example illustrating the use of this procedure is given in L-6.2.

(f) Conical Heads and Sections. The required thickness of a conical head or section under pressure on the convex side, either seamless or of built-up construction with butt joints, shall be determined in accordance with the following subparagraphs.

(1) When α is equal to or less than 60 deg.:

(a) cones having D_L/t_e values ≥ 10:

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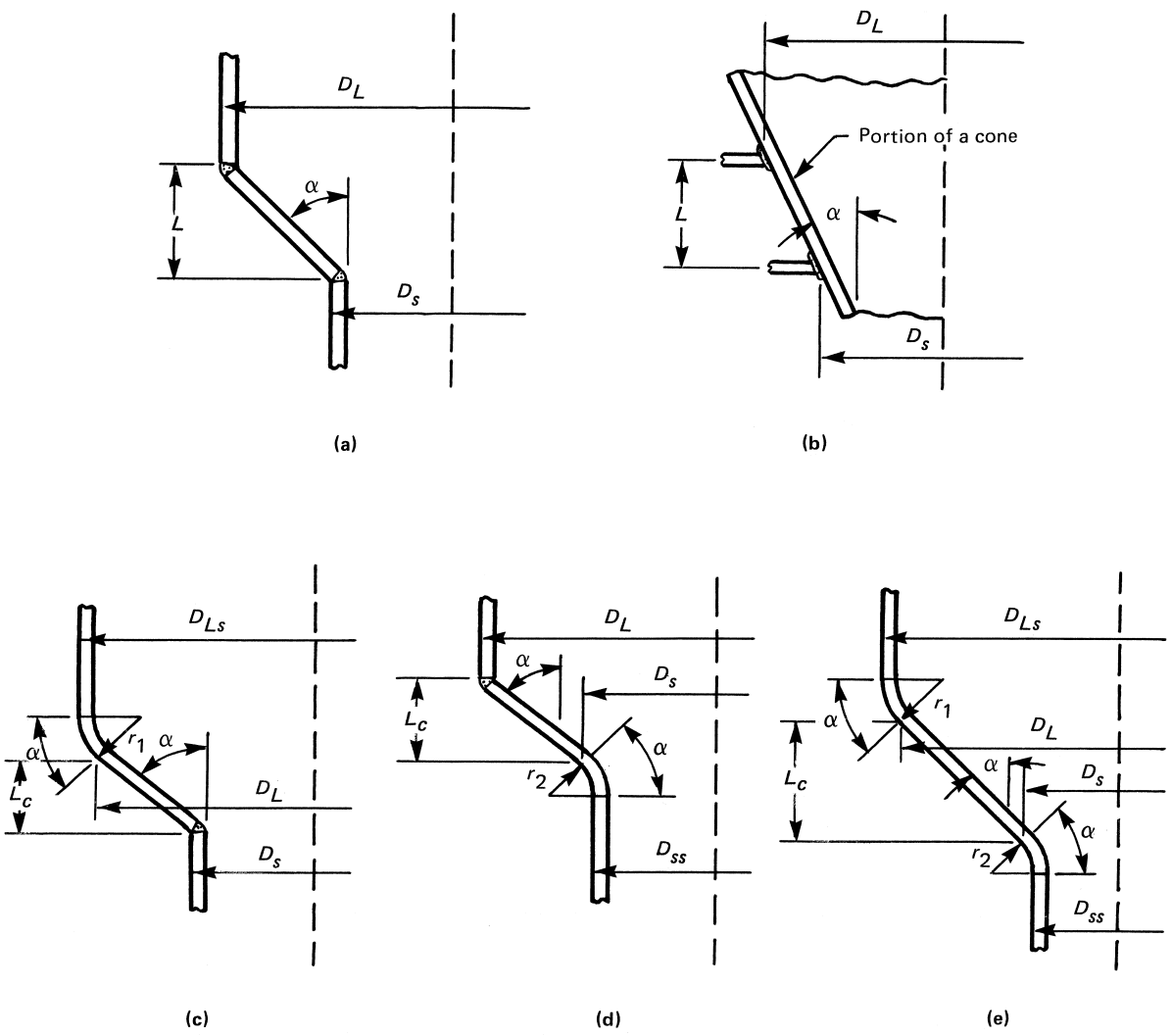


FIG. UG-33.1 LENGTH L OF SOME TYPICAL CONICAL SECTIONS FOR EXTERNAL PRESSURE

Step 1. Assume a value for t_e and determine the ratios L_e/D_L and D_L/t_e.

Step 2. Enter Fig. G of Subpart 3 of Section II, Part D at a value of L/D_o equivalent to the value of L_e/D_L determined in Step 1. For values of L_e/D_L greater than 50, enter the chart at a value of $L_e/D_L = 50$.

Step 3. Move horizontally to the line for the value of D_o/t equivalent to the value of D_L/t_e determined in Step 1. Interpolation may be made for intermediate values of D_L/t_e. From this point of intersection move vertically downwards to determine the value of factor A.

Step 4. Using the value of A calculated in Step 3, enter the applicable material chart in Subpart 3 of Section II, Part D for the material under consideration. Move vertically to an intersection with the material/temperature line for the design temperature (see UG-20). Interpolation may be made between lines for intermediate temperatures.

In cases where the value of A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material/temperature line, see Step 7.

Step 5. From the intersection obtained in Step 4, move horizontally to the right and read the value of factor B.

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Step 6. Using this value of B, calculate the value of the maximum allowable external working pressure P_a using the following formula:

$$P_a = \frac{4B}{3(D_L / t_e)}$$

Step 7. For values of A falling to the left of the applicable material/temperature line, the value of P_a can be calculated using the following formula:

$$P_a = \frac{2AE}{3(D_L / t_e)}$$

Step 8. Compare the calculated value of P_a obtained in Steps 6 or 7 with P. If P_a is smaller than P, select a larger value for t and repeat the design procedure until a value of P_a is obtained that is equal to or greater than P. An example illustrating the use of this procedure is given in L-6.4.

Step 9. Provide adequate reinforcement of the cone-to-cylinder juncture according to 1-8.

(b) cones having D_L/t_e values <10:

Step 1. Using the same procedure as given in (f)(1)(a) above, obtain the value of B. For values of D_L/t_e less than 4, the value of factor A can be calculated using the following formula:

$$A = \frac{1.1}{(D_L / t_e)^2}$$

For values of A greater than 0.10, use a value of 0.10.

Step 2. Using the value of B obtained in Step 1, calculate a value P_{a1} using the following formula:

$$P_{a1} = \left[\frac{2.167}{(D_L / t_e)} - 0.0833\right] B$$

Step 3. Calculate a value P_{a2} using the following formula:

$$P_{a2} = \frac{2S}{D_L / t_e}\left[1 - \frac{1}{D_L / t_e}\right]$$

where

S = the lesser of two times the maximum allowable stress value in tension at design metal temperature, from the applicable Table referenced by UG-23, or 0.9 times the yield strength of the material at design temperature, psi (kPa)

Values of yield strength are obtained from the applicable external pressure chart as follows.

(a) For a given temperature curve, determine the B value that corresponds to the right hand side termination point of the curve.

(b) The yield strength is twice the B value obtained in (a) above.

Step 4. The smaller of the values of P_{a1} calculated in Step 2, or P_{a2} calculated in Step 3 shall be used for the maximum allowable external working pressure P_a. Compare P_a with P. If P_a is smaller than P, select a larger value for t and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P.

Step 5. Provide adequate reinforcement of the cone-to-cylinder juncture according to 1-8. When the cone-to-cylinder juncture is a line of support, the moment of inertia at the cone-to-cylinder shall be provided in accordance with 1-8.

(2) When α of the cone is greater than 60 deg., the thickness of the cone shall be the same as the required thickness for a flat head under external pressure, the diameter of which equals the largest diameter of the cone (see UG-34).

(3) The thickness of an eccentric cone shall be taken as the greater of the two thicknesses obtained using both the smallest and largest α in the calculations.

(g) The required thickness of a toriconical head having pressure on the convex side, either seamless or of built-up construction with butt joints within the head, shall not be less than that determined from (f) above with the exception that L_e shall be determined as follows.

(1) For sketch (c) in Fig. UG-33.1,

$$L_e = r_1 \sin\alpha + \frac{L_c}{2}\left(\frac{D_L + D_s}{D_{Ls}}\right)$$

(2) For sketch (d) in Fig. UG-33.1,

$$L_e = r_2 \frac{D_{ss}}{D_L} \sin\alpha + \frac{L_c}{2}\left(\frac{D_L + D_s}{D_L}\right)$$

(3) For sketch (e) in Fig. UG-33.1,

$$L_e = \left(r_1 + r_2 \frac{D_{ss}}{D_{Ls}}\right) \sin\alpha + \frac{L_c}{2}\frac{(D_L + D_s)}{D_{Ls}}$$

When the knuckle-to-cylinder juncture is a line of support, the moment of inertia at the knuckle-to-cylinder juncture shall be provided in accordance with 1-8.

(h) When lap joints are used in formed head construction or for longitudinal joints in a conical head under external pressure, the thickness shall be determined by the rules in this paragraph, except that 2P shall be

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used instead of P in the calculations for the required thickness.

(i) The required length of skirt on heads convex to pressure shall comply with the provisions of UG-32(l) and (m) for heads concave to pressure.

(j) Openings in heads convex to pressure shall comply with the requirements of UG-36 through UG-46.

UG-34 UNSTAYED FLAT HEADS AND COVERS

(a) The minimum thickness of unstayed flat heads, cover plates and blind flanges shall conform to the requirements given in this paragraph. These requirements apply to both circular and noncircular[21] heads and covers. Some acceptable types of flat heads and covers are shown in Fig. UG-34. In this figure, the dimensions of the component parts and the dimensions of the welds are exclusive of extra metal required for corrosion allowance.

(b) The symbols used in this paragraph and in Fig. UG-34 are defined as follows:

C = a factor depending upon the method of attachment of head, shell dimensions, and other items as listed in (d) below, dimensionless. The factors for welded covers also include a factor of 0.667 which effectively increases the allowable stress for such constructions to 1.5S.

D = long span of noncircular heads or covers measured perpendicular to short span, in. (mm)

d = diameter, or short span, measured as indicated in Fig. UG-34, in. (mm)

E = joint efficiency, from Table UW-12, of any Category A weld as defined in UW-3(a)(1)

h_G = gasket moment arm, equal to the radial distance from the center line of the bolts to the line of the gasket reaction, as shown in Table 2-5.2, in. (mm)

L = perimeter of noncircular bolted head measured along the centers of the bolt holes, in. (mm)

m = the ratio t_r/t_s, dimensionless

P = internal design pressure (see UG-21), psi (kPa)

r = inside corner radius on a head formed by flanging or forging, in. (mm)

S = maximum allowable stress value in tension, psi (kPa), from applicable table of stress values referenced by UG-23

t = minimum required thickness of flat head or cover, in. (mm)

t_f = nominal thickness of the flange on a forged head, at the large end, as indicated in Fig. UG-34 sketch (b), in. (mm)

t_h = nominal thickness of flat head or cover, in. (mm)

t_r = required thickness of seamless shell, for pressure, in. (mm)

t_s = nominal thickness of shell, in. (mm)

t_w = thickness through the weld joining the edge of a head to the inside of a vessel, as indicated in Fig. UG-34 sketch (g), in. (mm)

t_1 = throat dimension of the closure weld, as indicated in Fig. UG-34 sketch (r), in. (mm)

W = total bolt load, lb (kN), given for circular heads for Formulas (3) and (4), 2-5(e)

Y = length of flange of flanged heads, measured from the tangent line of knuckle, as indicated in Fig. UG-34 sketches (a) and (c), in. (mm)

Z = a factor of noncircular heads and covers that depends on the ratio of short span to long span, as given in (c) below, dimensionless

(c) The thickness of flat unstayed heads, covers, and blind flanges shall conform to one of the following three requirements.[22]

(1) Circular blind flanges conforming to any of the flange standards listed in Table U-3 and further limited in UG-44 shall be acceptable for the diameters and pressure–temperature ratings in the respective standard when the blind flange is of the types shown in Fig. UG-34 sketches (j) and (k).

(2) The minimum required thickness of flat unstayed circular heads, covers and blind flanges shall be calculated by the following formula:

$$t = d\sqrt{CP/SE} \qquad (1)$$

except when the head, cover, or blind flange is attached by bolts causing an edge moment [sketches (j) and (k)] in which case the thickness shall be calculated by

$$t = d\sqrt{CP/SE + 1.9Wh_G/SEd^3} \qquad (2)^{**}$$

When using Formula (2), the thickness t shall be calculated for both operating conditions and gasket

[21] Special consideration shall be given to the design of shells, nozzle necks or flanges to which noncircular heads or covers are attached [see U-2(c)].

[22] The formulas provide safe construction as far as stress is concerned. Greater thicknesses may be necessary if deflection would cause leakage at threaded or gasketed joints.

** For some of the terms of the above equation(s), it may be necessary to convert millimeters to meters to obtain a rational result in SI units.

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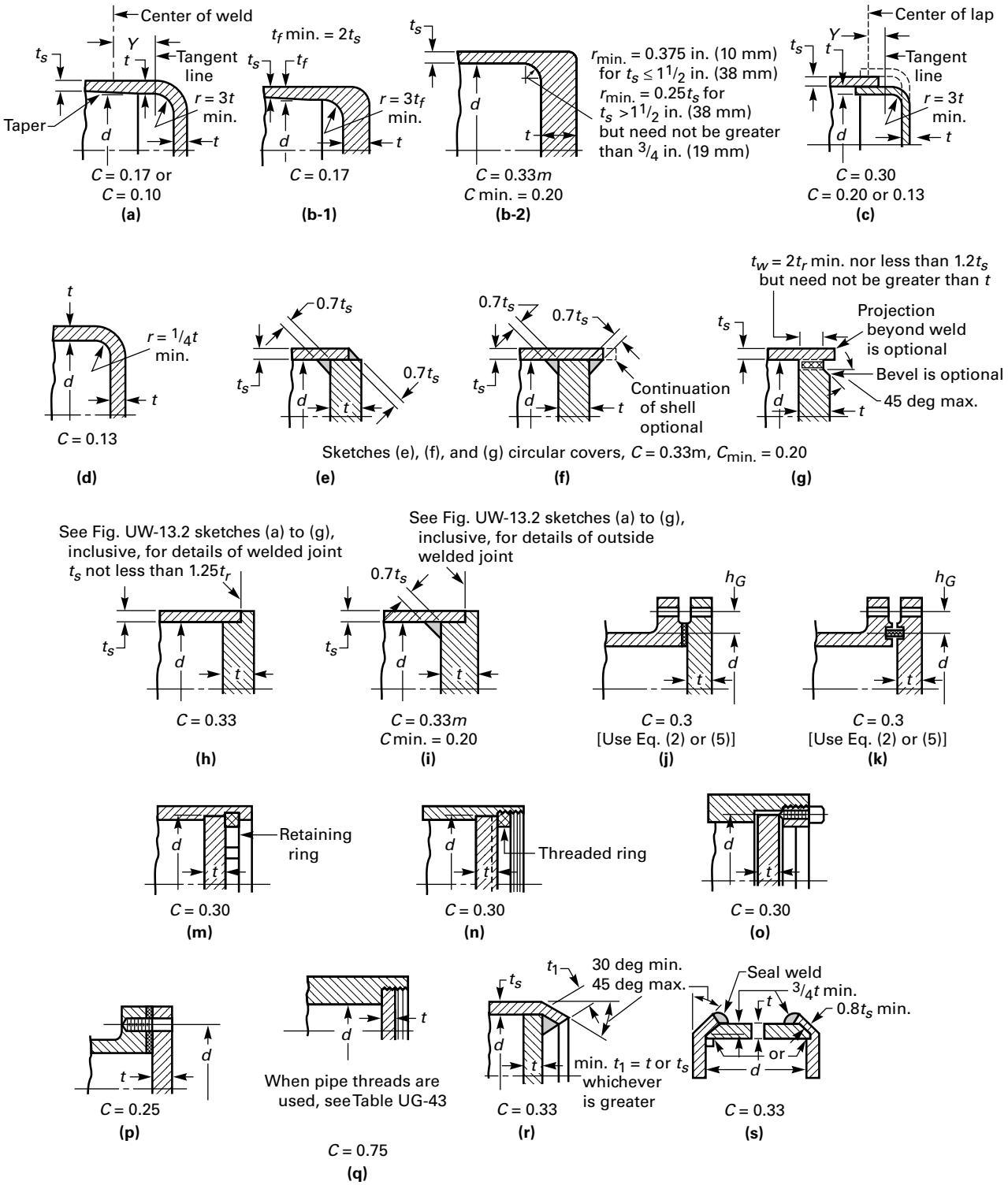


FIG. UG-34 SOME ACCEPTABLE TYPES OF UNSTAYED FLAT HEADS AND COVERS **01**
The Above Illustrations Are Diagrammatic Only. Other Designs That Meet the Requirements of UG-34 Are Acceptable.

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seating, and the greater of the two values shall be used. For operating conditions, the value of P shall be the design pressure, and the values of S at the design temperature and W from Formula (3) of 2-5(e) shall be used. For gasket seating, P equals zero, and the values of S at atmospheric temperature and W from Formula (4) of 2-5(e) shall be used.

(3) Flat unstayed heads, covers, or blind flanges may be square, rectangular, elliptical, obround, segmental, or otherwise noncircular. Their required thickness shall be calculated by the following formula:

$$t = d\sqrt{ZCP/SE} \tag{3}$$

where

$$Z = 3.4 - \frac{2.4d}{D} \tag{4}$$

with the limitation that Z need not be greater than two and one-half (2.5).

Formula (3) does not apply to noncircular heads, covers, or blind flanges attached by bolts causing a bolt edge moment [sketches (j) and (k)]. For noncircular heads of this type, the required thickness shall be calculated by the following formula:

$$t = d\sqrt{ZCP/SE + 6Wh_G/SELd^2} \tag{5}**$$

When using Formula (5), the thickness t shall be calculated in the same way as specified above for Formula (2).

(d) For the types of construction shown in Fig. UG-34, the minimum values of C to be used in Formulas (1), (2), (3), and (5) are:

Sketch (a). $C = 0.17$ for flanged circular and noncircular heads forged integral with or butt welded to the vessel with an inside corner radius not less than three times the required head thickness, with no special requirement with regard to length of flange, and where the welding meets all the requirements for circumferential joints given in Part UW.

$C = 0.10$ for circular heads, when the flange length for heads of the above design is not less than

$$Y = \left(1.1 - 0.8\,\frac{t_s^2}{t_h^2}\right)\sqrt{dt_h} \tag{6}$$

$C = 0.10$ for circular heads, when the flange length Y is less than the requirements in Formula (6) but the shell thickness is not less than

$$t_s = 1.12t_h\sqrt{1.1 - Y/\sqrt{dt_h}} \tag{7}$$

for a length of at least $2\sqrt{dt_s}$.

When $C = 0.10$ is used, the taper shall be at least 1:3.

Sketch (b-1). $C = 0.17$ for forged circular and noncircular heads integral with or butt welded to the vessel, where the flange thickness is not less than two times the shell thickness, the corner radius on the inside is not less than three times the flange thickness, and the welding meets all the requirements for circumferential joints given in Part UW.

Sketch (b-2). $C = 0.33m$ but not less than 0.20 for forged circular and noncircular heads integral with or butt welded to the vessel, where the flange thickness is not less than the shell thickness, the corner radius on the inside is not less than the following:

r_{min} = 0.375 in. (10 mm) for $t_s \le 1\frac{1}{2}$ in. (38 mm)

$r_{min} = 0.25t_s$ for $t_s > 1\frac{1}{2}$ in. (38 mm) but need not be greater than $\frac{3}{4}$ in. (19 mm)

The welding shall meet all the requirements for circumferential joints given in Part UW.

Sketch (c). $C = 0.13$ for circular heads lap welded or brazed to the shell with corner radius not less than $3t$ and Y not less than required by Formula (6) and the requirements of UW-13 are met.

$C = 0.20$ for circular and noncircular lap welded or brazed construction as above, but with no special requirement with regard to Y.

$C = 0.30$ for circular flanged plates screwed over the end of the vessel, with inside corner radius not less than $3t$, in which the design of the threaded joint against failure by shear, tension, or compression, resulting from the end force due to pressure, is based on a factor of safety of at least four, and the threaded parts are at least as strong as the threads for standard piping of the same diameter. Seal welding may be used, if desired.

Sketch (d). $C = 0.13$ for integral flat circular heads when the dimension d does not exceed 24 in. (610 mm), the ratio of thickness of the head to the dimension d

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is not less than 0.05 or greater than 0.25, the head thickness t_h is not less than the shell thickness t_s, the inside corner radius is not less than 0.25t, and the construction is obtained by special techniques of upsetting and spinning the end of the shell, such as employed in closing header ends.

Sketches (e), (f), and (g). $C = 0.33m$ but not less than 0.20 for circular plates, welded to the inside of a vessel, and otherwise meeting the requirements for the respective types of welded vessels. If a value of m less than 1 is used in calculating t, the shell thickness t_s shall be maintained along a distance inwardly from the inside face of the head equal to at least $2\sqrt{dt_s}$. The throat thickness of the fillet welds in sketches (e) and (f) shall be at least $0.7t_s$. The size of the weld t_w in sketch (g) shall be not less than 2 times the required thickness of a seamless shell nor less than 1.25 times the nominal shell thickness but need not be greater than the head thickness; the weld shall be deposited in a welding groove with the root of the weld at the inner face of the head as shown in the sketch.

$C = 0.33$ for noncircular plates, welded to the inside of a vessel and otherwise meeting the requirements for the respective types of welded vessels. The throat thickness of the fillet welds in sketches (e) and (f) shall be at least $0.7t_s$. The size of the weld t_w in sketch (g) shall be not less than 2 times the required thickness of a seamless shell nor less than 1.25 times the nominal shell thickness but need not be greater than the head thickness; the weld shall be deposited in a welding groove with the root of the weld at the inner face of the head as shown in the sketch.

Sketch (h). $C = 0.33$ for circular plates welded to the end of the shell when t_s is at least $1.25t_r$ and the weld details conform to the requirements of UW-13(e) and Fig. UW-13.2 sketches (a) to (g) inclusive. See also UG-93(d)(3).

Sketch (i). $C = 0.33m$ but not less than 0.20 for circular plates if an inside fillet weld with minimum throat thickness of $0.7t_s$ is used and the details of the outside weld conform to the requirements of UW-13(e) and Fig. UW-13.2 sketches (a) to (g) inclusive, in which the inside weld can be considered to contribute an amount equal to t_s to the sum of the dimensions a and b. See also UG-93(d)(3).

Sketches (j) and (k). $C = 0.3$ for circular and noncircular heads and covers bolted to the vessel as indicated in the figures. Note that Formula (2) or (5) shall be used because of the extra moment applied to the cover by the bolting.

When the cover plate is grooved for a peripheral gasket, as shown in sketch (k), the net cover plate thickness under the groove or between the groove and the outer edge of the cover plate shall be not less than

$$d\sqrt{1.9Wh_G/Sd^3} \quad **$$

for circular heads and covers, nor less than

$$d\sqrt{6Wh_G/SLd^2} \quad **$$

for noncircular heads and covers.

Sketches (m), (n), and (o). $C = 0.3$ for a circular plate inserted into the end of a vessel and held in place by a positive mechanical locking arrangement, and when all possible means of failure (either by shear, tension, compression, or radial deformation, including flaring, resulting from pressure and differential thermal expansion) are resisted with a factor of safety of at least four. Seal welding may be used, if desired.

Sketch (p). $C = 0.25$ for circular and noncircular covers bolted with a full-face gasket, to shells, flanges or side plates.

Sketch (q). $C = 0.75$ for circular plates screwed into the end of a vessel having an inside diameter d not exceeding 12 in. (305 mm); or for heads having an integral flange screwed over the end of a vessel having an inside diameter d not exceeding 12 in. (305 mm); and when the design of the threaded joint, against failure by shear, tension, compression, or radial deformation, including flaring, resulting from pressure and differential thermal expansion, is based on a factor of safety of at least four. If a tapered pipe thread is used, the requirements of Table UG-43 shall also be met. Seal welding may be used, if desired.

Sketch (r). $C = 0.33$ for circular plates having a dimension d not exceeding 18 in. (457 mm) inserted into the vessel as shown and otherwise meeting the requirements for the respective types of welded vessels. The end of the vessel shall be crimped over at least 30 deg., but not more than 45 deg. The crimping may be done cold only when this operation will not injure the metal. The throat of the weld shall be not less than the thickness of the flat head or shell, whichever is greater.

Sketch (s). $C = 0.33$ for circular beveled plates having a diameter d not exceeding 18 in. (457 mm), inserted into a vessel, the end of which is crimped over at least 30 deg., but not more than 45 deg., and when the undercutting for seating leaves at least 80% of the shell thickness. The beveling shall be not less

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than 75% of the head thickness. The crimping shall be done when the entire circumference of the cylinder is uniformly heated to the proper forging temperature for the material used. For this construction, the ratio t_s/d shall be not less than the ratio P/S nor less than 0.05. The maximum allowable pressure for this construction shall not exceed $P = S/5d$ for Customary units ($P = 5S/d$ for SI units).

This construction is not permissible if machined from rolled plate.

UG-35 OTHER TYPES OF CLOSURES

UG-35.1 Spherically Dished Covers

Requirements for design of circular spherically dished heads with bolting flanges are given in 1-6.

UG-35.2 Quick-Actuating (Quick-Opening) Closures

UG-35.2(a) Definitions

UG-35.2(a)(1) Quick-actuating or quick-opening closures are those that permit substantially faster access to the contents space of a pressure vessel than would be expected with a standard bolted flange connection (bolting through one or both flanges). Closures with swing bolts are not considered quick-actuating (quick-opening).

UG-35.2(a)(2) Holding elements are structural members of the closure used to attach or hold the cover to the vessel.

UG-35.2(a)(3) Locking components are structural items that are used to prevent opening of the closure while pressure is applied. Locking components may also be used as holding elements.

UG-35.2(a)(4) The locking mechanism or locking device consists of a combination of locking components.

UG-35.2(b) General Design Requirements

UG-35.2(b)(1) Quick-actuating closures shall be designed, such that the failure of a single locking component while the vessel is operating, will not:

(a) release the closure;

(b) result in the failure of any other locking component or holding element; and

(c) increase the stress in any other locking component or holding element by more than 50% above the allowable stress of the component.

UG-35.2(b)(2) Quick-actuating closures shall be designed and installed such that it may be determined by visual external observation that the holding elements are in good condition.

UG-35.2(b)(3) The closures shall also be designed so that all locking components can be verified to be fully engaged by visual observation or other means prior to the application of pressure to the vessel.

UG-35.2(b)(4) When installed, all vessels having quick-actuating closures shall be provided with a pressure indicating device visible from the operating area.

UG-35.2(c) Specific Design Requirements

UG-35.2(c)(1) Quick-actuating closures that are held in position by positive locking devices and that are fully released by partial rotation or limited movement of the closure itself or the locking mechanism and any closure that is other than manually operated shall be so designed that when the vessel is installed the following conditions are met:

(a) The closure and its holding elements are fully engaged in their intended operating position before pressure can be built up in the vessel.

(b) Pressure tending to force the closure clear of the vessel shall be released before the closure can be fully opened for access.

(c) In the event that compliance with (a) and (b) above is not inherent in the design of the closure and its holding elements, provisions shall be made so that devices to accomplish this can be added when the vessel is installed.

UG-35.2(c)(2) It is recognized that it is impractical to write requirements to cover the multiplicity of devices used for quick access, or to prevent negligent operation or the circumventing of safety devices. Any device or devices which will provide the safeguards broadly described in (1)(a), (1)(b), and (1)(c) above will meet the intent of this Division.

UG-35.2(d) Alternative Designs for Manually Operated Closures

UG-35.2(d)(1) Quick-actuating closures that are held in position by a locking mechanism designed for manual operation shall be so designed that there will be leakage of the contents of the vessel prior to disengagement of the locking components and release of the closure.

UG-35.2(d)(2) Manually operated closures need not satisfy (c)(1)(a), (c)(1)(b), or (c)(1)(c) above, but such closures shall be equipped with an audible or visible warning device that will warn the operator if pressure is applied to the vessel before the holding elements and locking components are fully engaged in their intended position or if an attempt is made to disengage the locking mechanism before the pressure within the vessel is released.

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OPENINGS AND REINFORCEMENTS[23]

(Typical examples of the application of these rules are given in Appendix L.)

01 UG-36 OPENINGS IN PRESSURE VESSELS

(a) Shape of Opening[24]

(1) Openings in cylindrical or conical portions of vessels, or in formed heads, shall preferably be circular, elliptical, or obround.[25] When the long dimension of an elliptical or obround opening exceeds twice the short dimensions, the reinforcement across the short dimensions shall be increased as necessary to provide against excessive distortion due to twisting moment.

(2) Openings may be of other shapes than those given in (1) above, and all corners shall be provided with a suitable radius. When the openings are of such proportions that their strength cannot be computed with assurance of accuracy, or when doubt exists as to the safety of a vessel with such openings, the part of the vessel affected shall be subjected to a proof hydrostatic test as prescribed in UG-101.

(b) Size of Openings

(1) Properly reinforced openings in cylindrical shells are not limited as to size except with the following provisions for design. The rules in UG-36 through UG-43 apply to openings not exceeding the following: for vessels 60 in. (1520 mm) inside diameter and less, one-half the vessel diameter, but not to exceed 20 in. (508 mm); for vessels over 60 in. (1520 mm) inside diameter, one-third the vessel diameter, but not to exceed 40 in. (1000 mm). For openings exceeding these limits, supplemental rules of 1-7 shall be satisfied in addition to UG-36 through UG-43.

(2) Properly reinforced openings in formed heads and spherical shells are not limited in size. For an opening in an end closure, which is larger than one-half the inside diameter of the shell, one of the following alternatives to reinforcement may also be used:

(a) a conical section as shown in Fig. UG-36 sketch (a);

(b) a cone with a knuckle radius at the large end as shown in Fig. UG-36 sketch (b);

(c) a reverse curve section as shown in Fig. UG-36 sketches (c) and (d); or

(d) using a flare radius at the small end as shown in Fig. UG-33.1 sketch (d).

The design shall comply with all the requirements of the rules for reducer sections [see (e) below] insofar as these rules are applicable.

(c) Strength and Design of Finished Openings

(1) All references to dimensions in this and succeeding paragraphs apply to the finished construction after deduction has been made for material added as corrosion allowance. For design purposes, no metal added as corrosion allowance may be considered as reinforcement. The finished opening diameter is the diameter *d* as defined in UG-37 and in Fig. UG-40.

(2)(a) Openings in cylindrical or conical shells, or formed heads shall be reinforced to satisfy the requirements in UG-37 except as given in (3) below.

(b) Openings in flat heads shall be reinforced as required by UG-39.

(3) Openings in vessels not subject to rapid fluctuations in pressure do not require reinforcement other than that inherent in the construction under the following conditions:

(a) welded, brazed, and flued connections meeting the applicable rules and with a finished opening not larger than:

$3\frac{1}{2}$ in. (89 mm) diameter — in vessel shells or heads $\frac{3}{8}$ in. (10 mm) or less in thickness;
$2\frac{3}{8}$ in. (60 mm) diameter — in vessel shells or heads over $\frac{3}{8}$ in. (10 mm) in thickness;

(b) threaded, studded, or expanded connections in which the hole cut in the shell or head is not greater than $2\frac{3}{8}$ in. (60 mm) diameter;

(c) no two isolated unreinforced openings, in accordance with (a) or (b) above, shall have their centers closer to each other than the sum of their diameters;

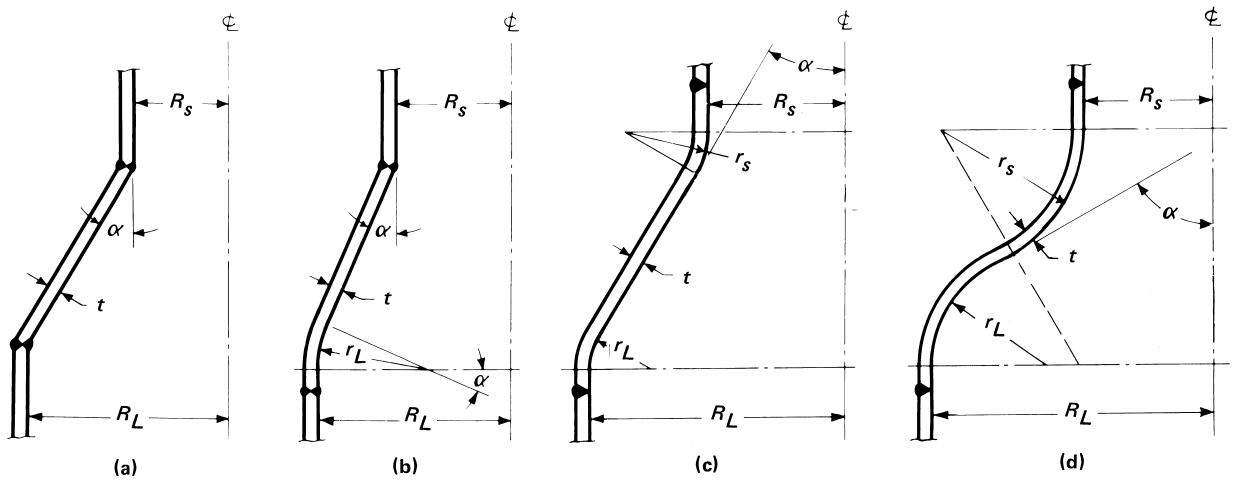
(d) no two unreinforced openings, in a cluster of three or more unreinforced openings in accordance with (a) or (b) above, shall have their centers closer

[23] The rules governing openings as given in this Division are based on the stress intensification created by the existence of a hole in an otherwise symmetrical section. External loadings such as those due to the thermal expansion or unsupported weight of connecting piping have not been evaluated. These factors should be given attention in unusual designs or under conditions of cyclic loading.

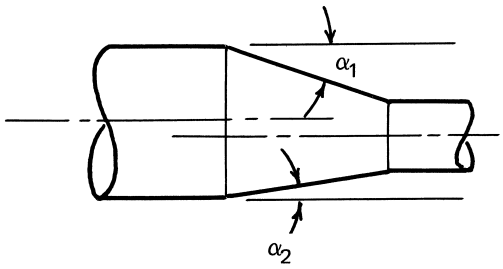
[24] The opening made by a pipe or a circular nozzle, the axis of which is not perpendicular to the vessel wall or head, may be considered an elliptical opening for design purposes.

[25] An obround opening is one which is formed by two parallel sides and semicircular ends.

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r_L shall not be less than the greater of 0.12 $(R_L + t)$ or $3t$; r_s has no dimensional requirement



$\alpha_1 > \alpha_2$; therefore use α_1 in design formulas

(e)

FIG. UG-36 LARGE HEAD OPENINGS — REVERSE-CURVE AND CONICAL SHELL-REDUCER SECTIONS

to each other than the following: for cylindrical or conical shells,

$$(1 + 1.5 \cos \theta)(d_1 + d_2);$$

for doubly curved shells and formed or flat heads,

$$2.5(d_1 + d_2)$$

where

θ = the angle between the line connecting the center of the openings and the longitudinal axis of the shell

d_1, d_2 = the finished diameters of the two adjacent openings

(d) Openings Through Welded Joints. Additional provisions governing openings through welded joints are given in UW-14.

(e) Reducer Sections Under Internal Pressure

(1) The formulas and rules of this paragraph apply to concentric reducer sections wherein all the longitudinal loads are transmitted wholly through the shell of the reducer. Where loads are transmitted in part or as a whole by other elements, e.g., inner shells, stays, or tubes, the rules of this paragraph do not apply.

(2) The thickness of each element of a reducer, as defined in (4) below, under internal pressure shall not be less than that computed by the applicable formula.

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In addition, provisions shall be made for any of the other loadings listed in UG-22, where such loadings are expected.

(3) The symbols defined in either UG-32(c) or below are used in this paragraph (see Fig. UG-36).

t = minimum required thickness of the considered element of a reducer after forming, in. (mm)
R_L = inside radius of larger cylinder, in. (mm)
R_s = inside radius of smaller cylinder, in. (mm)
r_L = inside radius of knuckle at larger cylinder, in. (mm)
α = one-half of the included (apex) angle of a conical element, deg.
r_s = radius to the inside surface of flare at the small end, in. (mm)

(4) Elements of a Reducer. A transition section reducer consisting of one or more elements may be used to join two cylindrical shell sections of different diameters but with a common axis provided the requirements of this paragraph are met.

(a) Conical Shell Section. The required thickness of a conical shell section, or the allowable working pressure for such a section of given thickness, shall be determined by the formulas given in UG-32(g).

(b) Knuckle Tangent to the Larger Cylinder. Where a knuckle is used at the large end of a reducer section, its shape shall be that of a portion of an ellipsoidal, hemispherical, or torispherical head. The thickness and other dimensions shall satisfy the requirements of the appropriate formulas and provisions of UG-32.

(5) Combination of Elements to Form a Reducer. When elements of (4) above, having different thicknesses are combined to form a reducer, the joints including the plate taper required by UW-9(c) shall lie entirely within the limits of the thinner element being joined.

(a) A reducer may be a simple conical shell section, Fig. UG-36 sketch (a), without knuckle, provided the half-apex angle α is not greater than 30 deg., except as provided for in 1-5(g). A reinforcement ring shall be provided at either or both ends of the reducer when required by the rules of 1-5.

(b) A toriconical reducer, Fig. UG-36 sketch (b), may be shaped as a portion of a toriconical head, UG-32(h), a portion of a hemispherical head plus a conical section, or a portion of an ellipsoidal head plus a conical section, provided the half-apex angle α is not greater than 30 deg., except as provided for in 1-5(g). A reinforcement ring shall be provided at the small end of the conical reducer element when required by the rules in 1-5.

(c) Reverse curve reducers, Fig. UG-36 sketches (c) and (d), may be shaped of elements other than those of (e)(4) above. See U-2(g).

(f) Reducers Under External Pressure. The rules of UG-33(f) shall be followed, where applicable, in the design of reducers under external pressure.

(g) Oblique Conical Shell Sections Under Internal Pressure. A transition section reducer consisting of an oblique conical shell section may be used to join two cylindrical shell sections of different diameters and axes, provided the following requirements are used.

(1) The required thickness shall be determined by the formulas given in UG-32(g).

(2) The angle α to be used shall be the largest included angle between the oblique cone and the attached cylindrical section [see Fig. UG-36 sketch (e)] and shall not be greater than 30 deg.

(3) Diametrical dimensions to be used in the design formulas shall be measured perpendicular to the axis of the cylinder to which the cone is attached.

(4) A reinforcement ring shall be provided at either or both ends of the reducer when required by the rules of 1-5.

UG-37 REINFORCEMENT REQUIRED FOR OPENINGS IN SHELLS AND FORMED HEADS

(a) Nomenclature. The symbols used in this paragraph are defined as follows:

A = total cross-sectional area of reinforcement required in the plane under consideration, sq in. (mm^2) (see Fig. UG-37.1) (includes consideration of nozzle area through shell if $S_n/S_v<1.0$)
A_1 = area in excess thickness in the vessel wall available for reinforcement, sq in. (mm^2) (see Fig. UG-37.1) (includes consideration of nozzle area through shell if $S_n/S_v<1.0$)
A_2 = area in excess thickness in the nozzle wall available for reinforcement, sq in. (mm^2) (see Fig. UG-37.1)
A_3 = area available for reinforcement when the nozzle extends inside the vessel wall, sq in. (mm^2) (see Fig. UG-37.1)
A_{41}, A_{42}, A_{43} = cross-sectional area of various welds available for reinforcement, sq in. (mm^2) (see Fig. UG-37.1)
A_5 = cross-sectional area of material added as reinforcement, sq in. (mm^2) (see Fig. UG-37.1)
c = corrosion allowance, in. (mm)
D = inside shell diameter, in. (mm)

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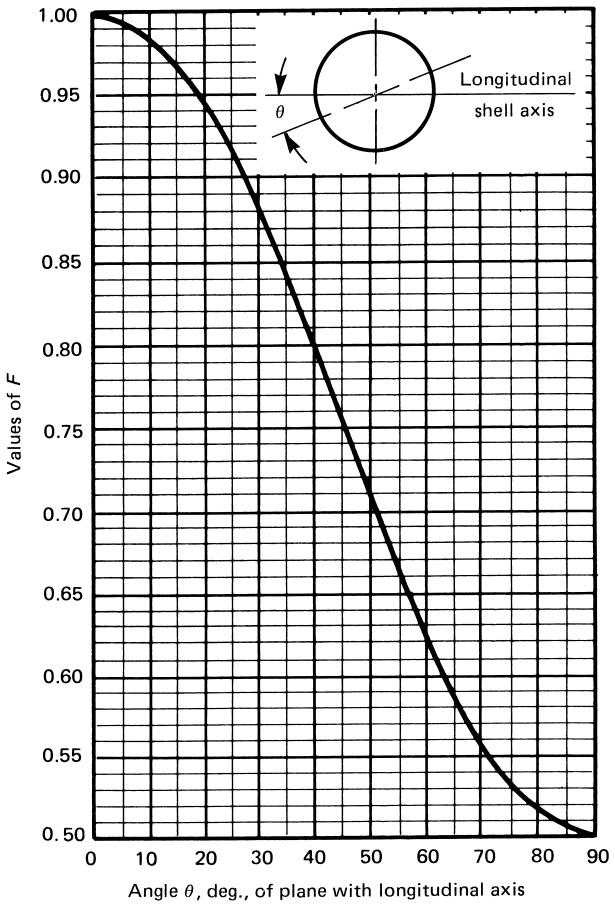


FIG. UG-37 CHART FOR DETERMINING VALUE OF *F*, AS REQUIRED IN UG-37

D_p = outside diameter of reinforcing element, in. (mm) (actual size of reinforcing element may exceed the limits of reinforcement established by UG-40; however, credit cannot be taken for any material outside these limits)

d = finished diameter of circular opening or finished dimension (chord length at midsurface of thickness excluding excess thickness available for reinforcement) of nonradial opening in the plane under consideration, in. (mm) [see Figs. UG-37.1 and UG-40]

E = 1 (see definitions for t_r and t_{rn})

E_1 = 1 when an opening is in the solid plate or in a Category B butt joint; or
= joint efficiency obtained from Table UW-12 when any part of the opening passes through any other welded joint

F = correction factor which compensates for the variation in internal pressure stresses on different planes with respect to the axis of a vessel. A value of 1.00 shall be used for all configurations except that Fig. UG-37 may be used for integrally reinforced openings in cylindrical shells and cones. [See UW-16(c)(1).]

h = distance nozzle projects beyond the inner surface of the vessel wall, in. (mm). (Extension of the nozzle beyond the inside surface of the vessel wall is not limited; however, for reinforcement calculations, credit shall not be taken for material outside the limits of reinforcement established by UG-40.)

K_1 = spherical radius factor (see definition of t_r and Table UG-37)

L = length of projection defining the thickened portion of integral reinforcement of a nozzle neck beyond the outside surface of the vessel wall [see Fig. UG-40 sketch (e)]

P = internal design pressure (see UG-21), psi (kPa)

R = inside radius of the shell course under consideration, in. (mm)

R_n = inside radius of the nozzle under consideration, in. (mm)

S = allowable stress value in tension (see UG-23), psi (kPa)

S_n = allowable stress in nozzle, psi (kPa) (see S, above)

S_v = allowable stress in vessel, psi (kPa) (see S, above)

S_p = allowable stress in reinforcing element (plate), psi (kPa) (see S, above)

f_r = strength reduction factor, not greater than 1.0 [see UG-41(a)]
$f_{r1} = S_n / S_v$ for nozzle wall inserted through the vessel wall
f_{r1} = 1.0 for nozzle wall abutting the vessel wall and for nozzles shown in Fig. UG-40, sketch (j), (k), (n) and (o).
$f_{r2} = S_n / S_v$
f_{r3} = (lesser of S_n or S_p)$/S_v$
$f_{r4} = S_p / S_v$

t = specified vessel wall thickness,[26] (not including forming allowances), in. (mm). For pipe it is the nominal thickness less manufacturing undertolerance allowed in the pipe specification.

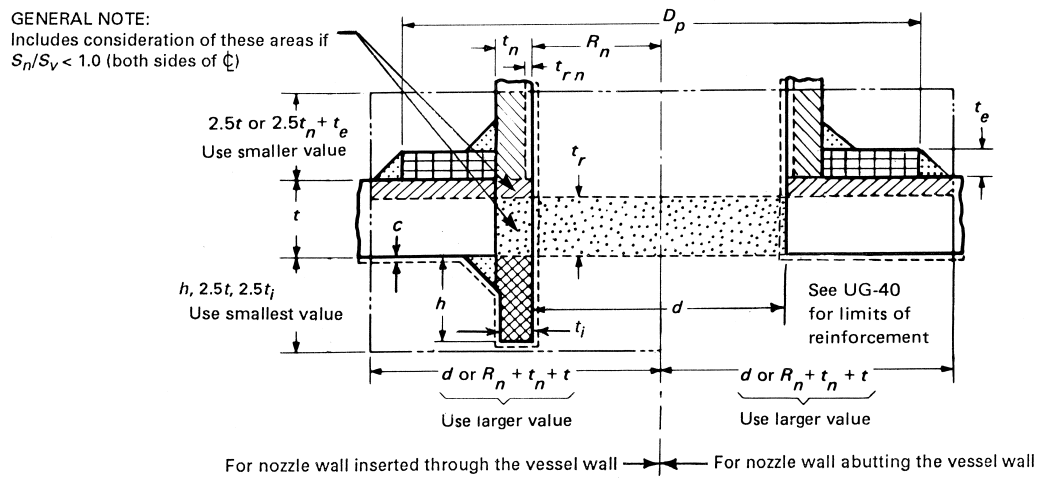
t_e = thickness or height of reinforcing element, in. (mm) (see Fig. UG-40)

t_i = nominal thickness of internal projection of nozzle wall, in. (mm)

t_r = required thickness, in. (mm), of a seamless shell

[26] In the corroded condition, see UG-16(e).

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Without Reinforcing Element

$A = d\,t_r\,F + 2t_n\,t_r\,F(1 - f_{r1})$	Area required
$A_1 = d(E_1\,t - Ft_r) - 2t_n\,(E_1 t - Ft_r)\,(1 - f_{r1})$ $= 2(t + t_n)(E_1 t - Ft_r) - 2t_n(E_1 t - Ft_r)(1 - f_{r1})$	Area available in shell; use larger value
$A_2 = 5(t_n - t_{rn})\,f_{r2}t$ $= 5(t_n - t_{rn})\,f_{r2}t_n$	Area available in nozzle projecting outward; use smaller value
$A_3 = 5t\,t_i\,f_{r2}$ $= 5t_i\,t_i\,f_{r2}$ $= 2h\,t_i\,f_{r2}$	Area available in inward nozzle; use smallest value
A_{41} = outward nozzle weld = $(\text{leg})^2 f_{r2}$	Area available in outward weld
A_{43} = inward nozzle weld = $(\text{leg})^2 f_{r2}$	Area available in inward weld
If $A_1 + A_2 + A_3 + A_{41} + A_{43} \geq A$	Opening is adequately reinforced
If $A_1 + A_2 + A_3 + A_{41} + A_{43} < A$	Opening is not adequately reinforced so reinforcing elements must be added and/or thicknesses must be increased

With Reinforcing Element Added

A = same as A, above	Area required
A_1 = same as A_1, above	Area available
$A_2 = 5(t_n - t_{rn})f_{r2}t$ $= 2(t_n - t_{rn})\,(2.5t_n + t_e)\,f_{r2}$	Area available in nozzle projecting outward; use smaller area
A_3 = same as A_3, above	Area available in inward nozzle
A_{41} = outward nozzle weld = $(\text{leg})^2 f_{r3}$	Area available in outward weld
A_{42} = outer element weld = $(\text{leg})^2 f_{r4}$	Area available in outer weld
A_{43} = inward nozzle weld = $(\text{leg})^2 f_{r2}$	Area available in inward weld
$A_5 = (D_p - d - 2t_n)\,t_e\,f_{r4}$ [Note (1)]	Area available in element
If $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5 \geq A$	Opening is adequately reinforced

NOTE:
(1) This formula is applicable for a rectangular cross-sectional element that falls within the limits of reinforcement.

FIG. UG-37.1 NOMENCLATURE AND FORMULAS FOR REINFORCED OPENINGS

(This Figure Illustrates a Common Nozzle Configuration and Is Not Intended to Prohibit Other Configurations Permitted by the Code.)

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TABLE UG-37
VALUES OF SPHERICAL RADIUS FACTOR K_1
Equivalent spherical radius = K_1D; $D/2h$ = axis ratio. For definitions, see 1-4(b). Interpolation permitted for intermediate values.

$D/2h$	. . .	3.0	2.8	2.6	2.4	2.2
K_1	. . .	1.36	1.27	1.18	1.08	0.99
$D/2h$	2.0	1.8	1.6	1.4	1.2	1.0
K_1	0.90	0.81	0.73	0.65	0.57	0.50

based on the circumferential stress, or of a formed head, computed by the rules of this Division for the designated pressure, using $E = 1$, except that:

(1) when the opening and its reinforcement are entirely within the spherical portion of a torispherical head, t_r is the thickness required by 1-4(d), using $M = 1$;

(2) when the opening is in a cone, t_r is the thickness required for a seamless cone of diameter D measured where the nozzle axis pierces the inside wall of the cone;

(3) when the opening and its reinforcement are in an ellipsoidal head and are located entirely within a circle the center of which coincides with the center of the head and the diameter of which is equal to 80% of the shell diameter, t_r is the thickness required for a seamless sphere of radius K_1D, where D is the shell diameter and K_1 is given by Table UG-37.

t_n = nozzle wall thickness,[26] in. (mm). Except for pipe, this is the wall thickness not including forming allowances. For pipe, use the nominal thickness [see UG-16(d)].

t_{rn} = required thickness of a seamless nozzle wall, in. (mm)

W = total load to be carried by attachment welds, lb (kN) (see UG-41)

(b) General. The rules in this paragraph apply to all openings other than:

(1) small openings covered by UG-36(c)(3);

(2) openings in flat heads covered by UG-39;

(3) openings designed as reducer sections covered by UG-36(e);

(4) large head openings covered by UG-36(b)(2);

(5) tube holes with ligaments between them conforming to the rules of UG-53.

Reinforcement shall be provided in amount and distribution such that the area requirements for reinforcement are satisfied for all planes through the center of the opening and normal to the vessel surface. For a circular opening in a cylindrical shell, the plane containing the axis of the shell is the plane of greatest loading due to pressure. Not less than half the required reinforcement shall be on each side of the center line of single openings.

(c) Design for Internal Pressure. The total cross-sectional area of reinforcement A required in any given plane through the opening for a shell or formed head under internal pressure shall be not less than

$$A = dt_rF + 2t_nt_rF(1 - f_{r1})$$

(d) Design for External Pressure

(1) The reinforcement required for openings in single-walled vessels subject to external pressure need be only 50% of that required in (c) above, where t_r is the wall thickness required by the rules for vessels under external pressure and the value of F shall be 1.0 in all external pressure reinforcement calculations.

(2) The reinforcement required for openings in each shell of a multiple-walled vessel shall comply with (1) above when the shell is subject to external pressure, and with (c) above when the shell is subject to internal pressure, regardless of whether or not there is a common nozzle secured to more than one shell by strength welds.

(e) Design for Alternate Internal and External Pressure. Reinforcement of vessels subject to alternate internal and external pressures shall meet the requirements of (c) above for internal pressure and of (d) above for external pressure.

(f) Details and formulas for required area and available area are given in Fig. UG-37.1.

UG-38 FLUED OPENINGS IN SHELLS AND FORMED HEADS

(a) Flued openings in shells and formed heads made by inward or outward forming of the head plate shall meet the requirements for reinforcement in UG-37. The thickness of the flued flange shall also meet the requirements of UG-27 and / or UG-28, as applicable, where L as used in UG-28 is the minimum depth of flange as shown in Fig. UG-38. The minimum thickness of the flued flange on a vessel subject to both internal and external pressure shall be the larger of the two thicknesses as determined above.

(b) The minimum depth of flange of a flued in opening exceeding 6 in. (152 mm) in any inside dimen-

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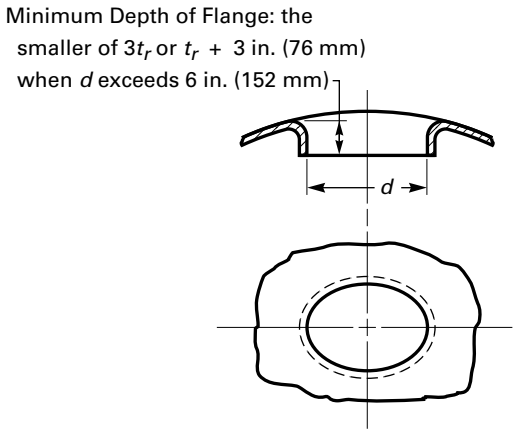


FIG. UG-38 MINIMUM DEPTH FOR FLANGE OF FLUED IN OPENINGS

sion, when not stayed by an attached pipe or flue, shall equal $3t_r$ or (t_r + 3 in.) (for SI units, t_r + 152 mm), whichever is less, where t_r is the required shell or head thickness. The depth of flange shall be determined by placing a straight edge across the side opposite the flued opening along the major axis and measuring from the straightedge to the edge of the flanged opening (see Fig. UG-38).

(c) There is no minimum depth of flange requirement for flued out openings.

(d) The minimum width of bearing surface for a gasket on a self-sealing flued opening shall be in accordance with UG-46(j).

UG-39 REINFORCEMENT REQUIRED FOR OPENINGS IN FLAT HEADS

UG-39(a) General. The rules in this paragraph apply to all openings in flat heads except opening(s) which do not exceed the size and spacing limits in UG-36(c)(3) and do not exceed one-fourth the head diameter or shortest span.

UG-39(b) Single and multiple openings in flat heads that have diameters equal to or less than one-half the head diameter may be reinforced as follows.

UG-39(b)(1) Flat heads that have a single opening with a diameter that does not exceed one-half the head diameter or shortest span, as defined in UG-34, shall have a total cross-sectional area of reinforcement for all planes through the center of the opening not less than that given by the formula

$$A = 0.5dt + tt_n\ (1 - f_{r1})$$

where d, t_n, and f_{r1} are defined in UG-37 and t in UG-34.

UG-39(b)(2) Multiple openings none of which have diameters exceeding one-half the head diameter and no pair having an average diameter greater than one-quarter the head diameter may be reinforced individually as required by (1) above when the spacing between any pair of adjacent openings is equal to or greater than twice the average diameter of the pair.

When spacing between adjacent openings is less than twice but equal to or more than $1\frac{1}{4}$ the average diameter of the pair, the required reinforcement for each opening in the pair, as determined by (1) above, shall be summed together and then distributed such that 50% of the sum is located between the two openings. Spacings of less than $1\frac{1}{4}$ the average diameter of adjacent openings shall be treated by rules of U-2(g).

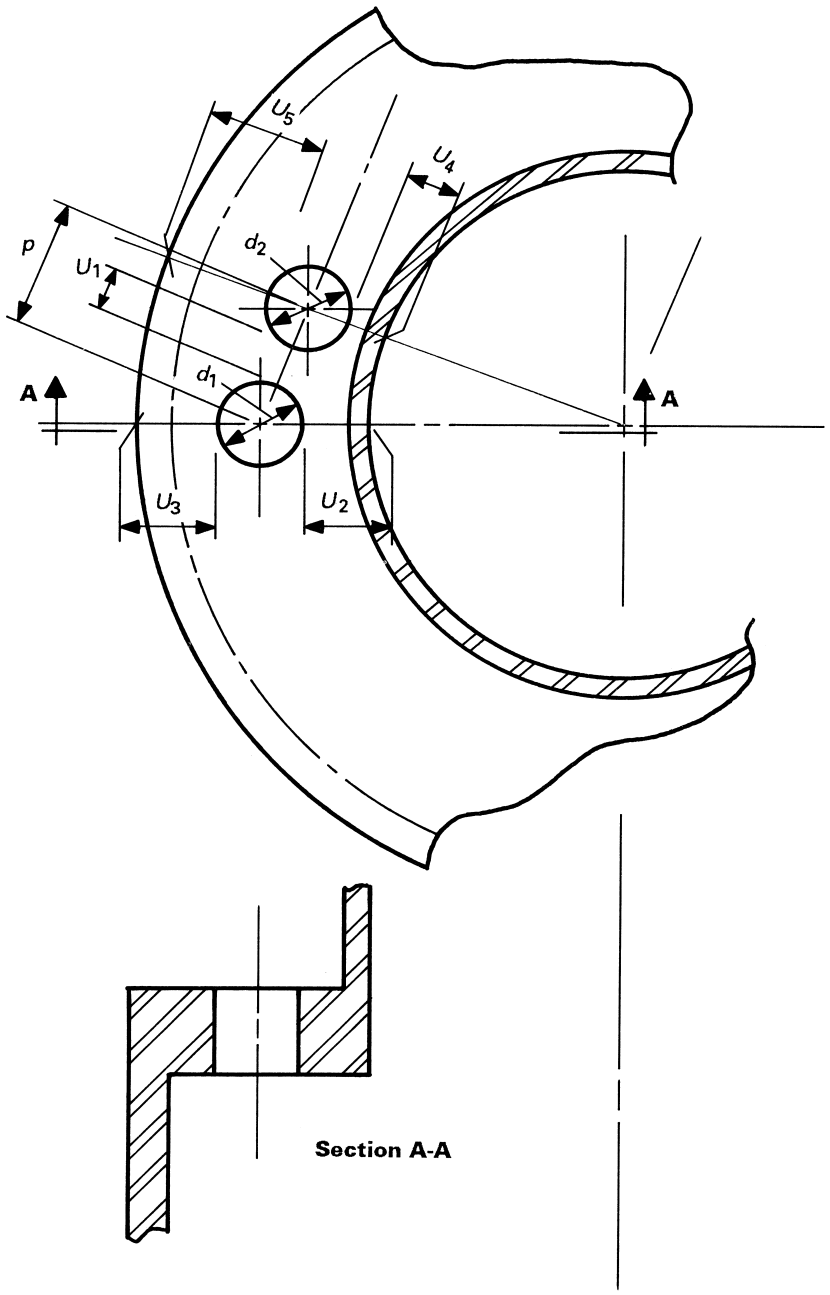
UG-39(b)(3) In no case shall the width of ligament between two adjacent openings be less than one-quarter the diameter of the smaller of the two openings in the pair. The width of ligament between the edge of any one opening and the edge of the flat head (such as U_3 or U_5 in Fig. UG-39) shall not be less than one-quarter the diameter of that one opening.

UG-39(c) Flat heads which have an opening with a diameter that exceeds one-half the head diameter or shortest span, as defined in UG-34, shall be designed as follows.

UG-39(c)(1) When the opening is a single, circular centrally located opening in a circular flat head, the head shall be designed according to Appendix 14 and related factors in Appendix 2. The head-to-shell junction may be integral, as shown in Fig. UG-34 sketches (a), (b-1), (b-2), (d), and (g). The head may also be attached by a butt weld or a full-penetration corner weld similar to the joints shown in Fig. UW-13.2 sketches (a), (b), (c), (d), (e), or (f). The large centrally located opening may have a nozzle which is integrally formed or integrally attached by a full penetration weld or may be plain without an attached nozzle or hub. The head thickness does not have to be calculated by UG-34 rules. The thickness that satisfies all the requirements of Appendix 14 meets the requirements of the Code.

UG-39(c)(2) Opening(s) may be located in the rim space surrounding the central opening. See Fig. UG-39.

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p = spacing, center-to-center, between openings
$U_1, U_2, \ldots$ = ligament width
$(d_1 + d_2)/2$ = average diameter of pair of openings

FIG. UG-39 MULTIPLE OPENINGS IN RIM OF HEADS WITH A LARGE CENTRAL OPENING

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Such openings may be reinforced by area replacement in accordance with the formula in (b)(1) above using as a required head thickness the thickness that satisfies rules of Appendix 14. Multiple rim openings shall meet spacing rules of (b)(2) and (b)(3) above. Alternatively, the head thickness that meets the rules of Appendix 14 may be increased by multiplying it by the square root of two (1.414) if only a single opening is placed in the rim space or if spacing p between two such openings is twice or more than their average diameter. For spacing less than twice their average diameter, the thickness that satisfies Appendix 14 shall be divided by the square root of efficiency factor e, where e is defined in (e)(2) below.

The rim opening(s) shall not be larger in diameter than one-quarter the differences in head diameter less central opening diameter. The minimum ligament width U shall not be less than one-quarter the diameter of the smaller of the two openings in the pair. A minimum ligament width of one-quarter the diameter of the rim opening applies to ligaments designated as U_2, U_4, U_3, and U_5 in Fig. UG-39.

UG-39(c)(3) When the large opening is any other type than that described in (c)(1) above, there are no specific rules given. Consequently, the requirements of U-2(g) shall be met.

UG-39(d) As an alternative to (b)(1) above, the thickness of flat heads and covers with a single opening with a diameter that does not exceed one-half the head diameter may be increased to provide the necessary reinforcement as follows.

UG-39(d)(1) In Formula (1) or (3) of UG-34(c), use 2C or 0.75 in place of C, whichever is the lesser; except that, for sketches (b-1), (b-2), (e), (f), (g), and (i) of Fig. UG-34, use 2C or 0.50, whichever is the lesser.

UG-39(d)(2) In Formula (2) or (5) of UG-34(c), double the quantity under the square root sign.

UG-39(e) Multiple openings none of which have diameters exceeding one-half the head diameter and no pair having an average diameter greater than one-quarter the head diameter may be reinforced as follows.

UG-39(e)(1) When the spacing between a pair of adjacent openings is equal to or greater than twice the average diameter of the pair, and this is so for all opening pairs, the head thickness may be determined by rules in (d) above.

UG-39(e)(2) When the spacing between adjacent openings in a pair is less than twice but equal to or greater than 1¼ the average diameter of the pair, the required head thickness shall be that determined by (d) above multiplied by a factor h, where

$$h = \sqrt{0.5/e}$$

$$e = [(p - d_{ave})/p]_{smallest}$$

where

e = smallest ligament efficiency of adjacent opening pairs in the head

p = center-to-center spacing of two adjacent openings

d_{ave} = average diameter of the same two adjacent openings

UG-39(e)(3) Spacings of less than 1¼ the average diameter of adjacent openings shall be treated by rules of U-2(g).

UG-39(e)(4) In no case shall the width of ligament between two adjacent openings be less than one-quarter the diameter of the smaller of the two openings in the pair.

UG-39(e)(5) The width of ligament between the edge of any one opening and the edge of the flat head (such as U_3 or U_5 in Fig. UG-39) shall not be less than one-quarter the diameter of that one opening.

UG-40 LIMITS OF REINFORCEMENT

(a) The boundaries of the cross sectional area in any plane normal to the vessel wall and passing through the center of the opening within which metal must be located in order to have value as reinforcement are designated as the limits of reinforcement for that plane (see Fig. UG-37.1). Figure UG-40 depicts thicknesses t, t_e, and t_n, or t_i and diameter d used in establishing the limits of reinforcement. All dimensions are in the corroded condition; for nomenclature, see UG-37(a).

(b) The limits of reinforcement, measured parallel to the vessel wall, shall be at a distance, on each side of the axis of the opening, equal to the greater of the following:

(1) the diameter d of the finished opening;

(2) the radius R_n of the finished opening plus the vessel wall thickness t, plus the nozzle wall thickness t_n.

(c) The limits of reinforcement, measured normal to the vessel wall, shall conform to the contour of the surface at a distance from each surface equal to the smaller of the following:

(1) 2½ times the vessel wall thickness t;

(2) 2½ times the nozzle wall thickness t_n plus the thickness t_e as defined in Fig. UG-40.

(d) Metal within the limits of reinforcement that may be considered to have reinforcing value shall include the following:

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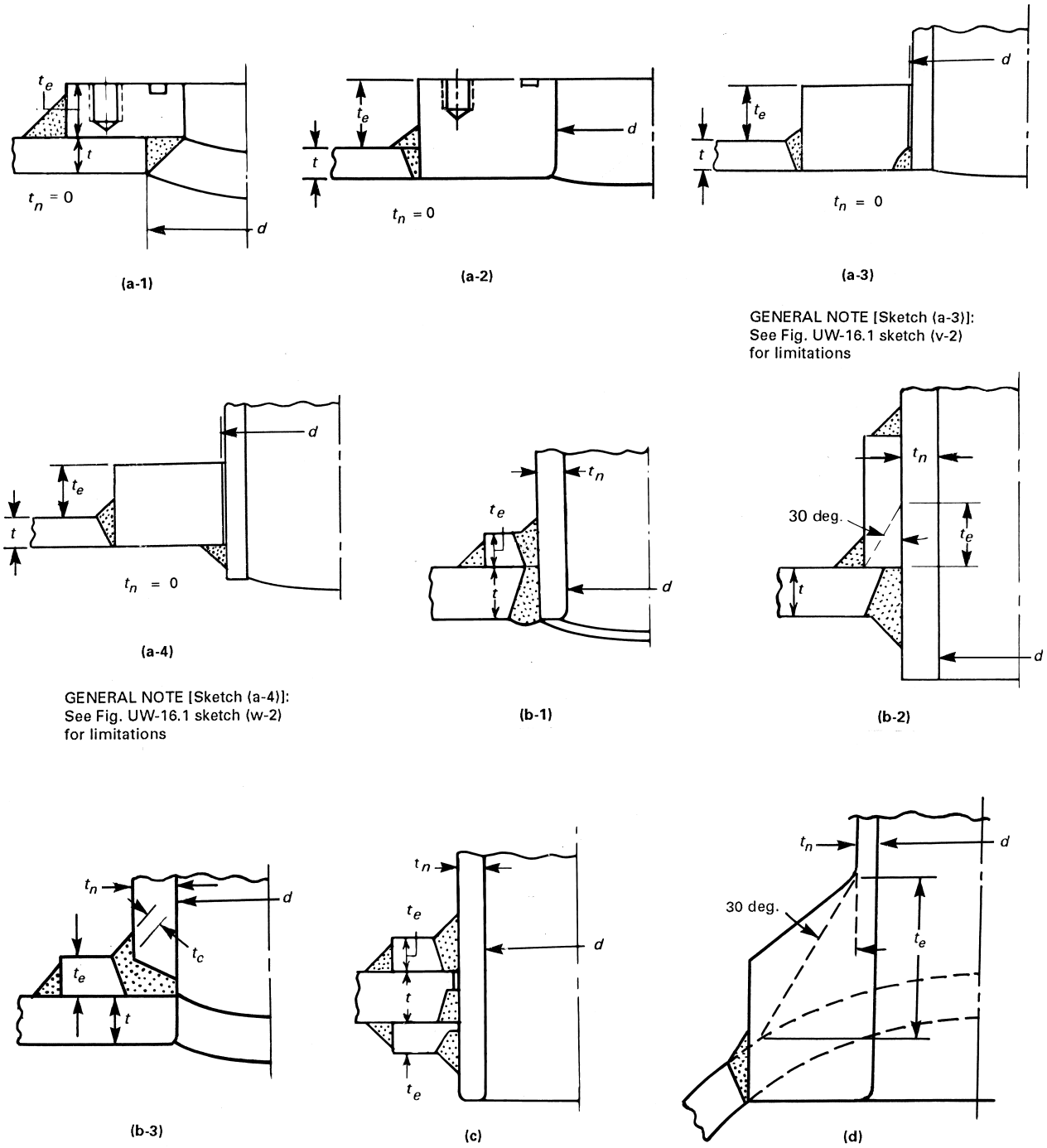


FIG. UG-40 SOME REPRESENTATIVE CONFIGURATIONS DESCRIBING THE REINFORCEMENT DIMENSION t_e AND THE OPENING DIMENSION d

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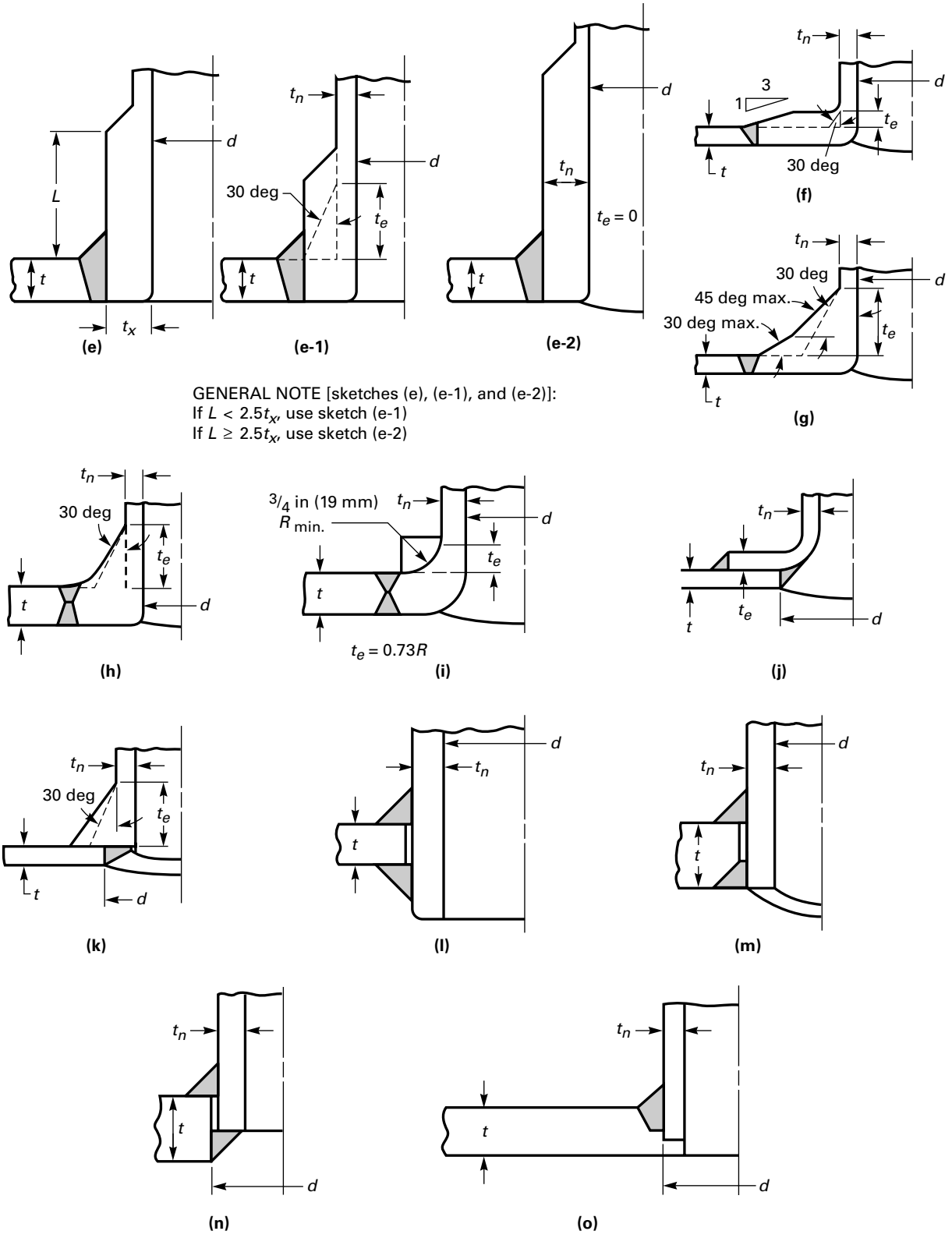


FIG. UG-40 SOME REPRESENTATIVE CONFIGURATIONS DESCRIBING THE REINFORCEMENT DIMENSION t_e AND THE OPENING DIMENSION d (CONT'D)

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(1) metal in the vessel wall over and above the thickness required to resist pressure and the thickness specified as corrosion allowance. the area in the vessel wall available as reinforcement is the larger of the values of A_1 given by the formulas in Fig. UG-37.1.

(2) metal over and above the thickness required to resist pressure and the thickness specified as corrosion allowance in that part of a nozzle wall extending outside the vessel wall. The maximum area in the nozzle wall available as reinforcement is the smaller of the values of A_2 given by the formulas in Fig. UG-37.1.

All metal in the nozzle wall extending inside the vessel wall A_3 may be included after proper deduction for corrosion allowance on all the exposed surface is made. No allowance shall be taken for the fact that a differential pressure on an inwardly extending nozzle may cause opposing stress to that of the stress in the shell around the opening:

(3) metal in attachment welds A_4 and metal added as reinforcement A_5.

(e) With the exception of studding outlet type flanges, bolted flange material within the limits of reinforcement shall not be considered to have reinforcing value.

UG-41 STRENGTH OF REINFORCEMENT

(a) Material used for reinforcement shall have an allowable stress value equal to or greater than that of the material in the vessel wall, except that when such material is not available, lower strength material may be used, provided the area of reinforcement is increased in inverse proportion to the ratio of the allowable stress values of the two materials to compensate for the lower allowable stress value of the reinforcement. No credit may be taken for the additional strength of any reinforcement having a higher allowable stress value than that of the vessel wall. Deposited weld metal outside of either the vessel wall or any reinforcing pad used as reinforcement shall be credited with an allowable stress value equivalent to the weaker of the materials connected by the weld. Vessel-to-nozzle or pad-to-nozzle attachment weld metal within the vessel wall or within the pad may be credited with a stress value equal to that of the vessel wall or pad, respectively.

(b) On each side of the plane defined in UG-40(a), the strength of the attachment joining the vessel wall and reinforcement or any two parts of the attached reinforcement shall be at least equal to the smaller of:

(1) the strength in tension of the cross section of the element or elements of reinforcement being considered (see $W_{1\text{-}1}$, $W_{2\text{-}2}$, and $W_{3\text{-}3}$ of Fig. UG-41.1 for examples and L-7 for numerical examples);

(2) the strength in tension of the area defined in UG-37 less the strength in tension of the reinforcing area which is integral in the vessel wall as permitted by UG-40(d)(1) (see *W* of Fig. UG-41.1 for examples and L-7 for numerical examples);

(3) for welded attachments, see UW-15 for exemptions to strength calculations.

(c) The strength of the attachment joint shall be considered for its entire length on each side of the plane of the area of reinforcement defined in UG-40. For obround openings, consideration shall also be given to the strength of the attachment joint on one side of the plane transverse to the parallel sides of the opening which passes through the center of the semicircular end of the opening.

(d) For detailed requirements for welded and brazed reinforcement see the appropriate paragraphs in the Parts devoted to these subjects (see UW-15 and UB-19).

UG-42 REINFORCEMENT OF MULTIPLE OPENINGS

(See UG-39 for multiple openings in flat heads.)

(a) When any two openings are spaced at less than two times their average diameter, so that their limits of reinforcement overlap [see Fig. UG-42 sketch (a)], the two openings shall be reinforced in the plane connecting the centers, in accordance with the rules of UG-37, UG-38, UG-40, and UG-41 with a combined reinforcement that has an area not less than the sum of the areas required for each opening. No portion of the cross section is to be considered as applying to more than one opening, nor to be considered more than once in a combined area.

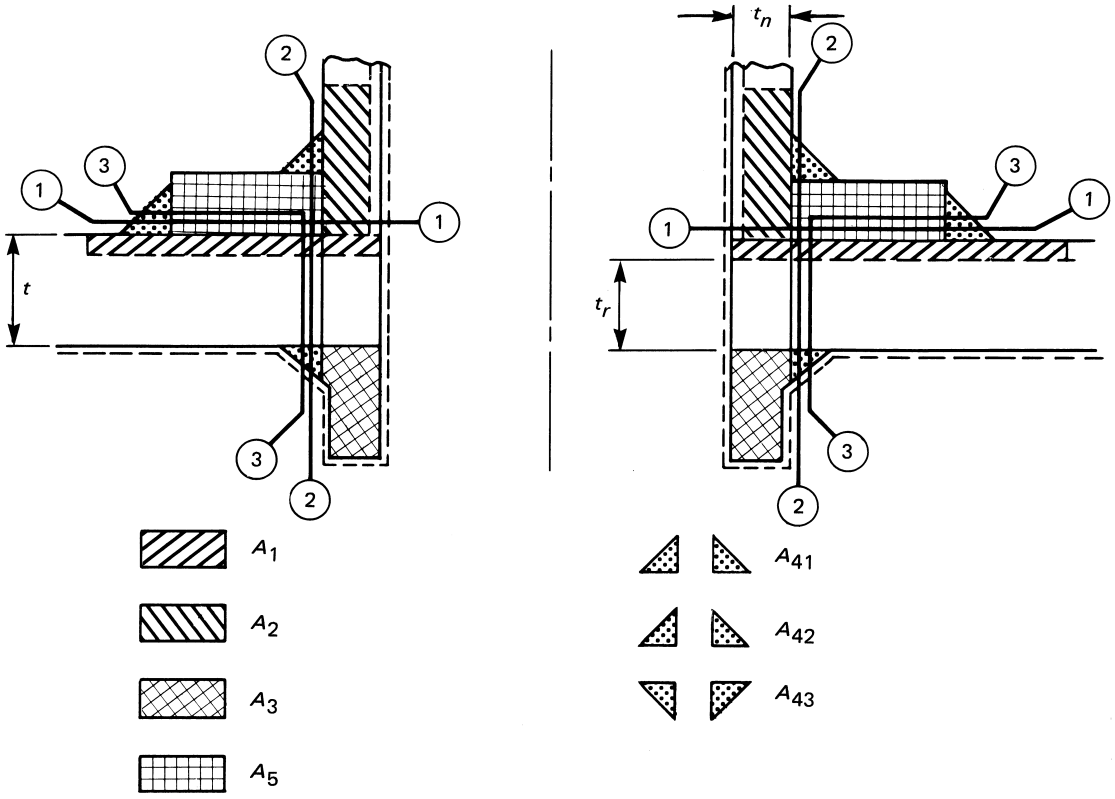
(1) The available area of the head or shell between openings having an overlap area shall be proportioned between the two openings by the ratio of their diameters.

(2) If the area of reinforcement between the two openings is less than 50% of the total required for the two openings, the supplemental rules of 1-7(a) and (c) shall be used.

(3) A series of openings all on the same center line shall be treated as successive pairs of openings.

(b) When more than two openings are spaced as in (a) above [see Fig. UG-42 sketch (b)], and are to be provided with a combined reinforcement, the minimum distance between centers of any two of these openings shall be $1\frac{1}{3}$ times their average diameter, and the area of reinforcement between any two openings shall be

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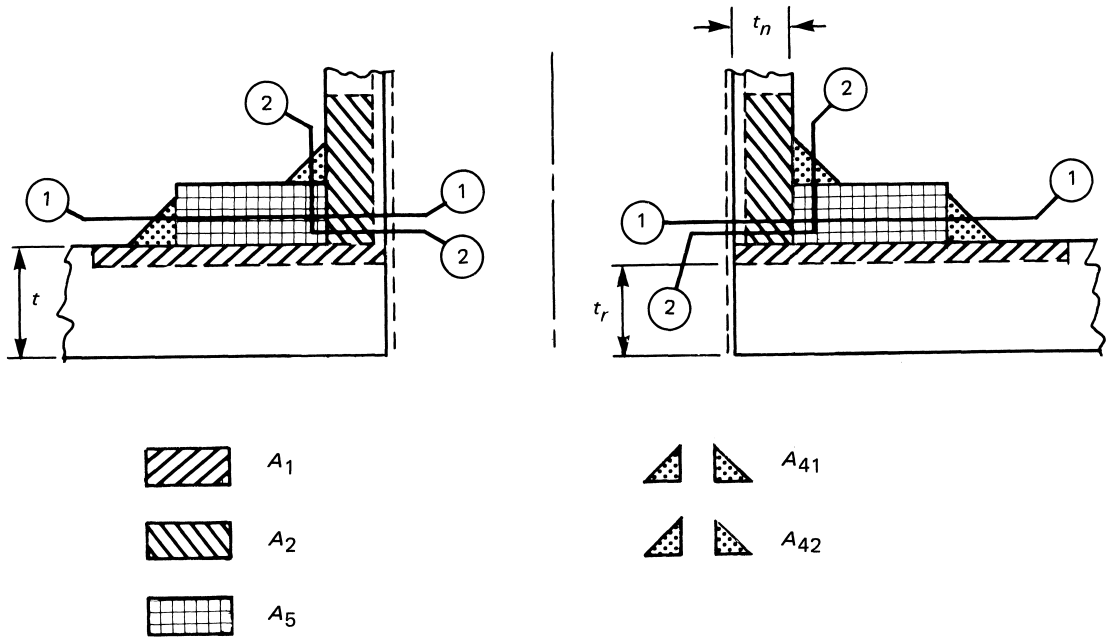
W = total weld load [UG-41(b)(2)]
= $[A - A_1 + 2t_n f_{r1}(E_1 t - F t_r)]S_v$
$W_{1\text{-}1}$ = weld load for strength path 1-1 [UG-41(b)(1)]
= $(A_2 + A_5 + A_{41} + A_{42})S_v$
$W_{2\text{-}2}$ = weld load for strength path 2-2 [UG-41(b)(1)]
= $(A_2 + A_3 + A_{41} + A_{43} + 2t_n t f_{r1})S_v$
$W_{3\text{-}3}$ = weld load for strength path 3-3 [UG-41(b)(1)]
= $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2t_n t f_{r1})S_v$

GENERAL NOTES:
(a) Areas A_1, A_2, A_3, A_5, and A_{4i} are modified by f_{rx} factors.
(b) Nomenclature is the same as in UG-37 and Fig. UG-37.1.

(a) Depicts Typical Nozzle Detail With Neck Inserted Through the Vessel Wall

FIG. UG-41.1 NOZZLE ATTACHMENT WELD LOADS AND WELD STRENGTH PATHS TO BE CONSIDERED

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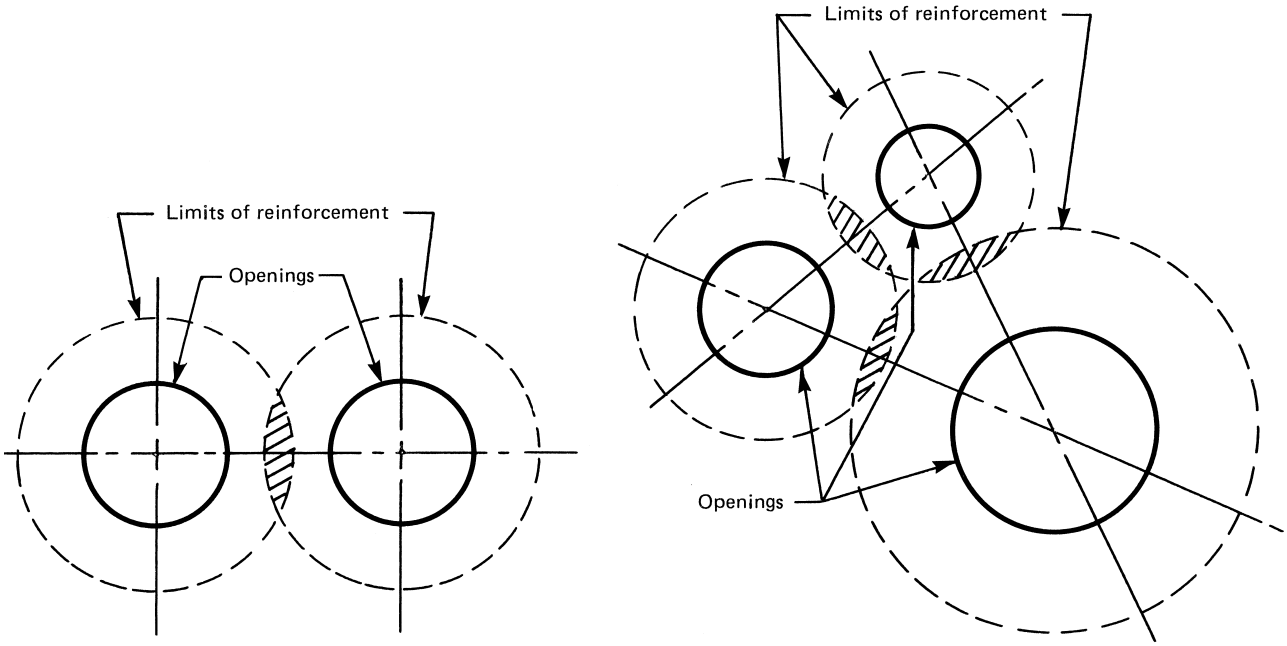
W = total weld load [UG-41(b)(2)]
= $(A - A_1)S_v$
$W_{1\text{-}1}$ = weld load for strength path 1-1 [UG-41(b)(1)]
= $(A_2 + A_5 + A_{41} + A_{42})S_v$
$W_{2\text{-}2}$ = weld load for strength path 2-2 [UG-41(b)(1)]
= $(A_2 + A_{41})S_v$

GENERAL NOTES:
(a) Areas A_1, A_2, A_5, and A_{4i} are modified by f_{rx} factors.
(b) Nomenclature is the same as in UG-37 and Fig. UG-37.1.

(b) Depicts Typical Nozzle Detail With Neck Abutting the Vessel Wall

FIG. UG-41.1 NOZZLE ATTACHMENT WELD LOADS AND WELD STRENGTH PATHS TO BE CONSIDERED (CONT'D)

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(a) Two Openings Spaced at Less Than Two Times Their Average Diameter

(b) More Than Two Openings Spaced at Less Than Two Times Their Average Diameter

FIG. UG-42 EXAMPLES OF MULTIPLE OPENINGS

at least equal to 50% of the total required for the two openings. If the distance between centers of two such openings is less than $1\frac{1}{3}$ times their average diameter, no credit for reinforcement shall be taken for any of the material between these openings. Such openings must be reinforced as described in (c) below.

(c) Alternatively, any number of adjacent openings, in any arrangement, may be reinforced by using an assumed opening enclosing all such openings. The limits for reinforcement of the assumed opening shall be those given in UG-40(b)(1) and (c)(1). The nozzle walls of the actual openings shall not be considered to have reinforcing value. When the diameter of the assumed opening exceeds the limits in UG-36(b)(1), the supplemental rules of 1-7(a) and (c) shall also be used.

(d) When a group of openings is reinforced by a thicker section butt welded into the shell or head, the edges of the inserted section shall be tapered as prescribed in UW-9(c).

(e) When a series of two or more openings in a cylindrical shell are arranged in a regular pattern, reinforcement of the openings may be provided per the rules of ligaments in UG-53.

UG-43 METHODS OF ATTACHMENT OF PIPE AND NOZZLE NECKS TO VESSEL WALLS

(a) General. Nozzles may be attached to the shell or head of a vessel by any of the methods of attachment given in this paragraph, except as limited in UG-36.

(b) Welded Connections. Attachment by welding shall be in accordance with the requirements of UW-15 and UW-16.

(c) Brazed Connections. Attachment by brazing shall be in accordance with the requirements of UB-17 through UB-19.

(d) Studded Connections. Connections may be made by means of studs. The vessel shall have a flat surface machined on the shell, or on a built-up pad, or on a properly attached plate or fitting. Drilled holes to be tapped shall not penetrate within one-fourth of the wall thickness from the inside surface of the vessel after deducting corrosion allowance, unless at least the minimum thickness required as above is maintained by adding metal to the inside surface of the vessel. The tapped holes shall also conform to the requirements of

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TABLE UG-43
MINIMUM NUMBER OF PIPE THREADS FOR CONNECTIONS

Size of pipe connection, NPS (DN)	½ & ¾ (DN 15 & 20)	1, 1¼, & 1½ (DN 25, 32, & 40)	2 (DN 50)	2½ & 3 (DN 65 & 80)	4–6 (DN 100–150)	8 (DN 200)	10 (DN 250)	12 (DN 300)
Threads engaged	6	7	8	8	10	12	13	14
Min. plate thickness required, in. (mm)	0.43 (11.0)	0.61 (15.5)	0.70 (17.8)	1.0 (25.4)	1.25 (31.8)	1.5 (38.1)	1.62 (41.2)	1.75 (44.5)

(g) below. Studded connections shall meet the requirements for reinforcement in UG-36 through UG-42.

(e) Threaded Connections. Pipes, tubes, and other threaded connections that conform to the ANSI/ASME Standard for Pipe Threads, General Purpose, Inch (ANSI/ASME B1.20.1) may be screwed into a threaded hole in a vessel wall, provided the pipe engages the minimum number of threads specified in Table UG-43 after allowance has been made for curvature of the vessel wall. The thread shall be a standard taper pipe thread except that a straight thread of at least equal strength may be used if other sealing means to prevent leakage are provided. A built-up pad or a properly attached plate or fitting may be used to provide the metal thickness and number of threads required in Table UG-43, or to furnish reinforcement when required.

Threaded connections larger than 4 in. pipe size (DN 100) shall not be used in vessels that contain liquids having a flash-point below 110°F (43°C), or flammable vapors, or flammable liquids at temperatures above that at which they boil under atmospheric pressure.

Threaded connections larger than 3 in. pipe size (DN 80) shall not be used when the maximum allowable working pressure exceeds 125 psi (861 kPa), except that this 3 in. pipe size (DN 80) restriction does not apply to plug closures used for inspection openings, end closures, or similar purposes, or to integrally forged openings in vessel heads meeting the requirement of UF-43.

(f) Expanded Connections. A pipe, tube, or forging may be attached to the wall of a vessel by inserting through an unreinforced opening and expanding into the shell, provided the diameter is not greater than 2 in. pipe size (DN 50). A pipe, tube, or forging not exceeding 6 in. (152 mm) in outside diameter may be attached to the wall of a vessel by inserting through a reinforced opening and expanding into the shell.

Such connections shall be:

(1) firmly rolled in and beaded; or

(2) rolled in, beaded, and seal-welded around the edge of the bead; or

(3) expanded and flared not less than ⅛ in. (3.2 mm) over the diameter of the hole; or

(4) rolled, flared, and welded; or

(5) rolled and welded without flaring or beading, provided:

(a) the ends extend at least ¼ in. (6 mm), but no more than ⅜ in. (10 mm), through the shell;

(b) the throat of the weld is at least 3⁄16 in. (4.8 mm), but no more than 5⁄16 in. (8 mm).

When the tube or pipe does not exceed 1½ in. (38 mm) in outside diameter, the shell may be chamfered or recessed to a depth at least equal to the thickness of the tube or pipe and the tube or pipe may be rolled into place and welded. In no case shall the end of the tube or pipe extend more than ⅜ in. (10 mm) beyond the shell.

Grooving of shell openings in which tubes and pipe are to be rolled or expanded is permissible.

Expanded connections shall not be used as a method of attachment to vessels used for the processing or storage of flammable and/or noxious gases and liquids unless the connections are seal-welded.

(g) Where tapped holes are provided for studs, the threads shall be full and clean and shall engage the stud for a length not less than the larger of d_s or

$$0.75\, d_s \times \frac{\text{Maximum allowable stress value of stud material at design temperature}}{\text{Maximum allowable stress value of tapped material at design temperature}}$$

in which d_s is the nominal diameter of the stud, except that the thread engagement need not exceed $1\frac{1}{2}d_s$.

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UG-44 FLANGES AND PIPE FITTINGS

The following standards covering flanges and pipe fittings are acceptable for use under this Division in accordance with the requirements of UG-11. Pressure–temperature ratings shall be in accordance with the appropriate standard except that the pressure–temperature ratings for ASME B16.9 and ASME B16.11 fittings shall be calculated as for straight seamless pipe in accordance with the rules of this Division including the maximum allowable stress for the material. The pressure–temperature ratings of ASME/ANSI B16.28 fittings shall be 80% of that calculated for straight seamless pipe in accordance with the rules of this Division unless 100% rating has been established by the fitting manufacturer in accordance with para. 9 of ASME B16.9. The thickness tolerance of the ASME standards shall apply.

UG-44(a) ASME/ANSI B16.5, Pipe Flanges and Flanged Fittings [see UG-11(a)(2)]

UG-44(b) ASME B16.9, Factory-Made Wrought Steel Buttwelding Fittings

UG-44(c) ASME B16.11, Forged Fittings, Socket-Welding and Threaded

UG-44(d) ANSI/ASME B16.15, Cast Bronze Threaded Fittings, Classes 125 and 250

UG-44(e) ASME B16.20, Metallic Gaskets for Pipe Flanges — Ring-Joint, Spiral-Wound, and Jacketed

UG-44(f) ASME B16.24, Cast Copper Alloy Pipe Flanges and Flanged Fittings, Class 150, 300, 400, 600, 900, 1500, and 2500

UG-44(g) ASME/ANSI B16.28, Wrought Steel Buttwelding Short Radius Elbows and Returns

UG-44(h) ASME/ANSI B16.42, Ductile Iron Pipe Flanges and Flanged Fittings, Class 150 and 300

UG-44(i) ASME B16.47, Large Diameter Steel Flanges, NPS 26 Through NPS 60

UG-44(j) A forged nozzle flange may use the ASME B16.5 pressure–temperature ratings for the flange material being used, provided all of the following are met.

UG-44(j)(1) The forged nozzle flange shall meet all dimensional requirements of a flanged fitting given in ASME B16.5 with the exception of the inside diameter. The inside diameter of the forged nozzle flange shall not exceed the inside diameter of the same size and class lap joint flange given in ASME B16.5.

UG-44(j)(2) The outside diameter of the forged nozzle neck shall be at least equal to the hub diameter of the same size and class ASME B16.5 lap joint flange; larger hub diameters shall be limited to nut stop diameter dimensions; see Fig. 2-4 sketches (12) and (12a).

UG-45 NOZZLE NECK THICKNESS 01

The minimum wall thickness of nozzle necks shall be the larger of (a) or (b) below. Shear stresses caused by UG-22 loadings shall not exceed the allowable shear stress in (c) below. For applications of rules in this paragraph refer to Appendix L, Examples 2, 5, and 8 (see L-7.2, L-7.5, and L-7.8, respectively).

UG-45(a) The minimum wall thickness of a nozzle neck or other connection (including access openings and openings for inspection) shall not be less than the thickness computed from the applicable loadings in UG-22 plus the thickness added for allowances for corrosion and threading, as applicable [see UG-31(c)(2)], on the connection.

UG-45(b) Additionally, the minimum thickness of a nozzle neck or other connection (except for access openings and openings for inspection only) shall not be less than the smaller of the nozzle wall thickness as determined by the applicable rule in (b)(1), (b)(2) or (b)(3) below, and the wall thickness as determined by (b)(4) below:

UG-45(b)(1) for vessels under internal pressure only, the thickness (plus corrosion allowance) required for pressure (assuming $E = 1.0$) for the shell or head at the location where the nozzle neck or other connection attaches to the vessel but in no case less than the minimum thickness specified for the material in UG-16(b);

UG-45(b)(2) for vessels under external pressure only, the thickness (plus corrosion allowance) obtained by using the external design pressure as an equivalent internal design pressure (assuming $E = 1.0$) in the formula for the shell or head at the location where the nozzle neck or other connection attaches to the vessel but in no case less than the minimum thickness specified for the material in UG-16(b);

UG-45(b)(3) for vessels designed for both internal and external pressure, the greater of the thicknesses determined by (b)(1) or (b)(2) above;

UG-45(b)(4) the minimum thickness[27] of standard wall pipe plus the thickness added for corrosion allowance on the connection; for nozzles larger than the largest pipe size included in ANSI/ASME B36.10M,

[27] The minimum thickness for all materials is that wall thickness listed in Table 2 of ANSI/ASME B36.10M, less 12½%. For diameters other than those listed as standard (STD) in the Table, this shall be based upon the next larger pipe size. When a material specification does not specify schedule weights conforming to ANSI/ASME B36.10M, the pipe weight indicated as regular shall be used when so designated in the specification. If not so designated, the heaviest schedule listed shall be used even though this is less than the thickness of standard weight pipe of ANSI/ASME B36.10M.

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the wall thickness of that largest size plus the thickness added for corrosion allowance on the connection.

UG-45(c) The allowable stress value for shear in the nozzle neck shall be 70% of the allowable tensile stress for the nozzle material.

UG-46 INSPECTION OPENINGS[28]

(a) All pressure vessels for use with compressed air and those subject to internal corrosion or having parts subject to erosion or mechanical abrasion (see UG-25), except as permitted otherwise in this paragraph, shall be provided with suitable manhole, handhole, or other inspection openings for examination and cleaning.

Compressed air as used in this paragraph is not intended to include air which has had moisture removed to provide an atmospheric dew point of −50°F (−46°C) or less.

Inspection openings may be omitted in vessels covered in UG-46(b), and in the shell side of fixed tubesheet heat exchangers. When inspection openings are not provided, the Manufacturer's Data Report shall include one of the following notations under remarks:

(1) "UG-46(b)" when telltale holes are used in lieu of inspection openings;

(2) "UG-46(a)" when inspection openings are omitted in fixed tubesheet heat exchangers;

(3) "UG-46(c)," "UG-46(d)," or "UG-46(e)" when provision for inspection is made in accordance with one of these paragraphs;

(4) the statement "for noncorrosive service."

(b) When provided with tell-tale holes complying with the provisions of UG-25, inspection openings as required in (a) above may be omitted in vessels not over 36 in. (914 mm). I.D. which are subject only to corrosion, provided that the holes are spaced one hole per 10 sq ft (0.9 m^2) (or fraction thereof) of internal vessel surface area where corrosion is expected with a minimum of four uniformly spaced holes per vessel. This provision does not apply to vessels for compressed air.

(c) Vessels over 12 in. (305 mm) I.D. under air pressure which also contain, as an inherent requirement of their operation, other substances which will prevent corrosion need not have openings for inspection only, provided the vessel contains suitable openings through which inspection can be made conveniently, and provided such openings are equivalent in size and number to the requirements for inspection openings in (f) below.

(d) For vessels 12 in. (305 mm) or less in inside diameter, openings for inspection only may be omitted if there are at least two removable pipe connections not less than NPS ¾ (DN 20).

(e) Vessels less than 16 in. (406 mm) and over 12 in. (305 mm) I.D. shall have at least two handholes or two threaded pipe plug inspection openings of not less than NPS 1½ (DN 40) except as permitted by the following: when vessels less than 16 in. (406 mm) and over 12 in. (305 mm) I.D. are to be installed so that inspection cannot be made without removing the vessel from the assembly, openings for inspection only may be omitted provided there are at least two removable pipe connections of not less than NPS 1½ (DN 40).

(f) Vessels that require access or inspection openings shall be equipped as follows.[29]

(1) All vessels less than 18 in. (457 mm) and over 12 in. (305 mm) I.D. shall have at least two handholes or two plugged, threaded inspection openings of not less than NPS 1½ (DN 40).

(2) All vessels 18 in. (457 mm) to 36 in. (914 mm), inclusive, I.D. shall have a manhole or at least two handholes or two plugged, threaded inspection openings of not less than NPS 2 (DN 50).

(3) All vessels over 36 in. (914 mm) I.D. shall have a manhole, except that those whose shape or use makes one impracticable shall have at least two handholes 4 in. × 6 in. (102 mm × 152 mm) or two equal openings of equivalent area.

(4) When handholes or pipe plug openings are permitted for inspection openings in place of a manhole, one handhole or one pipe plug opening shall be in each head or in the shell near each head.

(5) Openings with removable heads or cover plates intended for other purposes may be used in place of the required inspection openings provided they are equal at least to the size of the required inspection openings.

(6) A single opening with removable head or cover plate may be used in place of all the smaller inspection openings provided it is of such size and location as to afford at least an equal view of the interior.

(7) Flanged and/or threaded connections from which piping, instruments, or similar attachments can be removed may be used in place of the required inspection openings provided that:

(a) the connections are at least equal to the size of the required openings; and

(b) the connections are sized and located to afford at least an equal view of the interior as the required inspection openings.

[28] All dimensions given, for size of vessel on which inspection openings are required, are nominal.

[29] Dimensions referred to are nominal.

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(g) When inspection or access openings are required, they shall comply at least with the following requirements.

01 *(1)* An elliptical or obround manhole shall be not less than 12 in. × 16 in. (305 mm × 406 mm). A circular manhole shall be not less than 16 in. (406 mm) I.D.

(2) A handhole opening shall be not less than 2 in. × 3 in. (51 mm × 76 mm), but should be as large as is consistent with the size of the vessel and the location of the opening.

(h) All access and inspection openings in a shell or unstayed head shall be designed in accordance with the rules of this Division for openings.

(i) When a threaded opening is to be used for inspection or cleaning purposes, the closing plug or cap shall be of a material suitable for the pressure and no material shall be used at a temperature exceeding the maximum temperature allowed in this Division for that material. The thread shall be a standard taper pipe thread except that a straight thread of at least equal strength may be used if other sealing means to prevent leakage are provided.

(j) Manholes of the type in which the internal pressure forces the cover plate against a flat gasket shall have a minimum gasket bearing width of $^{11}/_{16}$ in. (18 mm).

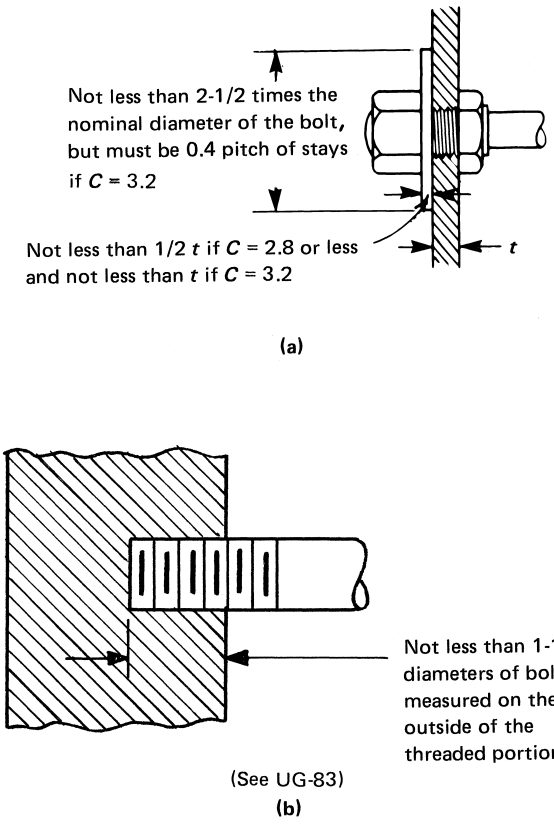


FIG. UG-47 ACCEPTABLE PROPORTIONS FOR ENDS OF STAYS

BRACED AND STAYED SURFACES

UG-47 BRACED AND STAYED SURFACES

(a) The minimum thickness and maximum allowable working pressure for braced and stayed flat plates and those parts which, by these rules, require staying as flat plates with braces or staybolts of uniform diameter symmetrically spaced, shall be calculated by the following formulas:

$$t = p\sqrt{\frac{P}{SC}} \quad (1)$$

$$P = \frac{t^2 SC}{p^2} \quad (2)$$

where

t = minimum thickness of plate, in. (mm)
P = internal design pressure (see UG-21), psi (kPa)
S = maximum allowable stress value in tension (see UG-23), psi (kPa)
p = maximum pitch, in. (mm). The maximum pitch is the greatest distance between any set of parallel straight lines passing through the centers of staybolts in adjacent rows. Each of the three parallel sets running in the horizontal, the vertical, and the inclined planes shall be considered.
C = 2.1 for welded stays or stays screwed through plates not over $^{7}/_{16}$ in. (11 mm) in thickness with ends riveted over
C = 2.2 for welded stays or stays screwed through plates over $^{7}/_{16}$ in. (11 mm) in thickness with ends riveted over
C = 2.5 for stays screwed through plates and fitted with single nuts outside of plate, or with inside and outside nuts, omitting washers; and for stays screwed into plates as shown in Fig. UG-47 sketch (b)
C = 2.8 for stays with heads not less than 1.3 times the diameter of the stays screwed through plates or made a taper fit and having the heads formed

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on the stays before installing them, and not riveted over, said heads being made to have a true bearing on the plate

C = 3.2 for stays fitted with inside and outside nuts and outside washers where the diameter of washers is not less than $0.4p$ and thickness not less than t

(b) The minimum thickness of plates to which stays may be applied, in other than cylindrical or spherical outer shell plates, shall be $^5/_{16}$ in. (8 mm) except for welded construction covered by UW-19.

(c) If a stayed jacket extends completely around a cylindrical or spherical vessel, or completely covers a formed head, it shall meet the requirements given in (a) above, and shall also meet the applicable requirements for shells or heads in UG-27(c) and (d) and UG-32. In addition, where any nozzle or other opening penetrates the cylindrical or spherical vessel, or completely covered head, and the jacket, the vessel or formed head shall be designed in accordance with UG-37(d)(2).

(d) When two plates are connected by stays and but one of these plates requires staying, the value of C shall be governed by the thickness of the plate requiring staying.

(e) Acceptable proportions for the ends of through stays with washers are indicated in Fig. UG-47 sketch (a). See UG-83.

(f) The maximum pitch shall be $8^1/_2$ in. (221 mm), except that for welded-in staybolts the pitch may be greater provided it does not exceed 15 times the diameter of the staybolt.

(g) When the staybolting of shells is unsymmetrical by reason of interference with butt straps or other construction, it is permissible to consider the load carried by each staybolt as the area calculated by taking the distance from the center of the spacing on one side of the bolt to the center of the spacing on the other side.

UG-48 STAYBOLTS

(a) The ends of staybolts or stays screwed through the plate shall extend beyond the plate not less than two threads when installed, after which they shall be riveted over or upset by an equivalent process without excessive scoring of the plates, or they shall be fitted with threaded nuts through which the bolt or stay shall extend.

(b) The ends of steel stays upset for threading shall be fully annealed.

(c) Requirements for welded-in staybolts are given in UW-19.

UG-49 LOCATION OF STAYBOLTS

(a) When the edge of a flat stayed plate is flanged, the distance from the center of the outermost stays to the inside of the supporting flange shall not be greater than the pitch of the stays plus the inside radius of the flange.

UG-50 DIMENSIONS OF STAYBOLTS

(a) The required area of a staybolt at its minimum cross section[30] and exclusive of any allowance for corrosion shall be obtained by dividing the load on the staybolt computed in accordance with (b) below by the allowable stress value for the material used, as given in Subsection C, and multiplying the result by 1.10.

(b) Load Carried by Stays. The area supported by a stay shall be computed on the basis of the full pitch dimensions, with a deduction for the area occupied by the stay. The load carried by a stay is the product of the area supported by the stay and the maximum allowable working pressure.

(c) Stays made of parts joined by welding shall be checked for strength using a joint efficiency of 60% for the weld.

LIGAMENTS

UG-53 LIGAMENTS

(a) The symbols used in the formulas and charts of this paragraph are defined as follows:

p = longitudinal pitch of tube holes, in. (mm)
p_1 = unit length of ligament, in. (mm)
p' = diagonal pitch of tube holes, in. (mm)
θ = angle of diagonal with longitudinal line, deg.
s = longitudinal dimension of diagonal pitch, in. (mm)
$= p' \cos \theta$
d = diameter of tube holes, in. (mm)
n = number of tube holes in length p_1

(b) When a cylindrical shell is drilled for tubes in a line parallel to the axis of the shell for substantially

[30] The minimum cross section is usually at the root of the thread.

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the full length of the shell as shown in Figs. UG-53.1 through UG-53.3, the efficiency of the ligaments between the tube holes shall be determined as follows.

(1) When the pitch of the tube holes on every row is equal (see Fig. UG-53.1), the formula is

$$\frac{p - d}{p} = \text{efficiency of ligament}$$

(2) When the pitch of tube holes on any one row is unequal (as in Figs. UG-53.2 and UG-53.3), the formula is

$$\frac{p_1 - nd}{p_1} = \text{efficiency of ligament}$$

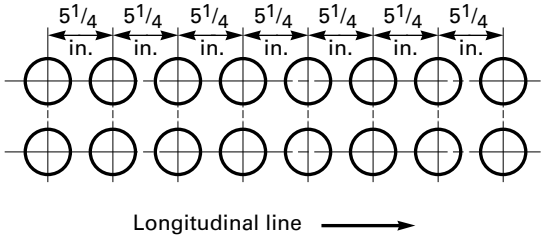
(c) When the adjacent longitudinal rows are drilled as described in (b) above, diagonal and circumferential ligaments shall also be examined. The least equivalent longitudinal efficiency shall be used to determine the minimum required thickness and the maximum allowable working pressure.

(d) When a cylindrical shell is drilled for holes so as to form diagonal ligaments, as shown in Fig. UG-53.4, the efficiency of these ligaments shall be determined by Figs. UG-53.5 and UG-53.6. Figure UG-53.5 is used to determine the efficiency of longitudinal and diagonal ligaments with limiting boundaries where the condition of equal efficiency of diagonal and longitudinal ligaments form one boundary and the condition of equal efficiency of diagonal and circumferential ligaments form the other boundary. Figure UG-53.6 is used for determining the equivalent longitudinal efficiency of diagonal ligaments. This efficiency is used in the formulas for setting the minimum required thickness and the maximum allowable working pressure.

(e) Figure UG-53.5 is used when either or both longitudinal and circumferential ligaments exist with diagonal ligaments. To use Fig. UG-53.5, compute the value of p'/p_1 and also the efficiency of the longitudinal ligament. Next find in the diagram, the vertical line corresponding to the longitudinal efficiency of the ligament and follow this line vertically to the point where it intersects the diagonal line representing the ratio of p'/p_1. Then project this point horizontally to the left, and read the diagonal efficiency of the ligament on the scale at the edge of the diagram. The minimum shell thickness and the maximum allowable working pressure shall be based on the ligament that has the lower efficiency.

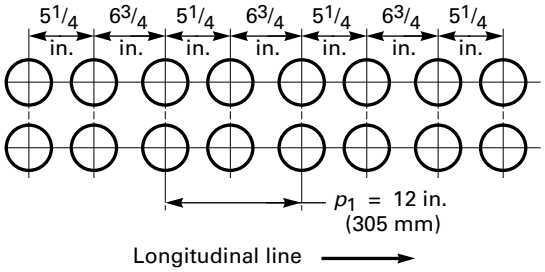
(f) Figure UG-53.6 is used for holes which are not in line, placed longitudinally along a cylindrical shell. The diagram may be used for pairs of holes for all planes between the longitudinal plane and the circumferential plane. To use Fig. UG-53.6, determine the angle θ between the longitudinal shell axis and the line between the centers of the openings, θ, and compute the value of p'/d. Find in the diagram, the vertical line corresponding to the value of θ and follow this line vertically to the line representing the value of p'/d. Then project this point horizontally to the left, and read the equivalent longitudinal efficiency of the diagonal ligament. This equivalent longitudinal efficiency is used to determine the minimum required thickness and the maximum allowable working pressure.

(g) When tube holes in a cylindrical shell are arranged in symmetrical groups which extend a distance greater than the inside diameter of the shell along lines parallel to the axis and the same spacing is used for each



GENERAL NOTE: $5\frac{1}{4}$ in. = 133 mm

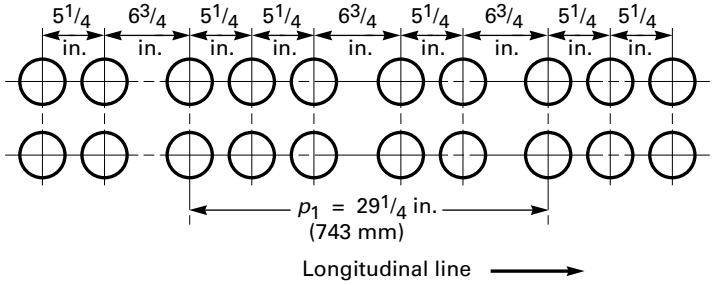
FIG. UG-53.1 EXAMPLE OF TUBE SPACING WITH PITCH OF HOLES EQUAL IN EVERY ROW



GENERAL NOTE: $5\frac{1}{4}$ in. = 133 mm
$6\frac{3}{4}$ in. = 171 mm

FIG. UG-53.2 EXAMPLE OF TUBE SPACING WITH PITCH OF HOLES UNEQUAL IN EVERY SECOND ROW

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GENERAL NOTE: $5\frac{1}{4}$ in. = 133 mm
$6\frac{3}{4}$ in. = 171 mm

FIG. UG-53.3 EXAMPLE OF TUBE SPACING WITH PITCH OF HOLES VARYING IN EVERY SECOND AND THIRD ROW

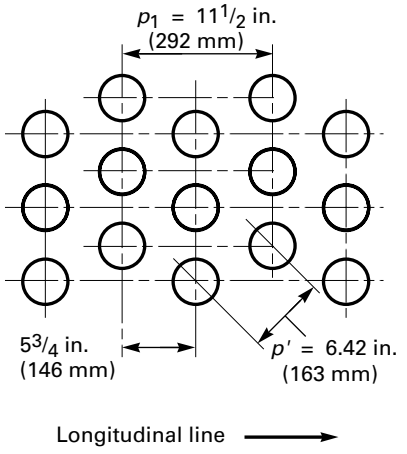


FIG. UG-53.4 EXAMPLE OF TUBE SPACING WITH TUBE HOLES ON DIAGONAL LINES

group, the efficiency for one of the groups shall be not less than the efficiency on which the maximum allowable working pressure is based.

(h) The average ligament efficiency in a cylindrical shell, in which the tube holes are arranged along lines parallel to the axis with either uniform or nonuniform spacing, shall be computed by the following rules and shall satisfy the requirements of both.[31]

(1) For a length equal to the inside diameter of the shell for the position which gives the minimum efficiency, the efficiency shall be not less than that on which the maximum allowable working pressure is based. When the inside diameter of the shell exceeds 60 in. (1520 mm), the length shall be taken as 60 in. (1520 mm) in applying this rule.

(2) For a length equal to the inside radius of the shell for the position which gives the minimum efficiency, the efficiency shall be not less than 80% of that on which the maximum allowable working pressure is based. When the inside radius of the shell exceeds 30 in., the length shall be taken as 30 in. (762 mm) in applying this rule.

(i) When ligaments occur in cylindrical shells made from welded pipe or tubes, and their calculated efficiency is less than 85% (longitudinal) or 50% (circumferential), the efficiency to be used in the formulas of UG-27 is the calculated ligament efficiency. In this case, the appropriate stress value in tension (see UG-23) may be multiplied by the factor 1.18.

(j) Examples illustrating the application of the rules in this paragraph are given in Appendix L.

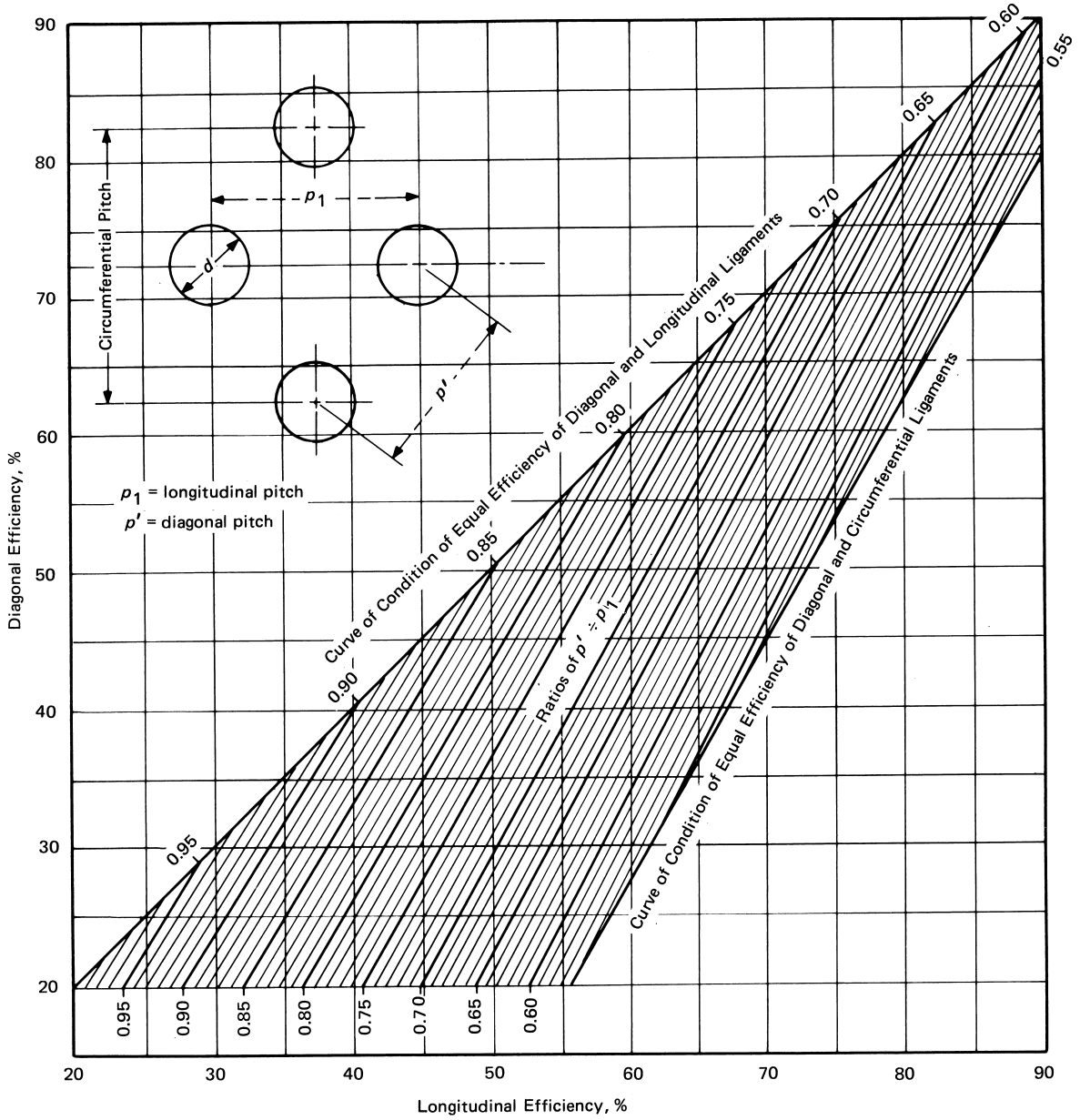
UG-54 SUPPORTS

(a) All vessels shall be so supported and the supporting members shall be arranged and/or attached to the vessel wall in such a way as to provide for the maximum imposed loadings (see UG-22 and UG-82).

(b) Appendix G contains suggested rules for the design of supports.

[31] The rules in this paragraph apply to ligaments between tube holes and not to single openings. They may give lower efficiencies in some cases than those for symmetrical groups which extend a distance greater than the inside diameter of the shell as covered in (e) above. When this occurs, the efficiencies computed by the rules under (b) above shall govern.

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NOTES:

(1) Equations are provided for the user's option in Notes (2), (3), and (4) below. The use of these equations is permitted for values beyond those provided by Fig. UG-53.5.

(2) Diagonal efficiency, $\% = \dfrac{J + 0.25 - (1 - 0.01E_{\text{long.}})\sqrt{0.75 + J}}{0.00375 + 0.005J}$, where $J = (p'/p_1)^2$

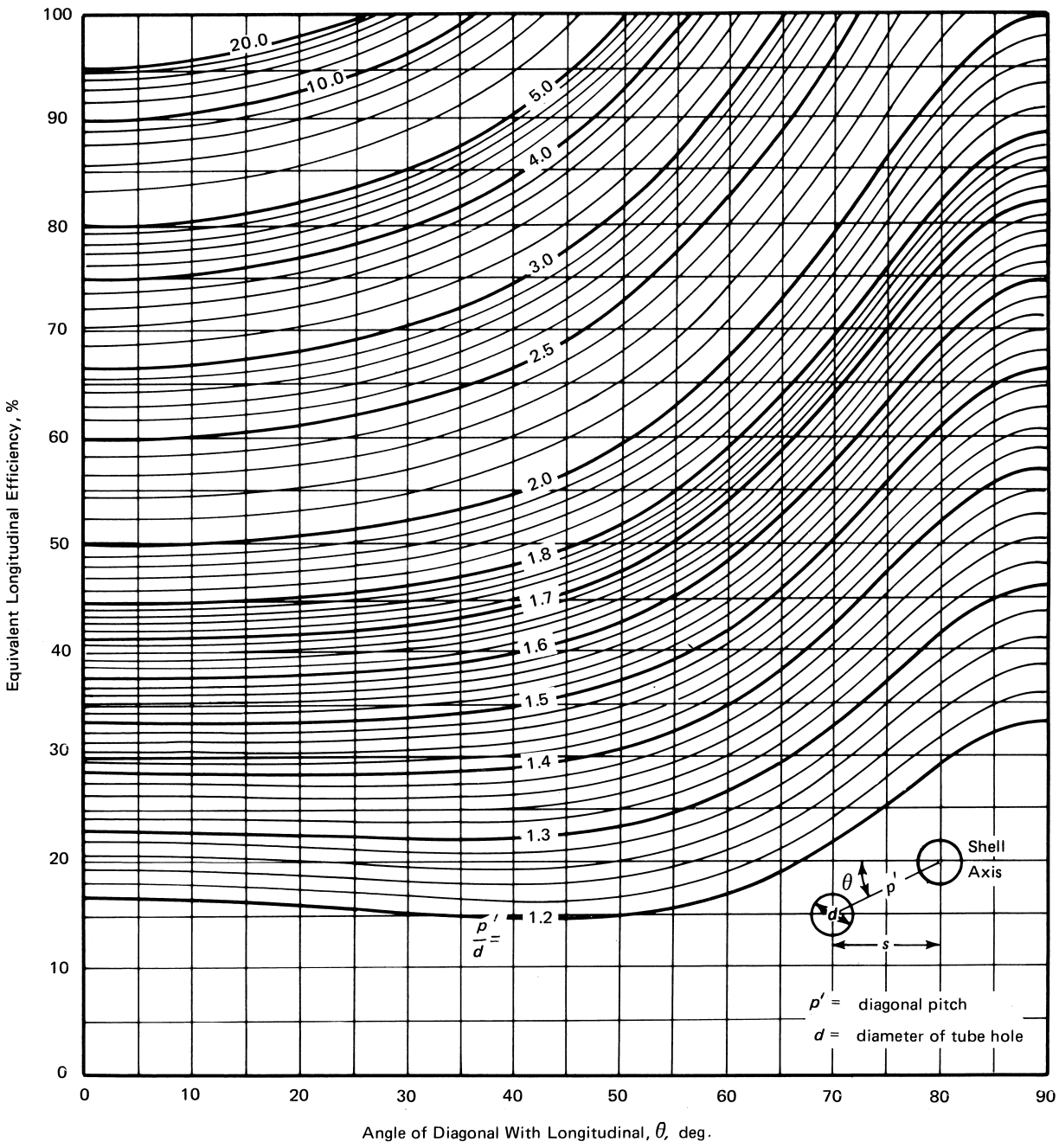
(3) Curve of condition of equal efficiency of diagonal and circumferential ligaments,

diagonal efficiency, $\% = \dfrac{200M + 100 - 2(100 - E_{\text{long.}})\sqrt{1 + M}}{(1 + M)}$, where $M = [(100 - E_{\text{long.}})/(200 - 0.5E_{\text{long.}})]^2$

(4) Longitudinal efficiency, $\% = E_{\text{long.}} = [(p_1 - d)/p_1]\,100$

FIG. UG-53.5 DIAGRAM FOR DETERMINING THE EFFICIENCY OF LONGITUDINAL AND DIAGONAL LIGAMENTS BETWEEN OPENINGS IN CYLINDRICAL SHELLS

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NOTES:

(1) The equation in Note (2) below is provided for the user's option. The use of the equation is prohibited beyond the range of the abscissa and ordinate shown.

(2) Equivalent longitudinal efficiency,

$$\% = \frac{\sec^2\theta + 1 - \left(\frac{\sec\theta}{p'/d}\right)\sqrt{3 + \sec^2\theta}}{0.015 + 0.005\sec^2\theta}$$

FIG. UG-53.6 DIAGRAM FOR DETERMINING EQUIVALENT LONGITUDINAL EFFICIENCY OF DIAGONAL LIGAMENTS BETWEEN OPENINGS IN CYLINDRICAL SHELLS

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UG-55 LUGS FOR PLATFORMS, LADDERS, AND OTHER ATTACHMENTS TO VESSEL WALLS

(a) Lugs or clips may be welded, brazed, or bolted to the outside or inside of the vessel to support ladders, platforms, piping, motor or machinery mounts, and attachment of insulating jackets (see UG-22). The material of the lugs or clips shall be in accordance with UG-4.

(b) External piping connected to a pressure vessel shall be installed so as not to overstress the vessel wall. (see UG-22 and UG-82).

(c) Appendix G provides guidance on the design of attachments.

FABRICATION

UG-75 GENERAL

The fabrication of pressure vessels and vessel parts shall conform to the general fabrication requirements in the following paragraphs and to the specific requirements for *Fabrication* given in the applicable Parts of Subsections B and C.

UG-76 CUTTING PLATES AND OTHER STOCK

(a) Plates, edges of heads, and other parts may be cut to shape and size by mechanical means such as machining, shearing, grinding, or by oxygen or arc cutting. After oxygen or arc cutting, all slag and detrimental discoloration of material which has been molten shall be removed by mechanical means prior to further fabrication or use.

(b) Ends of nozzles or manhole necks which are to remain unwelded in the completed vessel may be cut by shearing provided sufficient additional material is removed by any other method that produces a smooth finish.

(c) Exposed inside edges shall be chamfered or rounded.

01 UG-77 MATERIAL IDENTIFICATION (SEE UG-85)

(a) Material for pressure parts preferably should be laid out so that when the vessel is completed, one complete set of the original identification markings required by UG-94 will be plainly visible. The pressure vessel Manufacturer shall maintain traceability of the material to the original identification markings by one or more of the following methods: accurate transfer of the original identification markings to a location where the markings will be visible on the completed vessel; identification by a coded marking traceable to the original required marking; or recording the required markings using methods such as material tabulations or as built sketches which assure identification of each piece of material during fabrication and subsequent identification in the completed vessel. Such transfers of markings shall be made prior to cutting except that the Manufacturer may transfer markings immediately after cutting provided the control of these transfers is described in his written Quality Control System (see 10-6). Except as indicated in (b) below, material may be marked by any method acceptable to the Inspector. The Inspector need not witness the transfer of the marks but shall satisfy himself that it has been correctly done (see UHT-86).

(b) Where the service conditions prohibit die-stamping for material identification, and when so specified by the user, the materials manufacturer shall mark the required data on the plates in a manner which will allow positive identification upon delivery. The markings must be recorded so that each plate will be positively identified in its position in the completed vessel to the satisfaction of the Inspector. Transfer of markings for material that is to be divided shall be done as in (a) above.

(c) When material is formed into shapes by anyone other than the Manufacturer of the completed pressure vessel, and the original markings as required by the applicable material specification are unavoidably cut out, or the material is divided into two or more parts, the Manufacturer of the shape shall either:

(1) transfer the original identification markings to another location on the shape; or

(2) provide for identification by the use of a coded marking traceable to the original required marking, using a marking method agreed upon and described in the quality control system of the Manufacturer of the completed pressure vessel.

Identification in accordance with UG-93, in conjunction with the above modified marking requirements, shall be considered sufficient to identify these shapes. Manufacturer's Partial Data Reports and parts stamping are not a requirement unless there has been fabrication to the shapes that include welding, except as exempted by UG-11.

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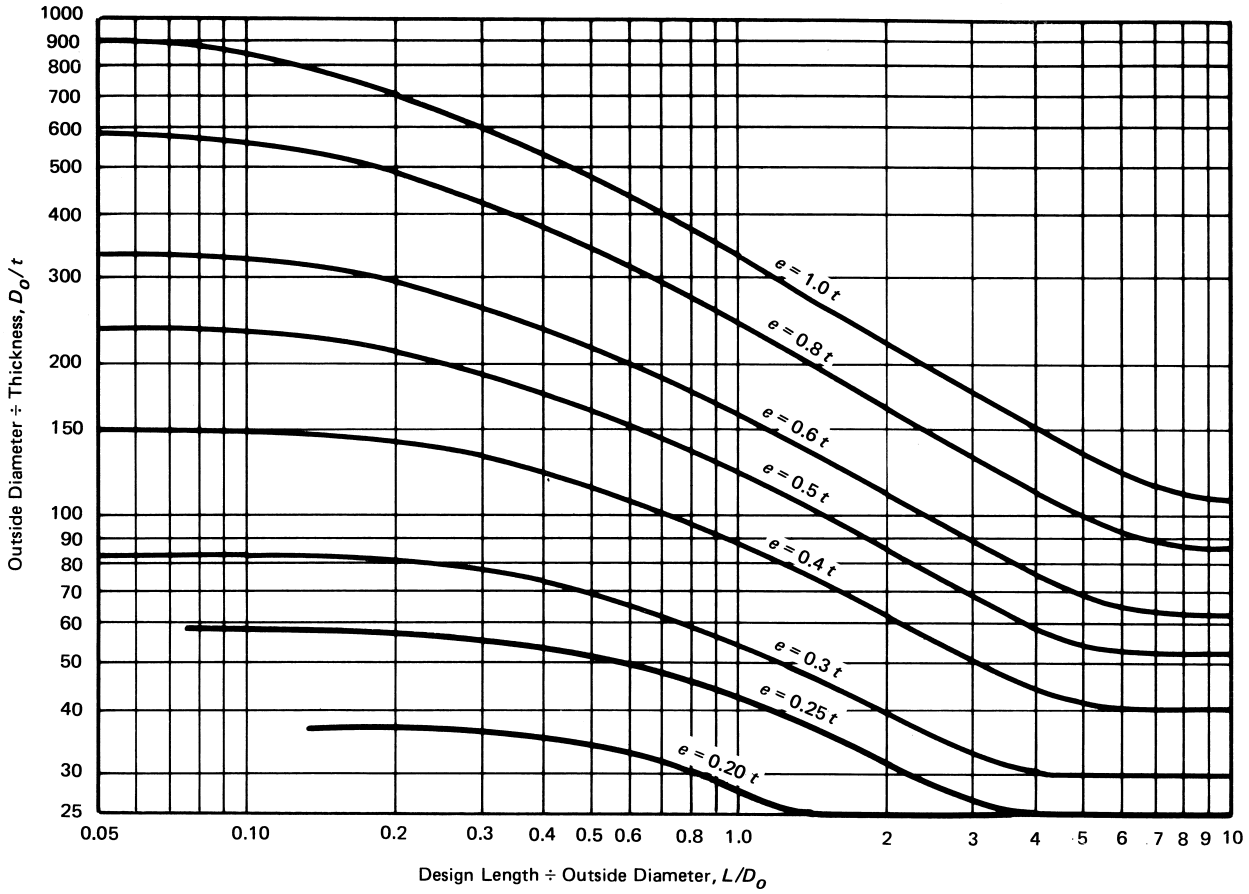


FIG. UG-80.1 MAXIMUM PERMISSIBLE DEVIATION FROM A CIRCULAR FORM *e* FOR VESSELS UNDER EXTERNAL PRESSURE

UG-78 REPAIR OF DEFECTS IN MATERIALS

Defects in material may be repaired provided acceptance by the Inspector is first obtained for the method and extent of repairs. Defective material that cannot be satisfactorily repaired shall be rejected.

UG-79 FORMING SHELL SECTIONS AND HEADS

(a) All plates for shell sections and for heads shall be formed to the required shape by any process that will not unduly impair the physical properties of the material. Limits are provided on cold working of all carbon and low alloy steels [see UCS-79(d) and UHT-79(a)].

(b) If the plates are to be rolled, the adjoining edges of longitudinal joints of cylindrical vessels shall first be shaped to the proper curvature by preliminary rolling or forming in order to avoid having objectionable flat spots along the completed joints (see UG-80).

UG-80 PERMISSIBLE OUT-OF-ROUNDNESS OF CYLINDRICAL, CONICAL, AND SPHERICAL SHELLS

(a) Internal Pressure. The shell of a completed vessel shall be substantially round and shall meet the following requirements.

(1) The difference between the maximum and minimum inside diameters at any cross section shall not exceed 1% of the nominal diameter at the cross section

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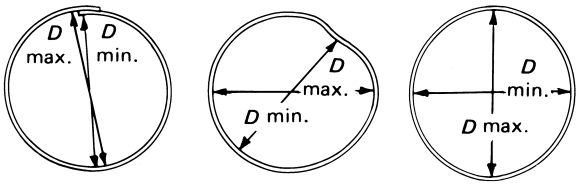


FIG. UG-80.2 EXAMPLE OF DIFFERENCES BETWEEN MAXIMUM AND MINIMUM INSIDE DIAMETERS IN CYLINDRICAL, CONICAL, AND SPHERICAL SHELLS

under consideration. The diameters may be measured on the inside or outside of the vessel. If measured on the outside, the diameters shall be corrected for the plate thickness at the cross section under consideration (see Fig. UG-80.2).

(2) When the cross section passes through an opening or within 1 I.D. of the opening measured from the center of the opening, the permissible difference in inside diameters given above may be increased by 2% of the inside diameter of the opening. When the cross section passes through any other location normal to the axis of the vessel, including head-to-shell junctions, the difference in diameters shall not exceed 1%.

For vessels with longitudinal lap joints, the permissible difference in inside diameters may be increased by the nominal plate thickness.

(b) External Pressure. The shell of a completed vessel to operate under external pressure shall meet the following requirements at any cross section.

(1) The out-of-roundness limitations prescribed in (a)(1) and (a)(2) above.

(2) The maximum plus-or-minus deviation from the true circular form, measured radially on the outside or inside of the vessel, shall not exceed the maximum permissible deviation e obtained from Fig. UG-80.1. Use

$$e = 1.0t$$

or

$$e = 0.2t$$

respectively, for points falling above or below these curves. Measurements shall be made from a segmental circular template having the design inside or outside radius (depending upon where the measurements are taken) and a chord length equal to twice the arc length obtained from Fig. UG-29.2. The values of L and D_o in Figs. UG-29.2 and UG-80.1 shall be determined as follows:

(a) for cylinders, L and D_o as defined in UG-28(b);

(b) for cones and conical sections, L and D_o values to be used in the figures are given below in terms of the definitions given in UG-33(b). In all cases below,

$$L_e = 0.5L(1 + D_s/D_L)$$

(1) at the large diameter end,

$$L = L_e$$

$$D_o = D_L$$

(2) at the small diameter end,

$$L = L_e(D_L/D_s)$$

$$D_o = D_s$$

(3) at the midlength diameter,

$$L = L_e[2D_L/(D_L + D_s)]$$

$$D_o = 0.5(D_L + D_s)$$

(4) at any crosssection having an outside diameter of D_x,

$$L = L_e(D_L/D_x)$$

$$D_o = D_x$$

(c) for spheres, L is one-half of the outside diameter D_o.

(3) For cylinders and spheres, the value of t shall be determined as follows.

(a) For vessels with butt joints, t is the nominal plate thickness less corrosion allowance.

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(b) For vessels with longitudinal lap joints, t is the nominal plate thickness and the permissible deviation is

$$t + e$$

(c) Where the shell at any cross section is made of plates having different thicknesses, t is the nominal thickness of the thinnest plate less corrosion allowance.

(4) For cones and conical sections, the value of t shall be determined as in (3) above, except that t in (a), (b), and (c) shall be replaced by t_e as defined in UG-33(b).

(5) The requirements of (b)(2) above shall be met in any plane normal to the axis of revolution for cylinders and cones and in the plane of any great circle for spheres. For cones and conical sections, a check shall be made at locations (1), (2), and (3) of (b)(2)(b) above and such other locations as may be necessary to satisfy manufacturers and inspectors that requirements are met.

(6) Measurements shall be taken on the surface of the base metal and not on welds or other raised parts of the material.

(7) The dimensions of a completed vessel may be brought within the requirements of this paragraph by any process which will not impair the strength of the material.

(8) Sharp bends and flat spots shall not be permitted unless provision is made for them in the design.

(9) If the nominal thickness of plate used for a cylindrical vessel exceeds the minimum thickness required by UG-28 for the external design pressure, and if such excess thickness is not required for corrosion allowance or loadings causing compressive forces, the maximum permissible deviation e determined for the nominal plate thickness used may be increased by the ratio of factor B for the nominal plate thickness used divided by factor B for the minimum required plate thickness; and the chord length for measuring $e_{\max}$ shall be determined by D_o/t for the nominal plate thickness used.

(10) Vessels fabricated of pipe may have permissible variations in diameter (measured outside) in accordance with those permitted under the specification covering its manufacture.

(11) An example illustrating the application of these rules for a vessel under external pressure is given in L-4.

UG-81 TOLERANCE FOR FORMED HEADS

(a) The inner surface of a torispherical, toriconical, hemispherical, or ellipsoidal head shall not deviate outside of the specified shape by more than $1\frac{1}{4}\%$ of D nor inside the specified shape by more than $\frac{5}{8}\%$ of D, where D is the nominal inside diameter of the vessel shell at point of attachment. Such deviations shall be measured perpendicular to the specified shape and shall not be abrupt. The knuckle radius shall not be less than that specified.

(b) Hemispherical heads or any spherical portion of a torispherical or ellipsoidal head designed for external pressure shall, in addition to satisfying (a) above, meet the tolerances specified for spheres in UG-80(b) using a value of 0.5 for L/D_o.

(c) Measurements for determining the deviations specified in (a) above shall be taken from the surface of the base metal and not from welds.

(d) The skirts of heads shall be sufficiently true to round so that the difference between the maximum and minimum inside diameters shall not exceed 1% of the nominal diameter.

(e) When the skirt of any unstayed formed head is machined to make a driving fit into or over a shell, the thickness shall not be reduced to less than 90% of that required for a blank head (see UW-13) or the thickness of the shell at the point of attachment. When so machined, the transition from the machined thickness to the original thickness of the head shall not be abrupt but shall be tapered for a distance of at least three times the difference between the thicknesses.

UG-82 LUGS AND FITTING ATTACHMENTS

All lugs, brackets, saddle type nozzles, manhole frames, reinforcement around openings, and other appurtenances shall be formed and fitted to conform reasonably to the curvature of the shell or surface to which they are attached.

(a) When pressure parts, such as saddle type nozzles, manhole frames, and reinforcement around openings, extend over pressure retaining welds, such welds shall be ground flush for the portion of the weld to be covered.

(b) When nonpressure parts, such as lugs, brackets, and support legs and saddles, extend over pressure retaining welds, such welds shall be ground flush as described in (a) above, or such parts shall be notched or coped to clear those welds.

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UG-83 HOLES FOR SCREW STAYS

Holes for screw stays shall be drilled full size or punched not to exceed $\frac{1}{4}$ in. (6 mm) less than full diameter of the hole for plates over $\frac{5}{16}$ in. (8 mm) in thickness and $\frac{1}{8}$ in. (3.2 mm) less than the full diameter of the hole for plates not exceeding $\frac{5}{16}$ in. (8 mm) in thickness, and then drilled or reamed to the full diameter. The holes shall be tapped fair and true with a full thread.

UG-84 CHARPY IMPACT TESTS

UG-84(a) General. Charpy impact tests in accordance with the provisions of this paragraph shall be made on weldments and all materials for shells, heads, nozzles, and other vessel parts subject to stress due to pressure for which impact tests are required by the rules in Subsection C.

UG-84(b) Test Procedures

UG-84(b)(1) Impact test procedures and apparatus shall conform to the applicable paragraphs of SA-370.

UG-84(b)(2) Unless permitted by Table UG-84.4, impact test temperature shall not be warmer than the minimum design metal temperature [see UG-20(b)]. The test temperature may be colder than the minimum specified in the material specification of Section II.

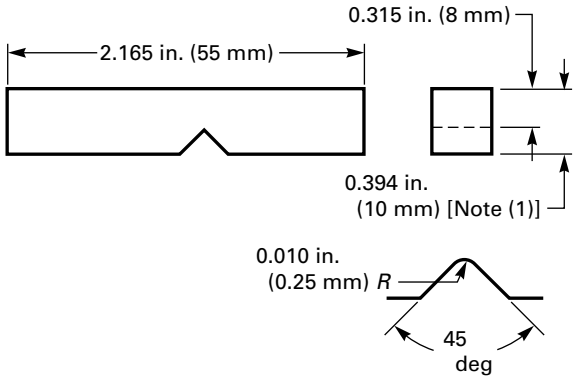
UG-84(c) Test Specimens

UG-84(c)(1) Each set of impact test specimens shall consist of three specimens.

UG-84(c)(2) The impact test specimens shall be of the Charpy V-notch type and shall conform in all respects to Fig. UG-84. The standard (10 mm × 10 mm) specimens, when obtainable, shall be used for nominal thicknesses of 0.438 in. (11.13 mm) or greater, except as otherwise permitted in (c)(2)(a) below.

01 *(a)* For materials that normally have absorbed energy in excess of 180 ft-lbf (245 J) when tested using full size (10 mm × 10 mm) specimens at the specified testing temperature, subsize (10 mm × 6.7 mm) specimens may be used in lieu of full size specimens. However, when this option is used, the acceptance value shall be 75 ft-lbf (102 J) minimum for each specimen and the lateral expansion in mils (mm) shall be reported.

UG-84(c)(3) For material from which full size (10 mm × 10 mm) specimens cannot be obtained, either due to the material shape or thickness, the specimens shall be either the largest possible standard subsize specimens obtainable or specimens of full material nominal thickness which may be machined to remove surface irregularities. [The test temperature criteria of (c)(5)(b) below shall apply for Table UCS-23 materials having a specified minimum tensile strength less than 95,000 psi (655 MPa) when the width along the notch is less than 80% of the material nominal thickness.] Alternatively, such material may be reduced in thickness to produce the largest possible Charpy subsize specimen. Toughness tests are not required where the maximum obtainable Charpy specimen has a width along the notch less than 0.099 in. (2.5 mm).



NOTE:
(1) See UG-84(c) for thickness of reduced size specimen.

FIG. UG-84 SIMPLE BEAM IMPACT TEST SPECIMENS (CHARPY TYPE TEST) 01

UG-84(c)(4)

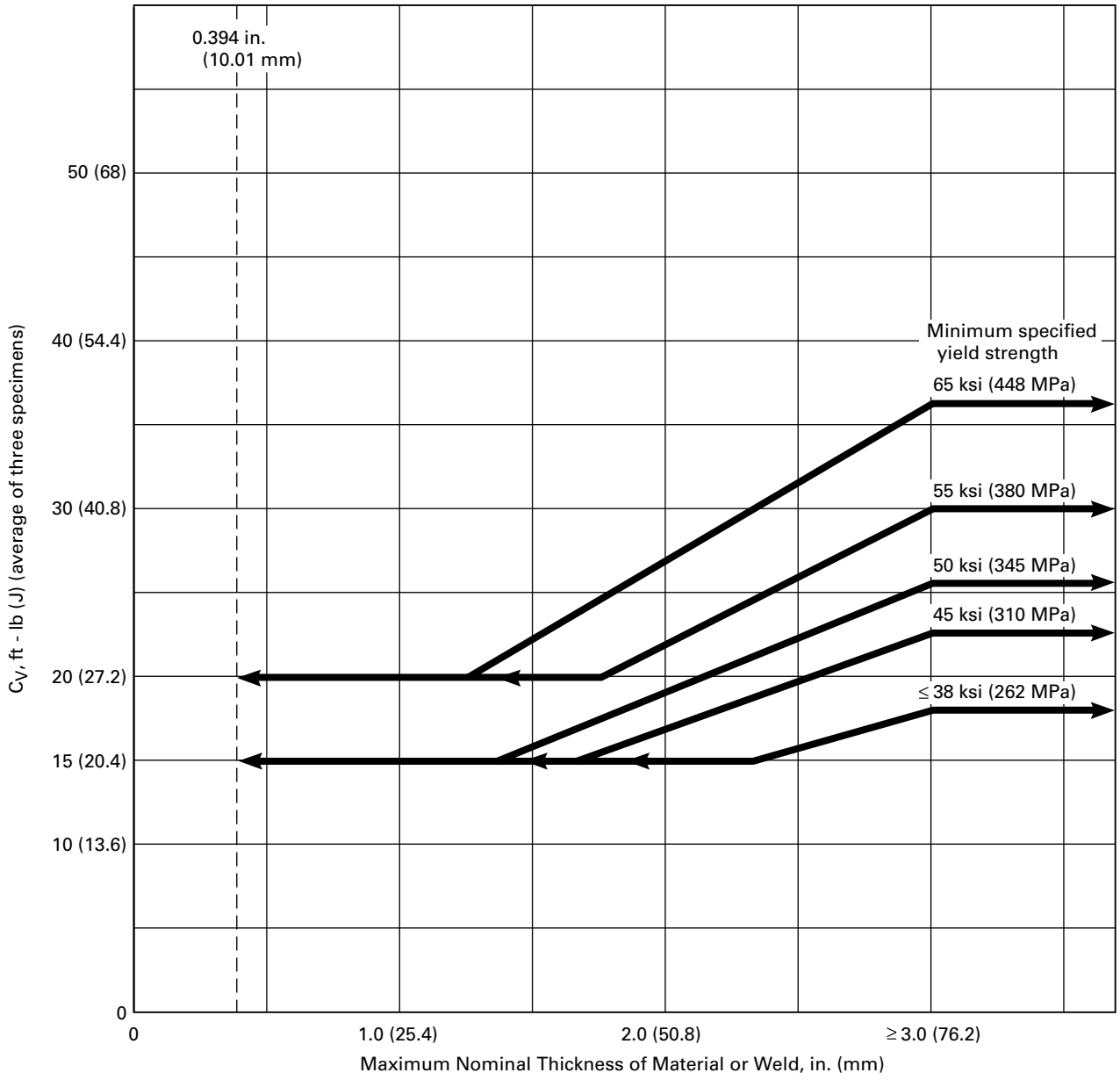
(a) The applicable minimum energy requirement for all specimen sizes for Table UCS-23 materials having a specified minimum tensile strength less than 95,000 psi (655 MPa) shall be that shown in Fig. UG-84.1, multiplied by the ratio of the actual specimen width along the notch to the width of a full-size (10 mm × 10 mm) specimen, except as otherwise provided in (c)(2)(a) above.

(b) The applicable minimum lateral expansion opposite the notch for all specimen sizes for Table UCS-23 materials, having a specified minimum tensile strength of 95,000 psi (655 MPa) or more, shall be as required in UHT-6(a)(3) and UHT-6(a)(4). For UHT materials, all requirements of UHT-6(a)(3) and UHT-6(a)(4) shall apply. For Table UHA-23 materials, all requirements of UHA-51 shall apply.

UG-84(c)(5) For all Charpy impact tests the following test temperature criteria shall be observed.

(a) For Materials of Nominal Thickness Equal to or Greater Than 0.394 in. (10.01 mm). Where the largest obtainable Charpy V-notch specimen has a width

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GENERAL NOTES:

(a) Interpolation between yield strengths shown is permitted.

(b) The minimum impact energy for one specimen shall not be less than $^2/_3$ of the average energy required for three specimens.

(c) Materials produced and impact tested in accordance with SA-320, SA-333, SA-334, SA-350, SA-352, SA-420, and SA-765 do not have to satisfy these energy values. They are acceptable for use at minimum design metal temperature not colder than the test temperature when the energy values required by the applicable specification are satisfied.

(d) For materials having a specified minimum tensile strength of 95 ksi (655 MPa) or more, see UG-84(c)(4)(b).

FIG. UG-84.1 CHARPY V-NOTCH IMPACT TEST REQUIREMENTS FOR FULL SIZE SPECIMENS FOR CARBON AND LOW ALLOY STEELS, HAVING A SPECIFIED MINIMUM TENSILE STRENGTH OF LESS THAN 95 ksi, LISTED IN TABLE UCS-23

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TABLE UG-84.2
CHARPY IMPACT TEST TEMPERATURE REDUCTION BELOW MINIMUM DESIGN METAL TEMPERATURE
For Table UCS-23 Materials Having a Specified Minimum Tensile Strength of Less Than 95,000 psi (655 MPa) When the Subsize Charpy Impact Width Is Less Than 80% of the Material Thickness

Actual Material Thickness [See UG-84(c)(5)(b)] of Charpy Impact Specimen Width Along the Notch[1]	
Thickness, in. (mm)	Temperature Reduction, °F (°C)
0.394 (Full-size standard bar) (10.01)	0 (0)
0.354 (8.99)	0 (0)
0.315 (8.00)	0 (0)
0.295 (3/4 size bar) (7.49)	5 (3)
0.276 (7.01)	8 (4)
0.262 (2/3 size bar) (6.65)	10 (6)
0.236 (5.99)	15 (8)
0.197 (1/2 size bar) (5.00)	20 (11)
0.158 (4.01)	30 (17)
0.131 (1/3 size bar) (3.33)	35 (19)
0.118 (3.00)	40 (22)
0.099 (1/4 size bar) (2.51)	50 (28)

NOTE:
(1) Straight line interpolation for intermediate values is permitted.

along the notch of at least 0.315 in. (8 mm), the Charpy test using such a specimen shall be conducted at a temperature not warmer than the minimum design metal temperature.[32] Where the largest possible test specimen has a width along the notch less than 0.315 in. (8 mm), the test shall be conducted at a temperature lower than the minimum design metal temperature[32] by the amount shown in Table UG-84.2 for that specimen width. [This latter requirement does not apply when the option of (c)(2)(a) above is used.]

(b) For Materials of Nominal Thickness Less Than 0.394 in. Where the largest obtainable Charpy V-notch specimen has a width along the notch of at least 80% of the material nominal thickness, the Charpy test of such a specimen shall be conducted at a temperature not warmer than the minimum design metal temperature.[32]

Where the largest possible test specimen has a width along the notch of less than 80% of the material nominal thickness, the test, for Table UCS-23 materials having specified minimum tensile strength of less than 95,000 psi (655 MPa), shall be conducted at a temperature lower than the minimum design metal temperature[32] by an amount equal to the difference (referring to Table UG-84.2) between the temperature reduction corresponding to the actual material thickness and the temperature reduction corresponding to the Charpy specimen width actually tested. [This latter requirement does not apply when the option of (c)(2)(a) above is used.] For Table UCS-23 materials having a specified minimum tensile strength of 95,000 psi (655 MPa) and over, for Table UHT-23 materials, and for Table UHA-23 materials, the test shall be conducted at a temperature not warmer than the minimum design temperature.

UG-84(c)(6) When the average value of the three specimens equals or exceeds the minimum value permitted for a single specimen and the value for more than one specimen is below the required average value, or when the value for one specimen is below the minimum value permitted for a single specimen, a retest of three additional specimens shall be made. The value for each of these retest specimens shall equal or exceed the required average value. 01

When an erratic result is caused by a defective specimen or there is uncertainty in test procedure, a retest will be allowed. When the option of (c)(2)(a) above is used for the initial test and the acceptance value of 75 ft-lbf (102 J) minimum is not attained, retest using full size (10 mm × 10 mm) specimens will be allowed.

UG-84(d) Impact Tests of Material

UG-84(d)(1) Reports or certificates of impact tests by the material manufacturer will be acceptable evidence that the material meets the requirements of this paragraph, provided the specimens comply with UCS-85, UHT-5, or UHT-81, as applicable.

UG-84(d)(2) The manufacturer of the vessel may have impact tests made to prove the suitability of a material which the material manufacturer has not impact tested provided the number of tests and the method of taking the test specimens shall be as specified for the material manufacturer (see UG-85).

UG-84(e) Procedural Requirements

UG-84(e)(1) Product Form Procedural Requirements. When no procedural requirements are listed in the material specifications, impact testing of each form of material shall comply with the applicable product form procedural requirements of the specifications listed in Table UG-84.3.

UG-84(e)(2) Small Parts. The manufacturer of small parts, either cast or forged, may certify a lot of not more than 20 duplicate parts by reporting the results of one set of impact specimens taken from one such part selected at random, provided the same specification and heat of material and the same process of production,

[32] Where applicable for Part UCS materials, the impact test temperature may be adjusted in accordance with UG-84(b)(2) and Table UG-84.4.

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TABLE UG-84.3
SPECIFICATIONS FOR IMPACT TESTED MATERIALS IN VARIOUS PRODUCT FORMS

Product Form	Spec. No.
Plates	
Parts UCS and UHT	SA-20, S5
Part UHA	SA-480
Pipe	SA-333
Tubes	SA-334
Forgings	SA-350
Castings	SA-352
Bolting materials (and bars)	SA-320
Piping fittings	SA-420

TABLE UG-84.4
IMPACT TEST TEMPERATURE DIFFERENTIAL

Minimum Specified Yield Strength, ksi (MPa)	Temperature Difference, °F (°C) [Note (1)]
≤40 (276)	10 (6)
≤55 (380)	5 (3)
>55 (380)	0 (0)

NOTE:
(1) Impact test temperature may be warmer than the minimum design temperature by the amount shown.

including heat treatment, were used for all of the lot. When the part is too small to provide the three specimens of at least minimum size shown in Fig. UG-84, no impact test need be made.

UG-84(e)(3) Small Vessels. For small vessels in conformance with U-1(j), one set of impact specimens of the material may represent all vessels from the same heat of material not in excess of 100 vessels or one heat-treatment furnace batch, whichever is smaller.

UG-84(f) Impact Testing of Welds

UG-84(f)(1) For steel vessels of welded construction the impact toughness of welds and heat affected zones of procedure qualification test plates and vessel impact test plates (production impact test plates) shall be determined as required herein.

UG-84(f)(2) All test plates shall be subjected to heat treatment, including cooling rates and aggregate time at temperature or temperatures as established by the Manufacturer for use in actual manufacture. Heat treatment requirements of UG-85, UCS-85, UHT-81, and UHT-82 shall apply to the test plates except that the provisions of UCS-85(f) are not applicable to test plates for welds joining P-No. 3, Gr. Nos. 1 and 2 materials.

UG-84(g) Location, Orientation, Temperature, and Values of Weld Impact Tests. All weld impact tests shall comply with the following.

UG-84(g)(1) Each set of weld metal impact specimens shall be taken across the weld with the notch in the weld metal. Each specimen shall be oriented so that the notch is normal to the surface of the material and one face of the specimen shall be within $^1/_{16}$ in. (1.6 mm) of the surface of the material.

UG-84(g)(2) Each set of heat affected zone impact specimens shall be taken across the weld and of sufficient length to locate, after etching, the notch in the heat affected zone. The notch shall be cut approximately normal to the material surface in such a manner as to include as much heat affected zone material as possible in the resulting fracture.

UG-84(g)(3) For welds made by a solid-state welding process, such as for electric resistance welded (ERW) pipe, the weld impact tests shall consist only of one set of three specimens taken across the weld with the notch at the weld center line. Each specimen shall be oriented so that the notch is normal to the surface of the material and one face of the specimen shall be within $^1/_{16}$ in. (1.6 mm) of the surface of the material. The weld impact tests are not required if the weld and the base metal have been: annealed, normalized, normalized and tempered, double normalized and tempered, or quenched and tempered.

UG-84(g)(4) The test temperature for welds and heat affected zones shall not be higher than required for the base materials.

UG-84(g)(5) Impact values shall be at least as high as those required for the base materials.

UG-84(h) Impact Tests of Welding Procedure Qualifications

UG-84(h)(1) General. For steel vessels of welded construction, the impact toughness of the welds and heat affected zones of the procedure qualification test plates shall be determined in accordance with (g) above and the following subparagraphs.

UG-84(h)(2) When Required. Welding procedure impact tests shall be made when required by UCS-67, UHT-82, or UHA-51. For vessels constructed to the rules of Part UCS, the test plate material shall satisfy all of the following requirements relative to the material to be used in production:

(a) be of the same P-Number and Group Number;

(b) be in the same heat treated condition; and

(c) meet the minimum notch toughness requirements of UG-84(c)(4) for the thickest material of the

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range of base material qualified by the procedure (see Fig. UG-84.1).

If impact tests are required for the deposited weld metal, but the base material is exempted from impact tests (as in UHA-51), welding procedure test plates shall be made. The test plate material shall be material of the same P-Number and Group Number used in the vessel. One set of impact specimens shall be taken with the notch approximately centered in the weld metal and perpendicular to the surface; the heat affected zone need not be impact tested.

When the welding procedure employed for production welding is used for fillet welds only, it shall be qualified by a groove weld qualification test. The qualification test plate or pipe material shall meet the requirements of (a), (b), and (c) above when impact testing is a requirement. This welding procedure test qualification is in addition to the requirements of Section IX, QW-202.2 for P-No. 11 materials.

UG-84(h)(3) Material Over 1½ in. (38 mm) Thick. When procedure tests are made on material over 1½ in. (38 mm) in thickness, three sets of impact specimens are required. One set of heat affected zone specimens shall be taken as described in (g)(2) above. Two sets of impact specimens shall be taken from the weld with one set located near [within 1/16 in. (1.6 mm)] the surface of one side of the material and one set taken as near as practical midway between the surface and the center of thickness of the opposite side as described in (g) above.

UG-84(h)(4) Essential Variables. The additional essential variables specified in Section IX, QW-250, for impact testing are required.

UG-84(i) Vessel (Production) Impact Test Plates

UG-84(i)(1) General. In addition to the requirements of (h) above, impact tests of welds and heat affected zones shall be made in accordance with (g) above for each qualified welding procedure used on each vessel or group of vessels as defined in (3) below. The vessel impact test plate shall be from one of the heats of steel used for the vessel or group of vessels. For Category A joints, the test plate shall, where practicable, be welded as an extension to the end of a production joint so that the test plate weldment will represent as nearly as practicable the quality and type of welding in the vessel joint. For Category B joints that are welded using a different welding procedure than used on Category A joints, a test plate shall be welded under the production welding conditions used for the vessel, using the same type of equipment and at the same location and using the same procedures as used for the joint, and it shall be welded concurrently with the production welds or as close to the start of production welding as practicable.

UG-84(i)(2) When Required. Vessel (production) impact test plates shall be made for all joints for which impact tests are required for the welding procedure by UCS-67, UHT-82, or UHA-51 (except where production test plates are specifically exempt by these paragraphs). Test shall be made of the weld metal and/or heat affected zone to the extent required by the procedure test (see UCS-67 and UHA-51).

UG-84(i)(3) Number of Vessel Impact Test Plates Required

(a) For each vessel, one test plate shall be made for each welding procedure used for joints of Categories A and B, unless the vessel is one of several as defined in (b) or (c) below.

In addition, for Category A and B joints the following requirements shall apply.

(1) If automatic or semiautomatic welding is performed, a test plate shall be made in each position employed in the vessel welding.

(2) If manual welding is also employed, a test plate shall be made in the flat position only, except if welding is to be performed in other positions a test plate need be made in the vertical position only (where the major portions of the layers of welds are deposited in the vertical upward direction). The vertically welded test plate will qualify the manual welding in all positions.

(b) For several vessels or parts of vessels, welded within any 3 month period at one location, the plate thickness of which does not vary by more than ¼ in. (6 mm), or 25%, whichever is greater, and of the same specification and grade of material, a test plate shall be made for each 400 ft (122 m) of joints welded by the same procedure.

(c) For small vessels not exceeding the volume limitations defined in U-1(j) made from one heat of material requiring impact tests, one welded test joint made from the same heat of material and welded with the same electrode and the same welding procedure may represent one lot of 100 vessels or less, or each heat treatment furnace batch, whichever is smaller.

UG-84(j) Rejection. If the vessel test plate fails to meet the impact requirements, the welds represented by the plate shall be unacceptable. Reheat treatment and retesting or retesting only are permitted.

UG-85 HEAT TREATMENT

When plate specification heat treatments are not performed by the material manufacturer, they shall be

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performed by, or be under the control of, the fabricator who shall then place the letter "T" following the letter "G" in the Mill plate marking (see SA-20) to indicate that the heat treatments required by the material specification have been performed. The fabricator shall also document in accordance with UG-93(b) that the specified heat treatment has been performed.

UCS-85, UHT-5(e), and UHT-81 provide requirements for heat treatment of test specimens.

INSPECTION AND TESTS

UG-90 GENERAL

(a) The inspection and testing of pressure vessels to be marked with the Code U Symbol and the testing of vessels to be marked with the Code UM Symbol shall conform to the general requirements for inspection and testing in the following paragraphs and in addition to the specific requirements for *Inspection and Tests* given in the applicable Parts of Subsections B and C.

(b) The Manufacturer has the responsibility of assuring that the quality control, the detailed examinations, and the tests required by this Division are performed. The Manufacturer shall perform his specified duties. See UG-92 and 10-15. Some, but not all, of these responsibilities, which are defined in the applicable rules, are summarized as follows:

(1) the Certificate of Authorization from the ASME Boiler and Pressure Vessel Committee authorizing the Manufacturer to fabricate the class of vessel being constructed [UG-117(a)];

(2) the drawings and design calculations for the vessel or part [10-5 and 10-15(d)];

(3) identification for all material used in the fabrication of the vessel or part (UG-93);

(4) securing Partial Data Reports [UG-120(c)];

(5) access for the Inspector in accordance with UG-92 and 10-15;

(6) examination of all materials before fabrication to make certain they have the required thickness, to detect defects [UG-93(d)], to make certain the materials are permitted by this Division (UG-4), and that traceability (UG-77) to the material identification (UG-93) has been maintained;

(7) documentation of impact tests when such tests are required (UF-5, UCS-66, UHA-51, UHT-6, and ULT-5);

(8) concurrence of the Inspector prior to any repairs (UG-78, UW-38, UF-37, and UF-38);

(9) examination of the shell and head sections to confirm they have been properly formed to the specified shapes within the permissible tolerances (UG-79, UG-80, UG-81, UF-27, and UF-29);

(10) qualification of the welding and/or brazing procedures before they are used in fabrication [UG-84(h), UW-28(b), and UB-31];

(11) qualification of welders and welding operators and brazers before using the welders or brazers in production work (UW-29, UW-48, UB-32, and UB-43);

(12) examination of all parts prior to joining to make certain they have been properly fitted for welding or brazing and that the surfaces to be joined have been cleaned and the alignment tolerances are maintained (UW-31, UW-32, UW-33, and UB-17);

(13) examination of parts as fabrication progresses, for material marking (UG-94), that defects are not evident (UG-95), and that dimensional geometries are maintained (UG-96 and UF-30);

(14) provision of controls to assure that all required heat treatments are performed (UW-2, UW-10, UG-85, UF-31, and 10-11);

(15) provision of records of nondestructive testing examinations performed on the vessel or vessel parts. This shall include retaining the radiographic film if radiographic examinations are performed (UW-51, UW-52, and 10-10);

(16) making the required hydrostatic or pneumatic test and having the required inspection performed during such test (UG-99, UG-100, and UW-50);

(17) applying the required stamping and/or nameplate to the vessel and making certain it is applied to proper vessel (UG-116, UG-118, and UG-119);

(18) preparing required Manufacturer's Data Report and having it certified by the Inspector (UG-120);

(19) providing for retention of radiographs (UW-51), ultrasonic test reports (12-4), and Manufacturer's Data Reports (UG-120).

(c)(1) The Inspector shall make all inspections specifically required of him plus such other inspections as he believes are necessary to enable him to certify that all vessels which he authorizes to be stamped with the Code Symbol have been designed and constructed in accordance with the requirements of this Division. Some, but not all, of the required inspections and verifications, which are defined in the applicable rules, are summarized as follows:

(a) verifying that the Manufacturer has a valid Certificate of Authorization [UG-117(a)] and is working to a Quality Control System [UG-117(e)];

(b) verifying that the applicable design calculations are available [U-2(b), U-2(c), 10-5, and 10-15(d)];

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(c) verifying that materials used in the construction of the vessel comply with the requirements of UG-4 through UG-14 (UG-93);

(d) verifying that all welding and brazing procedures have been qualified (UW-28, UW-47, and UB-42);

(e) verifying that all welders, welding operators, brazers, and brazing operators have been qualified (UW-29, UW-48, and UB-43);

(f) verifying that the heat treatments, including PWHT, have been performed (UG-85, UW-10, UW-40, UW-49, and UF-52);

(g) verifying that material imperfections repaired by welding were acceptably repaired [UG-78, UW-52(d)(2)(c), UF-37, and UF-47(c)];

(h) verifying that weld defects were acceptably repaired [UW-51(c) and UW-52(c)];

(i) verifying that required nondestructive examinations, impact tests, and other tests have been performed and that the results are acceptable (UG-84, UG-93, UW-50, UW-51, UW-52, and UB-44);

(j) making a visual inspection of vessel to confirm that the material identification numbers have been properly transferred (UG-77 and UG-94);

(k) making a visual inspection of the vessel to confirm that there are no material or dimensional defects (UG-95, UG-96, and UG-97);

(l) performing internal and external inspections and witnessing the hydrostatic or pneumatic tests (UG-96, UG-97, UG-99, UG-100, and UG-101);

(m) verifying that the required marking is provided (UG-115) and that any nameplate has been attached to the proper vessel;

(n) signing the Certificate of Inspection on the Manufacturer's Data Report when the vessel, to the best of his knowledge and belief, is in compliance with all the provisions of this Division.

(2) When multiple, duplicate pressure vessel fabrication makes it impracticable for the Inspector to personally perform each of his required duties,[33] the Manufacturer, in collaboration with the Inspector, shall prepare an inspection and quality control procedure setting forth, in complete detail, the method by which the requirements[33] of this Division will be maintained. This procedure shall be included in the Manufacturer's written Quality Control System [see UG-117(e)]. This procedure shall be submitted to and shall have received the acceptance of the inspection agency. It shall then be submitted by the inspection agency for written acceptance by the legal jurisdiction concerned [see UG-117(f)] and by an ASME Designee. The joint reviews required by UG-117(f) shall include an ASME Designee. The inspection procedure shall be used in the plant of the named Manufacturer by the inspection agency submitting it, and shall be carried out by an Inspector in the employ of that inspection agency. Any changes in this inspection and quality control procedure which affect the requirements of this Division are subject to review and acceptance by the parties required for a joint review. The Data Report for such a vessel shall include under "Remarks" the statement: "Constructed under the provisions of UG-90(c)(2)."

[33] See UG-90(b) and UG-90(c)(1) for summaries of the responsibilities of the Manufacturer and the duties of the Inspector.

UG-91 THE INSPECTOR

(a) All references to *Inspectors* throughout this Division mean the Authorized Inspector as defined in this paragraph. All inspections required by this Division of Section VIII shall be:

(1) by an Inspector regularly employed by an ASME accredited Authorized Inspection Agency,[34] i.e., the inspection organization of a state or municipality of the United States, a Canadian province, or an insurance company authorized to write boiler and pressure vessel insurance, except that

(2) inspections may be by the regularly employed user's Inspector in the case of a User-Manufacturer which manufactures pressure vessels exclusively for its own use and not for resale [see UG-116(a)(1)].

Except as permitted in (2) above, the Inspector shall not be in the employ of the Manufacturer. All Inspectors shall have been qualified by a written examination under the rules of any state of the United States or province of Canada which has adopted the Code.

(b) In addition to the duties specified, the Inspector has the duty to monitor the Manufacturer's Quality Control System as required in Appendix 10.

UG-92 ACCESS FOR INSPECTOR

The Manufacturer of the vessel shall arrange for the Inspector to have free access to such parts of all plants as are concerned with the supply or manufacture of materials for the vessel, when so requested. The Inspector shall be permitted free access, at all times while work on the vessel is being performed, to all parts of the Manufacturer's shop that concern the construction

[34] Whenever *Authorized Inspection Agency* or *AIA* is used in this Code, it shall mean an Authorized Inspection Agency accredited by ASME in accordance with the requirements in the latest edition of ASME QAI-1.

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of the vessel and to the site of field erected vessels during the period of assembly and testing of the vessel. The Manufacturer shall keep the Inspector informed of the progress of the work and shall notify him reasonably in advance when vessels will be ready for any required tests or inspections.

UG-93 INSPECTION OF MATERIALS

(a) Except as otherwise provided in UG-4(b), UG-10, UG-11, or UG-15, requirements for acceptance of materials furnished by the material manufacturer or material supplier in complete compliance with a material specification of Section II shall be as follows.

(1) For plates, the vessel Manufacturer shall obtain the material test report or certificate of compliance as provided for in the material specification and the Inspector shall examine the Material Test Report or certificate of compliance and shall determine that it represents the material and meets the requirements of the material specification.

(2) For all other product forms, the material shall be accepted as complying with the material specification if the material specification provides for the marking of each piece with the specification designation, including the grade, type, and class if applicable, and each piece is so marked.

(3) If the material specification does not provide for the marking of each piece as indicated in (a)(2) above, the material shall be accepted as complying with the material specification provided the following requirements are met.

(a) Each bundle, lift, or shipping container is marked with the specification designation, including the grade, type, and class if applicable by the material manufacturer or supplier.

(b) The handling and storage of the material by the vessel Manufacturer shall be documented in his Quality Control System such that the Inspector can determine that it is the material identified in (a)(3)(a) above. Traceability to specific lot, order, or heat is not required. Traceability is required only to material specification and grade and type and class, if applicable.

(4) For pipe or tube where the length is not adequate for the complete marking in accordance with the material specification or not provided in accordance with (a)(3) above, the material shall be acceptable as complying with the material specification provided the following are met:

(a) a coded marking is applied to each piece of pipe or tube by the material manufacturer or material supplier; and

(b) the coded marking applied by the material manufacturer or material supplier is traceable to the specification designation, including the grade, type, and class if applicable.

(b) Except as otherwise provided in UG-4(b), UG-10, UG-11, or UG-15, when some requirements of a material specification of Section II have been completed by other than the material manufacturer [see UG-84(d) and UG-85], then the vessel Manufacturer shall obtain supplementary material test reports or certificates of compliance and the Inspector shall examine these documents and shall determine that they represent the material and meet the requirements of the material specification.

(c) When requirements or provisions of this Division applicable to materials exceed or supplement the requirements of the material specification of Section II (see UG-24, UG-84, and UG-85), then the vessel Manufacturer shall obtain supplementary material test reports or certificates of compliance and the Inspector shall examine these documents and shall determine that they represent the material and meet the requirements or provisions of this Division.

(d) All materials to be used in constructing a pressure vessel shall be examined before fabrication for the purpose of detecting, as far as possible, imperfections which would affect the safety of the vessel.

(1) Particular attention should be given to cut edges and other parts of rolled plate which would disclose the existence of serious laminations, shearing cracks, and other imperfections.

(2) All materials that are to be tested in accordance with the requirements of UG-84 shall be inspected for surface cracks.

(3) When a pressure part is to be welded to a flat plate thicker than $\frac{1}{2}$ in. (13 mm) to form a corner joint under the provision of UW-13(e), the weld joint preparation in the flat plate shall be examined before welding as specified in (d)(4) below by either the magnetic particle or liquid penetrant methods. After welding, both the peripheral edge of the flat plate and any remaining exposed surface of the weld joint preparation shall be reexamined by the magnetic particle or liquid penetrant methods as specified in (d)(4) below. When the plate is nonmagnetic, only the liquid penetrant method shall be used. The requirements of this paragraph shall not apply to those joints when 80% or more of the pressure load is carried by tubes, stays, or braces.

(4) For Fig. UW-13.2 the weld joint preparation and the peripheral edges of flat plate forming a corner joint shall be examined as follows:

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(a) the weld edge preparation of typical weld joint preparations in the flat plate as shown in sketches (b), (c), (d), (f), and (n);

(b) the outside peripheral edge of the flat plate after welding as shown in sketches (a), (b), (c), and (d);

(c) the outside peripheral edge of the flat plate after welding, as shown in sketches (e), (f), and (g) if the distance from the edge of the completed weld to the peripheral edge of the flat plate is less than the thickness of the flat plate such as defined in UG-34(b);

(d) the inside peripheral surface of the flat plate after welding as shown in sketches (m) and (n);

(e) no examination is required on the flat plate as shown in sketches (h), (i), (j), (k), and (l).

(e) The Inspector shall assure himself that the thickness and other dimensions of material comply with the requirements of this Division.

(f) The Inspector shall satisfy himself that the inspection and marking requirements of UG-24 have been complied with for those castings assigned a casting quality factor exceeding 80%.

UG-94 MARKING ON MATERIALS

The Inspector shall inspect materials used in the construction to see that they bear the identification required by the applicable material specification, except as otherwise provided in UG-4(b), UG-10, UG-11, UG-15, or UG-93. Should the identifying marks be obliterated or the material be divided into two or more parts, the marks shall be properly transferred by the manufacturer as provided in UG-77(a). See UG-85.

UG-95 EXAMINATION OF SURFACES DURING FABRICATION

As fabrication progresses, all materials used in the construction shall be examined for imperfections that have been uncovered during fabrication as well as to determine that the work has been done properly.

UG-96 DIMENSIONAL CHECK OF COMPONENT PARTS

(a) The Manufacturer shall examine the pressure retaining parts to make certain they conform to the prescribed shape and meet the thickness requirements after forming. The Manufacturer of the vessel shall furnish accurately formed templates as required by the Inspector for verification. See UG-80.

(b) Before attaching nozzles, manhole frames, nozzle reinforcement and other appurtenances to the inside or outside of the vessel they shall be examined to make certain they properly fit the vessel curvature. See UG-82.

(c) The Inspector shall satisfy himself that the above dimensional requirements have been met. This shall include making such dimensional measurements as he considers necessary.

UG-97 INSPECTION DURING FABRICATION

(a) When conditions permit entry into the vessel, as complete an examination as possible shall be made before final closure.

(b) The Inspector shall make an external inspection of the completed vessel at the time of the final hydrostatic test or pneumatic test.

(c) All welds, including the nozzle welds, of homogeneously lead-lined vessels shall be visually inspected on the inside prior to application of lining. A visual examination of the lining shall be made after completion to assure that there are no imperfections which might impair the integrity of the lining and subject the vessel to corrosion effects.

UG-98 MAXIMUM ALLOWABLE WORKING PRESSURE

UG-98(a) The maximum allowable working pressure for a vessel is the maximum pressure permissible at the top of the vessel in its normal operating position at the designated coincident temperature specified for that pressure. It is the least of the values found for maximum allowable working pressure for any of the essential parts of the vessel by the principles given in (b) below, and adjusted for any difference in static head that may exist between the part considered and the top of the vessel. (See 3-2.)

UG-98(b) The maximum allowable working pressure for a vessel part is the maximum internal or external pressure, including the static head thereon, as determined by the rules and formulas in this Division, together with the effect of any combination of loadings listed in UG-22 which are likely to occur, for the designated coincident temperature, excluding any metal thickness specified as corrosion allowance. See UG-25.

UG-98(c) Maximum allowable working pressure may be determined for more than one designated operating temperature, using for each temperature the applicable allowable stress value.

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UG-99 STANDARD HYDROSTATIC TEST

(a) A hydrostatic test shall be conducted on all vessels after:

(1) all fabrication has been completed, except for operations which could not be performed prior to the test such as weld end preparation [see U-1(e)(1)(a)], cosmetic grinding on the base material which does not affect the required thickness; and

(2) all examinations have been performed, except those required after the test.

The completed vessels, except those tested in accordance with the requirements of UG-100 and UG-101, shall have satisfactorily passed the hydrostatic test prescribed in this paragraph.

(b) Except as otherwise permitted in (a) above and 27-3, vessels designed for internal pressure shall be subjected to a hydrostatic test pressure which at every point in the vessel is at least equal to 1.3 times the maximum allowable working pressure[35] to be marked on the vessel multiplied by the lowest ratio (for the materials of which the vessel is constructed) of the stress value *S* for the test temperature on the vessel to the stress value *S* for the design temperature (see UG-21). All loadings that may exist during this test shall be given consideration.

(c) A hydrostatic test based on a calculated pressure may be used by agreement between the user and the manufacturer. The hydrostatic test pressure at the top of the vessel shall be the minimum of the test pressures calculated by multiplying the basis for calculated test pressure as defined in 3-2 for each pressure element by 1.3 and reducing this value by the hydrostatic head on that element. When this pressure is used, the Inspector shall reserve the right to require the manufacturer or the designer to furnish the calculations used for determining the hydrostatic test pressure for any part of the vessel.

(d) The requirements of (b) above represent the minimum standard hydrostatic test pressure required by this Division. The requirements of (c) above represent a special test based on calculations. Any intermediate value of pressure may be used. This Division does not specify an upper limit for hydrostatic test pressure. However, if the hydrostatic test pressure is allowed to exceed, either intentionally or accidentally, the value determined as prescribed in (c) above to the degree that the vessel is subjected to visible permanent distortion, the Inspector shall reserve the right to reject the vessel.

(e) Combination units [see UG-19(a) and UG-21] shall be tested by one of the following methods.

(1) Pressure chambers of combination units that have been designed to operate independently shall be hydrostatically tested as separate vessels, that is, each chamber shall be tested without pressure in the adjacent chamber. If the common elements of a combination unit are designed for a larger differential pressure than the higher maximum allowable working pressure to be marked on the adjacent chambers, the hydrostatic test shall subject the common elements to at least their design differential pressure, corrected for temperature as in (b) above, as well as meet the requirements of (b) or (c) above for each independent chamber.

(2) When pressure chambers of combination units have their common elements designed for the maximum differential pressure that can possibly occur during startup, operation, and shutdown, and the differential pressure is less than the higher pressure in the adjacent chambers, the common elements shall be subjected to a hydrostatic test pressure of at least 1.3 times the differential pressure to be marked on the unit, corrected for temperature as in UG-99(b).

Following the test of the common elements and their inspection as required by (g) below, the adjacent chambers shall be hydrostatically tested simultaneously [see (b) or (c) above]. Care must be taken to limit the differential pressure between the chambers to the pressure used when testing the common elements.

The vessel stamping and the vessel Data Report must describe the common elements and their limiting differential pressure. See UG-116(j) and UG-120(b).

(f) Single-wall vessels designed for a vacuum or partial vacuum only, and chambers of multichamber vessels designed for a vacuum or partial vacuum only, shall be subjected to an internal hydrostatic test or when a hydrostatic test is not practicable, to a pneumatic test in accordance with the provisions of UG-100. Either type of test shall be made at a pressure not less than 1.3 times the difference between normal atmospheric pressure and the minimum design internal absolute pressure.

(g) Following the application of the hydrostatic test pressure, an inspection shall be made of all joints and connections. This inspection shall be made at a pressure not less than the test pressure divided by 1.3. Except for leakage that might occur at temporary test closures for those openings intended for welded connections, leakage is not allowed at the time of the required visual inspection. Leakage from temporary seals shall

[35] The maximum allowable working pressure may be assumed to be the same as the design pressure when calculations are not made to determine the maximum allowable working pressure.

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be directed away so as to avoid masking leaks from other joints.

The visual inspection of joints and connections for leaks at the test pressure divided by 1.3 may be waived provided:

(1) a suitable gas leak test is applied;

(2) substitution of the gas leak test is by agreement reached between Manufacturer and Inspector;

(3) all welded seams which will be hidden by assembly be given a visual examination for workmanship prior to assembly;

(4) the vessel will not contain a "lethal" substance.

(h) Any nonhazardous liquid at any temperature may be used for the hydrostatic test if below its boiling point. Combustible liquids having a flash point less than 110°F (43°C), such as petroleum distillates, may be used only for near atmospheric temperature tests. It is recommended that the metal temperature during hydrostatic test be maintained at least 30°F (17°C) above the minimum design metal temperature, but need not exceed 120°F (48°C), to minimize the risk of brittle fracture. [See UG-20 and General Note (6) to Fig. UCS-66.2.] The test pressure shall not be applied until the vessel and its contents are at about the same temperature. If the test temperature exceeds 120°F (48°C), it is recommended that inspection of the vessel required by (g) above be delayed until the temperature is reduced to 120°F (48°C) or less.

CAUTION: A small liquid relief valve set to $1\frac{1}{3}$ times the test pressure is recommended for the pressure test system, in case a vessel, while under test, is likely to be warmed up materially with personnel absent.

(i) Vents shall be provided at all high points of the vessel in the position in which it is to be tested to purge possible air pockets while the vessel is filling.

(j) Before applying pressure, the test equipment shall be examined to see that it is tight and that all low-pressure filling lines and other appurtenances that should not be subjected to the test pressure have been disconnected.

(k) Vessels, except for those in lethal service, may be painted or otherwise coated either internally or externally, and may be lined internally, prior to the pressure test. However, the user is cautioned that such painting/coating/lining may mask leaks that would otherwise have been detected during the pressure test.

UG-100 PNEUMATIC TEST[36] (SEE UW-50)

(a) Subject to the provisions of UG-99(a)(1) and (a)(2), a pneumatic test prescribed in this paragraph may be used in lieu of the standard hydrostatic test prescribed in UG-99 for vessels:

(1) that are so designed and/or supported that they cannot safely be filled with water;

(2) not readily dried, that are to be used in services where traces of the testing liquid cannot be tolerated and the parts of which have, where possible, been previously tested by hydrostatic pressure to the pressure required in UG-99.

(b) Except for enameled vessels, for which the pneumatic test pressure shall be at least equal to, but need not exceed, the maximum allowable working pressure to be marked on the vessel, the pneumatic test pressure shall be at least equal to 1.1 times the maximum allowable working pressure to be stamped on the vessel multiplied by the lowest ratio (for the materials of which the vessel is constructed) of the stress value *S* for the test temperature of the vessel to the stress value *S* for the design temperature (see UG-21). In no case shall the pneumatic test pressure exceed 1.1 times the basis for calculated test pressure as defined in 3-2.

(c) The metal temperature during pneumatic test shall be maintained at least 30°F (17°C) above the minimum design metal temperature to minimize the risk of brittle fracture. [See UG-20 and General Note (6) to Fig. UCS-66.2.]

(d) The pressure in the vessel shall be gradually increased to not more than one-half of the test pressure. Thereafter, the test pressure shall be increased in steps of approximately one-tenth of the test pressure until the required test pressure has been reached. Then the pressure shall be reduced to a value equal to the test pressure divided by 1.1 and held for a sufficient time to permit inspection of the vessel. Except for leakage that might occur at temporary test closures for those openings intended for welded connections, leakage is not allowed at the time of the required visual inspection.

[36] In some cases it is desirable to test vessels when partly filled with liquids. For such vessels a combined hydrostatic and pneumatic test may be used as an alternative to the pneumatic test of this paragraph, provided the liquid level is set so that the maximum stress including the stress produced by pneumatic pressure at any point in the vessel (usually near the bottom) or in the support attachments, does not exceed 1.3 times the allowable stress value of the material multiplied by the applicable joint efficiency. After setting the liquid level to meet this condition, the test is conducted as prescribed in (b) and (c) above.

Air or gas is hazardous when used as a testing medium. It is therefore recommended that special precautions be taken when air or gas is used for test purposes.

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Leakage from temporary seals shall be directed away so as to avoid masking leaks from other joints.

The visual inspection of the vessel at the required test pressure divided by 1.1 may be waived provided:

(1) a suitable gas leak test is applied;

(2) substitution of the gas leak test is by agreement reached between Manufacturer and Inspector;

(3) all welded seams which will be hidden by assembly be given a visual examination for workmanship prior to assembly;

(4) the vessel will not contain a "lethal" substance.

(e) Vessels, except for those in lethal service, may be painted or otherwise coated either internally or externally, and may be lined internally, prior to the pressure test. However, the user is cautioned that such painting/coating/lining may mask leaks that would otherwise have been detected during the pressure test.

UG-101 PROOF TESTS TO ESTABLISH MAXIMUM ALLOWABLE WORKING PRESSURE

UG-101(a) General

UG-101(a)(1) The maximum allowable working pressure for vessels or vessel parts for which the strength cannot be computed with a satisfactory assurance of accuracy (see U-2) shall be established in accordance with the requirements of this paragraph, using one of the test procedures applicable to the type of loading and to the material used in construction.

UG-101(a)(2) Provision is made in these rules for two types of tests to determine the internal maximum allowable working pressure:

(a) tests based on yielding of the part to be tested. These tests are limited to materials with a ratio of minimum specified yield to minimum specified ultimate strength of 0.625 or less.

(b) tests based on bursting of the part.

UG-101(a)(3) Safety of testing personnel should be given serious consideration when conducting proof tests, and particular care should be taken during bursting tests in (m) below.

UG-101(b) The tests in these paragraphs may be used only for the purpose of establishing the maximum allowable working pressure of those elements or component parts for which the thickness cannot be determined by means of the design rules given in this Division. The maximum allowable working pressure of all other elements or component parts shall not be greater than that determined by means of the applicable design rules.

Tests to establish the maximum allowable working pressure of vessels, or vessel parts, shall be witnessed by and be acceptable to the Inspector, as indicated by his signature on the Manufacturer's report of the test. The report shall include sufficient detail to describe the test, the instrumentation and the methods of calibration used, and the results obtained. The report shall be made available to the Inspector for each application [see U-2(b) and UG-90(2)].

UG-101(c) The vessel or vessel part for which the maximum allowable working pressure is to be established shall not previously have been subjected to a pressure greater than 1.3 times the desired or anticipated maximum allowable working pressure, adjusted for operating temperature as provided in (k) below.

UG-101(d) Duplicate and Similar Parts. When the maximum allowable working pressure of a vessel or vessel part has been established by a proof test, duplicate parts, or geometrically similar parts, that meet all of the requirements in (d)(1) or (d)(2) below, need not be proof tested but shall be given a hydrostatic pressure test in accordance with UG-99, or a pneumatic pressure test in accordance with UG-100, except as otherwise provided in UCI-101, and UCD-101.

UG-101(d)(1) Duplicate Parts. All of the following requirements shall be met in order to qualify a part as a duplicate of the part that had been proof tested:

(a) same basic design configuration and type of construction;

(b) the material of the duplicate part is either:

(1) the same material specifications:

(a) alloy;

(b) grade, class;

(c) type, form;

(d) heat treatment; or

(2) the same or closely similar material when only the material specification, the alloy, grade, or form is different, provided the material meets the following additional requirements:

(a) has allowable stress in tension equal to or greater than the material used in the proof tested part at the test temperature [see (k) below];

(b) has the same P-Number (Section IX);

(c) for carbon or low alloy steels (Part UCS), has the same or tougher material grouping in UCS-66, Fig. UCS-66, and Notes;

(c) the nominal dimensions, diameter, or width and height, of the duplicate parts shall be the same, and the corresponding nominal thicknesses shall be the same as those used in the proof test. The length shall not be longer than that proof tested.

(d) heat treatment shall be the same as performed on the original part that was tested;

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(e) the MAWP shall be calculated according to (e) below;

(f) when there are permissible deviations from the original part that was proof tested, a supplement to the original Proof Test Report shall be prepared that states and evaluates each deviation.

UG-101(d)(2) Geometrically Similar Parts. The maximum allowable working pressure for geometrically similar parts may be established by a series of proof tests that uniformly cover the complete range of sizes, pressure, or other variables by interpolation from smooth curves plotted from the results of the tests.[37]

(a) Sufficient tests shall be performed to provide at least five data points that are at increments that are within 20% to 30% of the range covered.

(b) The curves shall be based on the lower bound of the test data.

(c) Extrapolation is not permitted.

UG-101(e) Proof test methods UG-101(l), (m), (n), and (o) below establish a pressure at which the test is terminated. The results of the test are recorded in a Proof Test Report according to UG-101(b).

UG-101(e)(1) The MAWP for the first duplicate part, as defined in UG-101(d), to be put into service, shall be calculated according to the equations given in the proof test method applied.

The requirements for NDE are given in UG-24 and UW-12. Other requirements are based on thickness or material. These apply to parts which are to be put into service. It is not necessary to examine the part actually tested.

UG-101(e)(2) For subsequent duplicate parts, the MAWP may be recalculated for a different extent of NDE in a supplement to the original Proof Test Report.

UG-101(e)(3) The effect of the location of a weld joint may be evaluated and included in the Proof Test Report.

UG-101(f) A retest shall be allowed on a duplicate vessel or vessel part if errors or irregularities are obvious in the test results.

UG-101(g) In tests for determination of governing stresses, sufficient locations on the vessel shall be investigated to ensure that measurements are taken at the most critical areas. As a check that the measurements are being taken on the most critical areas, the Inspector may require a brittle coating to be applied on all areas of probable high stress concentrations in the test procedures given in (n) and (o) below. The surfaces shall be suitably cleaned before the coating is applied in order to obtain satisfactory adhesion. The technique shall be suited to the coating material.

NOTE: Strains should be measured as they apply to membrane stresses and to bending stresses within the range covered by UG-23(c).

UG-101(h) Application of Pressure. In the procedures given in (l), (n), and (o) below, the Displacement Measurement Test, the hydrostatic pressure in the vessel or vessel part shall be increased gradually until approximately one-half the anticipated working pressure is reached. Thereafter, the test pressure shall be increased in steps of approximately one-tenth or less of the anticipated maximum allowable working pressure until the pressure required by the test procedure is reached. The pressure shall be held stationary at the end of each increment for a sufficient time to allow the observations required by the test procedure to be made, and shall be released to zero to permit determination of any permanent strain after any pressure increment that indicates an increase in strain or displacement over the previous equal pressure increment.

UG-101(i) Corrosion Allowance. The test procedures in this paragraph give the maximum allowable working pressure for the thickness of material tested. The thickness of the pressure vessel that is to be proof tested should be the corroded thickness. When this is not practical and when the thickness as tested includes extra thickness as provided in UG-25, the maximum allowable working pressure at which the vessel shall be permitted to operate shall be determined by multiplying the maximum allowable working pressure obtained from the test by the ratio

$$(t - c)^n / t^n$$

where

t = nominal thickness of the material at the weakest point, in. (mm)

c = allowance added for corrosion, erosion, and abrasion, in. (mm)

n = 1 for curved surfaces such as parts of cylinders, spheres, cones with angle $\alpha \leq 60$ deg; for stayed surfaces similar to those described in UW-19(b) and (c); and parts whose stress due to bending is ≤67% of the total stress

n = 2 for flat or nearly flat surfaces, such as flat sides, flanges, or cones with angle $\alpha > 60$ deg (except for stayed surfaces noted above) unless it can be shown that the stress due to bending at the limiting location is <67% of the total stress

UG-101(j) Determination of Yield Strength and Tensile Strength

[37] Examples of the use of modeling techniques are found in UG-127(a)(1)(b)(2) and UG-131(d)(2)(b), or refer to text books on the subject.

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UG-101(j)(1) For proof tests based on yielding, (l), (n), or (o) below, the yield strength (or yield point for those materials which exhibit that type of yield behavior indicated by a "sharp-kneed" portion of the stress-strain diagram) of the material in the part tested shall be determined in accordance with the method prescribed in the applicable material specification and as described in ASTM E 8, Tension Testing of Metallic Materials. For proof tests based on bursting, [see (m) below], the tensile strength instead of the yield strength of the material in the part tested shall be similarly determined.

UG-101(j)(2) Yield or tensile strength so determined shall be the average from three or four specimens cut from the part tested after the test is completed. The specimens shall be cut from a location where the stress during the test has not exceeded the yield strength. The specimens shall not be flame cut because this might affect the strength of the material. If yield or tensile strength is not determined by test specimens from the pressure part tested, alternative methods are given in (l), (m), (n), and (o) below for evaluation of proof test results to establish the maximum allowable working pressure.

UG-101(j)(3) When excess stock from the same piece of wrought material is available and has been given the same stress relieving heat treatment as the pressure part, the test specimens may be cut from this excess stock. The specimen shall not be removed by flame cutting or any other method involving sufficient heat to affect the properties of the specimen. When the sheet material is used, test specimens obtained from another piece cut from the same coil of sheet used in the proof tested component meet the requirements of this paragraph.

UG-101(k) Maximum Allowable Working Pressure at Higher Temperatures. The maximum allowable working pressure for vessels and vessel parts that are to operate at temperatures at which the allowable stress value of the material is less than at the test temperature shall be determined by the following formula:

$$P_0 = P_t \frac{S}{S_2}$$

where

P_0 = maximum allowable working pressure at the design temperature, psi (kPa)

P_t = maximum allowable working pressure at test temperature, psi (kPa)

S = maximum allowable stress value at the design temperature, as given in the tables referenced in UG-23 but not to exceed S_2, psi (kPa)

S_2 = maximum allowable stress value for the material used in the test at test temperature as given in the tables referenced in UG-23, psi (kPa)

UG-101(l) Brittle-Coating Test Procedure

UG-101(l)(1) Subject to the limitations of (a)(2)(a) above, this procedure may be used only for vessels and vessel parts under internal pressure, constructed of materials having a definitely determinable yield point. The component parts that require proof testing shall be coated with a brittle coating in accordance with (g) above. Pressure shall be applied in accordance with (h) above. The parts being proof tested shall be examined between pressure increments for signs of yielding as evidenced by flaking of the brittle coating, or by the appearance of strain lines. The application of pressure shall be stopped at the first sign of yielding, or if desired, at some lower pressure.

UG-101(l)(2) The maximum allowable working pressure P in pounds per square inch at test temperature for parts tested under this paragraph shall be computed by one of the following formulas.

(a) If the average yield strength is determined in accordance with (j) above,

$$P = 0.5H \frac{S_y}{S_{y\,\mathrm{avg}}}$$

(b) To eliminate the necessity of cutting tensile specimens and determining the actual yield strength of the material under test, one of the following formulas may be used to determine the maximum allowable working pressure.

(1) For carbon steel meeting an acceptable Code specification, with a specified minimum tensile strength of not over 70,000 psi (480 MPa), for Customary units,

$$P = 0.5H \left(\frac{S_\mu}{S_\mu + 5000} \right)$$

for SI units,

$$P = 0.5H \left(\frac{S_\mu}{S_\mu + 34{,}285} \right)$$

(2) For any acceptable material listed in this Division,

$$P = 0.4H$$

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where

H = hydrostatic test pressure at which the test was stopped, psi (kPa)

S_y = specified minimum yield strength at room temperature, psi (kPa)

$S_{y\ \mathrm{avg}}$ = actual average yield strength from test specimens at room temperature, psi (kPa)

S_μ = specified minimum tensile strength at room temperature, psi (kPa)

When the formula in (l)(2)(b)(1) or (l)(2)(b)(2) above is used, the material in the pressure part shall have had no appreciable cold working or other treatment that would tend to raise the yield strength above the normal.

The maximum allowable working pressure at other temperatures shall be determined as provided in (k) above.

UG-101(m) Bursting Test Procedure

UG-101(m)(1) This procedure may be used for vessels or vessel parts under internal pressure when constructed of any material permitted to be used under the rules of this Division. The maximum allowable working pressure of any component part proof tested by this method shall be established by a hydrostatic test to failure by rupture of a full-size sample of such pressure part. The hydrostatic pressure at which rupture occurs shall be determined. Alternatively, the test may be stopped at any pressure before rupture that will satisfy the requirements for the desired maximum allowable working pressure.

UG-101(m)(2) The maximum allowable working pressure P in pounds per square inch (kilopascals) at test temperature for parts tested under this paragraph shall be computed by one of the following formulas:

01 *(a)* parts constructed of materials other than cast materials:

$$P = \frac{B}{4} \times \frac{S_\mu E}{S_{\mu\ \mathrm{avg}}} \quad \text{or} \quad P = \frac{B}{4} \times \frac{S_\mu E}{S_{\mu r}}$$

(b) parts constructed of cast iron — see UCI-101; parts constructed of cast ductile iron — see UCD-101;

01 *(c)* parts constructed of cast materials, except cast iron and ductile iron:

$$P = \frac{Bf}{4} \times \frac{S_\mu E}{S_{\mu\ \mathrm{avg}}} \quad \text{or} \quad P = \frac{Bf}{4} \times \frac{S_\mu E}{S_{\mu r}}$$

where

B = bursting test pressure, or hydrostatic test pressure at which the test was stopped, psi (kPa)

E = efficiency of welded joint, if used (see Table UW-12)

f = casting quality factor as specified in UG-24

S_μ = specified minimum tensile strength at room temperature, psi (kPa)

$S_{\mu\ \mathrm{avg}}$ = average actual tensile strength of test specimens at room temperature, psi (kPa)

$S_{\mu\ r}$ = maximum tensile strength of range of specification at room temperature, psi (kPa)

The maximum allowable working pressure at other temperatures shall be determined as provided in (k) above.

UG-101(n) Strain Measurement Test Procedure

UG-101(n)(1) Subject to limitations of (a)(2)(a) above, this procedure may be used for vessels or vessel parts under internal pressure, constructed of any material permitted to be used under the rules of this Division. Strains shall be measured in the direction of the maximum stress at the most highly stressed parts [see (g) above] by means of strain gages of any type capable of indicating incremental strains to 0.00005 in./in. (0.005%). It is recommended that the gage length be such that the expected maximum strain within the gage length does not exceed the expected average strain within the gage length by more than 10%. The strain gages and the method of attachment shall be shown by test to be reliable and the results documented for a range of strain values that is at least 50% higher than expected, when used with the material surface finish and configuration being considered. [See (e) above.]

UG-101(n)(2) Pressure shall be applied as provided in (h) above. After each increment of pressure has been applied, readings of the strain gages and the hydrostatic pressure shall be taken and recorded. The pressure shall be released and any permanent strain at each gage shall be determined after any pressure increment that indicates an increase in strain for this increment over the previous equal pressure increment. Only one application of each increment of pressure is required.

UG-101(n)(3) Two curves of strain against test pressure shall be plotted for each gage line as the test progresses, one showing the strain under pressure and one showing the permanent strain when the pressure is removed. The test may be discontinued when the test pressure reaches the value H which will, by the formula, justify the desired working pressure, but shall not exceed the pressure at which the plotted points for the most highly strained gage line reaches the value given below for the material used:

(a) 0.2% permanent strain for aluminum-base and nickel-base alloys;

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(b) 0.2% permanent strain for carbon low alloy and high alloy steels;

(c) 0.5% strain under pressure for copper-base alloys.

UG-101(n)(4) The maximum allowable working pressure P in pounds per square inch (kilopascals) at test temperature for parts tested under this paragraph shall be computed by one of the following formulas.

(a) If the average yield strength is determined in accordance with (j) above,

$$P = 0.5H\left(\frac{S_y}{S_{y\ \mathrm{avg}}}\right)$$

(b) If the actual average yield strength is not determined by test specimens,

$$P = 0.4H$$

where

H = hydrostatic test pressure at which the test was stopped in accordance with (n)(3) above, psi (kPa)

S_y = specified minimum yield strength at room temperature, psi (kPa)

$S_{y\ \mathrm{avg}}$ = actual average yield strength from test specimens at room temperature, psi (kPa)

The maximum allowable working pressure at other temperatures shall be determined as provided in (k) above.

UG-101(o) Displacement Measurement Test Procedure

UG-101(o)(1) Subject to the limitations of (a)(2)(a) above, this procedure may be used only for vessels and vessel parts under internal pressure, constructed of materials having a definitely determinable yield point. Displacement shall be measured at the most highly stressed parts [see (g) above] by means of measuring devices of any type capable of measuring to 0.001 in. (0.02 mm). The displacement may be measured between two diametrically opposed reference points in a symmetrical structure, or between a reference point and a fixed base point. Pressure shall be applied as provided in (h) above.

UG-101(o)(2) After each increment of pressure has been applied, readings of the displacement and hydrostatic test pressure shall be taken and recorded. The pressure shall be released and any permanent displacement shall be determined after any pressure increment that indicates an increase in measured displacement for this increment over the previous equal pressure increment. Only one application of each increment is required. Care must be taken to assure that the readings represent only displacements of the parts on which measurements are being made and do not include any slip of the measuring devices or any movement of the fixed base points or of the pressure part as a whole.

UG-101(o)(3) Two curves of displacement against test pressure shall be plotted for each reference point as the test progresses, one showing the displacement under pressure and one showing the permanent displacement when the pressure is removed. The application of pressure shall be stopped when it is evident that the curve through the points representing displacement under pressure has deviated from a straight line.

UG-101(o)(4) The pressure coincident with the proportional limit of the material shall be determined by noting the pressure at which the curve representing displacement under pressure deviates from a straight line. The pressure at the proportional limit may be checked from the curve of permanent displacement by locating the point where the permanent displacement begins to increase regularly with further increases in pressure. Permanent deformation at the beginning of the curve that results from the equalization of stresses and irregularities in the material may be disregarded.

UG-101(o)(5) The maximum allowable working pressure P in pounds per square inch (kilopascals) at test temperature for parts tested under this paragraph shall be computed by one of the following formulas.

(a) If the average yield strength is determined in accordance with (j) above,

$$P = 0.5H\left(\frac{S_y}{S_{y\ \mathrm{avg}}}\right)$$

(b) To eliminate the necessity of cutting tensile specimens and determining the actual yield strength of the material under test, one of the following formulas may be used to determine the maximum allowable working pressure.

(1) For carbon steel, meeting an acceptable Code specification, with a specified minimum tensile strength of not over 70,000 psi (480 MPa), for Customary units

$$P = 0.5H\left(\frac{S_\mu}{S_\mu + 5000}\right)$$

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for SI units,

$$P = 0.5H\left(\frac{S_\mu}{S_\mu + 34{,}285}\right)$$

(2) For any acceptable material listed in this Division,

$$P = 0.4H$$

where

H = hydrostatic test pressure coincident with the proportional limit of the weakest element of the component part tested, psi (kPa)

S_y = specified minimum yield strength at room temperature, psi (kPa)

$S_{y\ avg}$ = actual average yield strength from test specimens at room temperature, psi (kPa)

S_μ = specified minimum tensile strength at room temperature, psi (kPa)

When the formula in (o)(5)(b)(1) or (o)(5)(b)(2) above is used, the material in the pressure part shall have had no appreciable cold working or other treatment that would tend to raise the yield strength above the normal. The maximum allowable working pressure at other temperatures shall be determined as provided in (k) above.

UG-101(p) Procedure for Vessels Having Chambers of Special Shape Subject to Collapse

UG-101(p)(1) Pressure chambers of vessels, portions of which have a shape other than that of a complete circular cylinder or formed head, and also jackets of cylindrical vessels which extend over only a portion of the circumference, which are not fully staybolted as required by UG-28(i), shall withstand without excessive deformation a hydrostatic test of not less than three times the desired maximum allowable working pressure.

UG-101(p)(2) The maximum allowable working pressure at other temperatures shall be determined as provided in (k) above.

UG-102 TEST GAGES

(a) An indicating gage shall be connected directly to the vessel. If the indicating gage is not readily visible to the operator controlling the pressure applied, an additional indicating gage shall be provided where it will be visible to the operator throughout the duration of the test. For large vessels, it is recommended that a recording gage be used in addition to indicating gages.

(b) Dial indicating pressure gages used in testing shall be graduated over a range of about double the intended maximum test pressure, but in no case shall the range be less than $1\frac{1}{2}$ nor more than 4 times that pressure. Digital reading pressure gages having a wider range of pressure may be used provided the readings give the same or greater degree of accuracy as obtained with dial pressure gages.

(c) All gages shall be calibrated against a standard deadweight tester or a calibrated master gage. Gages shall be recalibrated at any time that there is reason to believe that they are in error.

UG-103 NONDESTRUCTIVE TESTING

Where magnetic particle examination is prescribed in this Division it shall be done in accordance with Appendix 6. Where liquid penetrant examination is prescribed it shall be done in accordance with Appendix 8.

MARKING AND REPORTS

UG-115 GENERAL

(a) The marking and certification of all pressure vessels built under this Division shall comply with the requirements of the following paragraphs and in addition with the requirements for *Marking and Reports* given in the applicable Parts of Subsections B and C.

(b) The units of measurement used in Manufacturer's Data Reports, Manufacturer's Certificates of Compliance (UG-120), and capacity certification of pressure relief devices, and in marking or stamping pressure vessels, pressure vessel parts, and pressure relief devices, required by this Division, shall be either:

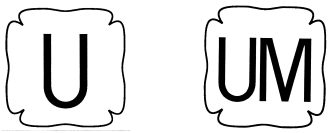
(1) U. S. Customary units (ft-lb) exclusively; or

(2) both U. S. Customary units (ft-lb) and metric, in which case the U. S. Customary units shall be considered the standard, and the metric units shall be shown parenthetically.

UG-116 REQUIRED MARKING

(a) Each pressure vessel shall be marked with the following:

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(a) (b)

FIG. UG-116 OFFICIAL SYMBOLS FOR STAMP TO DENOTE THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS' STANDARD

(1)(a) the official Code U Symbol shown in Fig. UG-116 sketch (a) on vessels inspected in accordance with the requirements in UG-90 through UG-97 (when inspected by a user's Inspector as provided in UG-91, the word USER shall be marked above the Code Symbol); or

(b) the official UM Symbol shown in Fig. UG-116 sketch (b) on vessels constructed in accordance with the provisions in U-1(j).

(2) name of the Manufacturer of the pressure vessel preceded by the words "certified by";

(3) maximum allowable working pressure[38,39] _____ psi at _____°F;

(4) minimum design metal temperature _____°F at maximum allowable working pressure _____ psi[38]

(5) Manufacturer's serial number;

(6) year built.

(b)(1) The type of construction used for the vessel shall be indicated directly under the Code Symbol by applying the appropriate letter(s) as follows: vessels having Category A, B, or C joints (except nozzles or other openings and their attachment) in or joining parts of the vessels:

Type of Construction	Letter(s)
Arc or gas welded	W
Pressure welded (except resistance)	P
Brazed	B
Resistance welded	RES

(2) Vessels embodying a combination of types of construction shall be marked to indicate all of the types of construction used.

(c) When a vessel is intended for special service and the special requirements have been complied with [see UG-120(d)], the appropriate lettering shall be applied as listed below:

Lethal Service	L
Unfired Steam Boiler	UB
Direct Firing	DF

This lettering shall be separated by a hyphen and applied after the lettering of (b) above.

(d) The maximum allowable working pressure and temperature to be indicated on vessels embodying a combination of types of construction and material shall be based on the most restrictive detail of construction and material used.

(e) When a vessel has been radiographed in accordance with UW-11, marking shall be applied under the Code Symbol as follows:

(1) "RT 1" when all pressure-retaining butt welds, other than Category B and C butt welds associated with nozzles and communicating chambers that neither exceed NPS 10 (DN 250) nor $1\frac{1}{8}$ in. (29 mm) wall thickness [except as required by UHT-57(a)], have been radiographically examined for their full length in the manner prescribed in UW-51; full radiography of the above exempted Category B and C butt welds, if performed, may be recorded on the Manufacturer's Data Report; or

(2) "RT 2" when the complete vessel satisfies the requirements of UW-11(a)(5) and when the spot radiography requirements of UW-11(a)(5)(b) have been applied; or

(3) "RT 3" when the complete vessel satisfies the spot radiography requirements of UW-11(b); or

(4) "RT 4" when only part of the complete vessel has satisfied the radiographic requirements of UW-11(a) or where none of the markings "RT 1," "RT 2," or "RT 3" are applicable.

The extent of radiography and the applicable joint efficiencies shall be noted on the Manufacturer's Data Report.

(f)(1) The letters HT shall be applied under the Code Symbol when the complete vessel has been postweld heat treated as provided in UW-10.

(2) The letters PHT shall be applied under the Code Symbol when only part of the complete vessel has been postweld heat treated as provided in UW-10. The extent of the postweld heat treatment shall be noted on the Manufacturer's Data Report.

(g) The Manufacturer shall have a valid Certificate of Authorization, and, with the acceptance of the Inspector, shall apply the Code Symbol to the vessel, which,

[38] When a pressure vessel is expected to operate at more than one pressure and temperature condition, other values of maximum allowable working pressure with the coincident permissible temperature may be added as required. See UG-20(b).

[39] The maximum allowable working pressure may be assumed to be the same as the design pressure when calculations are not made to determine the maximum allowable working pressure.

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together with the final certification [see U-1(j) and UG-120] shall indicate that all requirements of this Division have been met.

(1) Except as provided in (2) below, the Code Symbol shall be applied after the hydrostatic test or pneumatic test.

(2) The Code Symbol may be preapplied to a nameplate. The nameplate may be attached to the vessel after the final fabrication and examination sequence but before the hydrostatic tests or pneumatic test provided the procedure for sequence of stamping is described in the Manufacturer's accepted Quality Control System.

(h) Parts of vessels for which Partial Data Reports are required in UG-120(c) shall be marked by the parts Manufacturer with the following:

(1) the official Code Symbol shown in Fig. UG-116 sketch (a), above the word "PART";

(2) name of the Manufacturer of the part of the pressure vessel preceded by the words "certified by";

(3) the Manufacturer's serial number.

This requirement does not apply to such items as handhole covers, manhole covers and their accessories. [See (l) below.]

(i) All required markings shall be located in a conspicuous place on the vessel, preferably near a manhole or handhole (see M-3).

(j) Either of the following arrangements may be used in marking vessels having two or more independent pressure chambers designed for the same or different operating conditions. Each detachable chamber shall be marked so as to identify it positively with the combined unit.

(1) The marking may be grouped in one location on the vessel provided it is arranged so as to indicate clearly the data applicable to each chamber including the maximum differential pressure for the common elements when this pressure is less than the higher pressure in the adjacent chambers.

(2) The complete required marking may be applied to each independent pressure chamber, provided additional marking, such as stock space, jacket, tubes, or channel box, is used to indicate clearly to which chamber the data apply.

(k) In multiple-chamber vessels, only the parts of those chambers which are required to be built under this Division (see U-1) need bear the required marking. However, it is recommended that Manufacturers indicate on such vessels the working conditions for which the non-Code chambers were designed.

(l) Removable pressure parts shall be permanently marked in a manner to identify them with the vessel or chamber of which they form a part. This does not apply to manhole covers, handhole covers, and their accessory parts provided the marking requirements of UG-11 are met.

UG-117 CERTIFICATES OF AUTHORIZATION AND CODE SYMBOL STAMPS

UG-117(a) A Certificate of Authorization to use the Code U, UM, or UV Symbols shown in Figs. UG-116 and UG-129 will be granted by the Society pursuant to the provisions of the following paragraphs. Stamps for applying the Code Symbol shall be obtained from the Society.

UG-117(b) Application for Authorization. Any organization desiring a Certificate of Authorization shall apply to the Boiler and Pressure Vessel Committee of the Society, on forms issued by the Society,[40] specifying the Stamp desired and the scope of Code activities to be performed. When an organization intends to build Code items in plants in more than one geographical area, either separate applications for each plant or a single application listing the addresses of all such plants may be submitted. Each application shall identify the Authorized Inspection Agency providing Code inspection at each plant. A separate Certificate of Authorization will be prepared and a separate fee charged by the Society for each plant. Applicants for a UM Certificate of Authorization must already hold an S or U Certificate.

Each applicant must agree that each Certificate of Authorization and each Code Symbol Stamp are at all times the property of the Society, that they will be used according to the rules and regulations of this Division of the Code, and that they will be promptly returned to the Society upon demand, or when the applicant discontinues the Code activities covered by his Certificate, or when the Certificate of Authorization has expired and no new Certificate has been issued. The holder of a Code Symbol Stamp shall not allow any other organization to use it.

UG-117(c) Issuance of Authorization. Authorization to use Code Symbol Stamps may be granted or withheld by the Society in its absolute discretion. If authorization is granted, and the proper administrative fee paid, a Certificate of Authorization evidencing permission to use any such Symbol, expiring on the triennial anniversary date thereafter, except for UM Certificates [see (f) below], will be forwarded to the applicant. Each

[40] The application forms and related information and instructions may be obtained by writing to the Secretary, ASME Boiler and Pressure Vessel Committee, Three Park Avenue, New York, N.Y. 10016.

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such certificate will identify the Code Symbol to be used, and the type of shop and/or field operations for which authorization is granted (see Appendix DD). The Certificate will be signed by the Chairman of the Boiler and Pressure Vessel Committee and the Director of Accreditation.

Six months prior to the date of expiration of any such Certificate, the applicant must apply for a renewal of such authorization and the issuance of a new Certificate. The Society reserves the absolute right to cancel or refuse to renew such authorization, returning, pro rata, fees paid for the unexpired term. The Boiler and Pressure Vessel Committee may at any time make such regulations concerning the issuance and use of Code Symbol Stamps as it deems appropriate, and all such regulations shall become binding upon the holders of any valid Certificates of Authorization.

UG-117(d) Inspection Agreement. As a condition of obtaining and maintaining a Certificate of Authorization to use the U or UM Code Symbol Stamps, the Manufacturer must have in force at all times an inspection contract or agreement with an Authorized Inspection Agency as defined in UG-91 to provide inspection services. This inspection agreement is a written agreement between the Manufacturer and the Inspection Agency which specifies the terms and conditions under which the inspection services are to be furnished and which states the mutual responsibilities of the Manufacturer and the Authorized Inspectors. A Certificate Holder shall notify the Society whenever his agreement with an Authorized Inspection Agency is cancelled or changed to another Authorized Inspection Agency. Neither Manufacturers nor Assemblers of pressure relief valves are required to have an inspection agreement with an Authorized Inspection Agency.

UG-117(e) Quality Control System. Any Manufacturer or Assembler holding or applying for a Certificate of Authorization to use the U, UM, or UV Stamp shall have, and demonstrate, a Quality Control System to establish that all Code requirements, including material, design, fabrication, examination (by the Manufacturer), inspection of vessel and vessel parts (by the Authorized Inspector), pressure testing, and certification will be met. The Quality Control System shall be in accordance with the requirements of Appendix 10.

UG-117(f) Evaluation for Authorization and Reauthorization. Before issuance or triennial renewal of a Certificate of Authorization for use of the U or UM Stamp, the Manufacturer's facilities and organization are subject to a joint review by a representative of his inspection agency and an individual certified as an ASME Designee who is selected by the concerned legal jurisdiction. A written description or checklist of the Quality Control System which identifies what documents and what procedures the Manufacturer will use to produce a Code item shall be available for review.

A written report to the Society shall be made jointly by the ASME Designee and the Inspection Agency employed by the Manufacturer to do his Code inspection. This report is then reviewed by the Subcommittee on Boiler and Pressure Vessel Accreditation, which will either issue a Certificate of Authorization or notify the applicant of deficiencies revealed by the review. In such a case, the applicant will be given an opportunity to explain or correct these deficiencies.

Certificates of Authorization will be endorsed to indicate the scope of activity authorized. Authorization may include field operations if the review team determines that these operations are adequately described in the quality control manual, and this determination is accepted by the Society.

Before issuance or renewal of a Certificate of Authorization for use of the UV Stamp, the valve Manufacturer's or Assembler's facilities and organization are subject to a review by a representative from an ASME designated organization. A written description or checklist of the quality control system, which identifies the documents and procedures the Manufacturer or Assembler will use to produce Code pressure relief valves, shall be available for review. The representative from an ASME designated organization shall make a written report to the Society, where the Subcommittee on Boiler and Pressure Vessel Accreditation will act on it as described above.

The purpose of the review is to evaluate the applicant's Quality Control System and its implementation. The applicant shall demonstrate sufficient administrative and fabrication functions of the system to show that he has the knowledge and ability to produce the Code items covered by his Quality Control System. Fabrication functions may be demonstrated using current work, a mock-up, or a combination of the two.

Certificates of Authorization for use of U and UV Stamps are valid for 3 years. UM Certificates are valid for 1 year, but reviews after the first and second years of each 3 year period are performed by the Authorized Inspection Agency only.

The Manufacturer may at any time make changes in the Quality Control System concerning the methods of achieving results, subject to acceptance by the Authorized Inspector. For Manufacturers of multiple duplicate pressure vessels,[41] acceptance of these changes by the

[41] See UG-90(c)(2) for additional requirements applicable to multiple, duplicate pressure vessel fabrication.

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ASME Designee is also required. For Manufacturers and Assemblers of UV stamped pressure relief valves, such acceptance shall be by the ASME designated organization.

For those areas where there is no jurisdiction or where a jurisdiction does not choose to select an ASME Designee to review a vessel or vessel parts Manufacturer's facility, that function shall be performed by an ASME Designee selected by ASME. Where the jurisdiction is the Manufacturer's Inspection Agency, the joint review and joint report shall be made by the jurisdiction and an ASME Designee selected by ASME.

UG-117(g) Code Construction Before Receipt of Certificate of Authorization. When used to demonstrate his Quality Control System, a Manufacturer may start fabricating Code items before receipt of a Certificate of Authorization to use a Code Symbol Stamp under the following conditions.

UG-117(g)(1) The fabrication is done with the participation of the Authorized Inspector and is subject to his acceptance.

UG-117(g)(2) The activity is in conformance with the applicant's Quality Control System.

UG-117(g)(3) The item is stamped with the appropriate Code Symbol and certified once the applicant receives his Certificate of Authorization from the Society.

UG-118 METHODS OF MARKING

UG-118(a) The required marking shall be stamped directly on the vessel as provided in (b) and (c) below or shown on a separate nameplate as provided in UG-119.

UG-118(b) When the marking required by UG-116 is applied directly to the vessel, it shall be stamped with letters and figures at least $^{5}/_{16}$ in. (8 mm) high. Unless the requirements of (b)(1) or (2) below are met, such stamping shall not be used on vessels constructed of steel plates less than $^{1}/_{4}$ in. (6 mm) thick or of nonferrous plates less than $^{1}/_{2}$ in. (13 mm) thick but may be used on vessels constructed of thicker plates. The character size may be reduced as shown below for small diameter vessels with space limitations.

Nominal Outside Vessel Diameter		Character Size
min., in. (mm)	max., in. (mm)	min., in. (mm)
. . .	$3^{1}/_{2}$ (89)	$^{1}/_{8}$ (3.2)
$>3^{1}/_{2}$ (89)	$4^{1}/_{2}$ (114)	$^{3}/_{16}$ (4.8)
$>4^{1}/_{2}$ (114)	$6^{5}/_{8}$ (168)	$^{1}/_{4}$ (6)

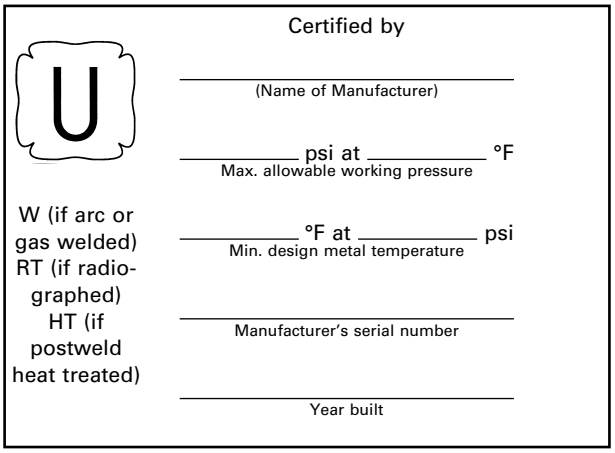


FIG. UG-118 FORM OF STAMPING

GENERAL NOTE: Information within parentheses is not part of the required marking. Phrases identifying data may be abbreviated; minimum abbreviations shall be MAWP, MDMT, S/N, and year, respectively.

UG-118(b)(1) For ferrous materials:

(a) the materials shall be limited to P-No. 1 Gr. Nos. 1 and 2;

(b) the minimum nominal plate thickness shall be 0.1875 in. (4.8 mm), or the minimum nominal pipe wall thickness shall be 0.154 in. (3.91 mm);

(c) the minimum design metal temperature shall be no colder than −20°F (−29°C);

UG-118(b)(2) for nonferrous materials:

(a) the materials shall be limited to aluminum as follows: SB-209 Alloys 3003, 5083, 5454, and 6061; SB-241 Alloys 3003, 5083, 5086, 5454, 6061, and 6063; and SB-247 Alloys 3003, 5083, and 6061;

(b) the minimum nominal plate thickness shall be 0.249 in. (6.32 mm), or the minimum nominal pipe thickness shall be 0.133 in. (3.38 mm).

UG-118(c) The stamping shall be arranged substantially as shown in Fig. UG-118 when space permits and shall be located in a conspicuous place on the vessel [see UG-116(j)].

UG-119 NAMEPLATES

(a) Nameplates shall be used on vessels except when markings are directly applied in accordance with UG-118. Nameplates shall be metal suitable for the intended service and shall bear the markings called for in UG-116. The marking arrangement shall be substantially as shown in Fig. UG-118. Required nameplates shall

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be located in a conspicuous place on the vessel [see UG-116(j)].

(b) The nameplate thickness shall be sufficient to resist distortion due to the application of the marking and to be compatible with the method of attachment. The nameplate nominal thickness shall not be less than 0.020 in.

(c) Nameplates may have markings produced by either casting, etching, embossing, debossing, stamping, or engraving, except that the Code Symbol shall be stamped on the nameplate.

(1) The required markings on a nameplate shall be in characters not less than $^{5}/_{32}$ in. (4 mm) high, except that characters for pressure relief device markings may be smaller.

(2) Characters shall be either indented or raised at least 0.004 in. (0.10 mm) and shall be legible and readable.

(d) The nameplate may be marked before it is affixed to the vessel, in which case the Manufacturer shall ensure that the nameplate with the correct marking has been applied to the proper vessel, and the Inspector shall satisfy himself that this has been done.

(e) The nameplate shall be attached to the vessel or to a pad, bracket, or structure which is welded, brazed, or soldered directly to the vessel. The nameplate shall be located within 30 in. (762 mm) of the vessel. Removal shall require the willful destruction of the nameplate, or its attachment system. (See M-3.)

(1) Nameplates may be attached either by welding, brazing, or soldering.

(2) Nameplates may be attached by tamper-resistant mechanical fasteners of suitable metal construction.

(3) Nameplates may be attached with pressure-sensitive acrylic adhesive systems provided that, in addition to the requirements of this paragraph, those of Appendix 18 are met.

(f) An additional nameplate in accordance with (a) through (d) may be installed on the skirt, supports, jacket, or other permanent attachment to a vessel. All data on the additional plate, including the Code Symbol, shall be as required for the mandatory nameplate. The marking need not be witnessed by the Inspector. The additional nameplate shall be marked: "DUPLICATE."

(g) When a nameplate is employed, the Manufacturer's name or identifying trademark, and vessel serial number (or National Board Number, if applicable,) may also be marked directly on the vessel in close proximity to the nameplate attachment. The marking shall be of a visible permanent type that is not detrimental to the vessel, and its location shall be indicated on the Data Report.

(1) If the thickness limitations of UG-118 preclude marking directly on the vessel shell or heads, it may be applied to the skirt, supports, jacket, or other permanent attachment to the vessel.

UG-120 DATA REPORTS

(a) A Data Report shall be filled out on Form U-1 or Form U-1A by the Manufacturer and shall be signed by the Manufacturer and the Inspector for each pressure vessel marked with the Code U Symbol. Same day production of vessels may be reported on a single Form provided all of the following requirements are met:

(1) vessels must be identical;

(2) vessels must be manufactured for stock or for the same user or his designated agent;

(3) serial numbers must be in uninterrupted sequence; and

(4) the Manufacturer's written Quality Control System includes procedures to control the development, distribution, and retention of the Data Reports.

The number of lines on the Data Report used to describe multiple components (e.g., nozzles, shell courses) may be increased or decreased as necessary to provide space to describe each component. If addition of lines used to describe multiple components results in the Data Report exceeding one page, space must be provided for the Manufacturer and Authorized Inspector to initial and date each of the additional pages. Horizontal spacing for information on each line may be altered as necessary. All information must be addressed; however, footnotes described in the remarks block are acceptable, e.g., for multiple cases of "none" or "not applicable."

A copy of the Manufacturer's Data Report shall be furnished to the user or his designated agent and, upon request, to the Inspector. The Manufacturer shall either keep a copy of the Manufacturer's Data Report on file for at least 5 years or the vessel may be registered and the Data Report filed with the National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Avenue, Columbus, Ohio 43229.

A Manufacturer's Certificate of Compliance on Form U-3 shall be completed and signed by the Manufacturer for each pressure vessel marked with the Code UM Symbol. This Certificate shall be maintained by the Manufacturer for 5 years and a copy made available upon request. Identical vessels up to 1 day's production may be recorded on a single Certificate of Compliance.

(b) Both chambers of combination units must be described on the same Data Report. When the common

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elements of such units are designed for a differential pressure, this limiting pressure must also be reported.

(c) Partial Data Reports. Data Reports for pressure vessel parts requiring inspection under this Division which are furnished by other than the shop of the Manufacturer responsible for the vessel to be marked with the Code Symbol shall be executed on the applicable Partial Data Report, Form U-2 or Form U-2A, by the parts Manufacturer and his Inspector in accordance with the requirements of this Division and shall be forwarded, in duplicate, to the Manufacturer of the completed vessel [see U-2(b)]. Form U-2A may be used for this purpose provided all the applicable information is recorded on this Form; otherwise Form U-2 shall be used. These Partial Data Reports, together with his own inspection, shall be the final Inspector's authority to witness the application of a Code Symbol to the vessel [see UG-90(c)]. When Form U-2 or Form U-2A is used, it shall be attached to the associated Form U-1 or Form U-1A by the Manufacturer of the vessel to be marked with the Code Symbol.

(1) Data Reports for those parts of a pressure vessel which are furnished by a parts Manufacturer to the user of an existing Code vessel as replacement or repair parts shall be executed on Form U-2 or U-2A by the parts Manufacturer and his Inspector in accordance with the requirements of this Division. A copy of the parts Manufacturer's Partial Data Report shall be furnished to the user or his designated agent and maintained in accordance with (a) above.

(2) The parts Manufacturer shall indicate under "Remarks" the extent he has performed any or all of the design functions. When the parts Manufacturer performs only a portion of the design, he shall state which portions of the design he performed.

(3) Same day production of vessel parts may be reported on a single Form U-2 or Form U-2A provided all of the following are met:

(a) vessel parts shall be identical;

(b) Manufacturer's serial numbers must be in uninterrupted sequence; and

(c) the Manufacturer's written Quality Control System includes procedures to control the development, distribution, and retention of the Partial Data Reports.

(4) For guidance in preparing Partial Data Reports, see Appendix W.

(d) This Division, in paragraphs such as UW-2, UF-1, UF-32(b), UB-1, UB-22, UCS-66, UNF-56, UHA-51, UCL-27, and UHT-6, establishes special requirements to qualify a vessel for certain "special services." (Paragraphs, such as UW-2, prohibit certain types of construction or materials in some special services.) The special services to which special requirements are applicable are classified as follows:

(1) lethal service [for example, see UW-2(a)];

(2) services below certain temperatures (for example, see UW-2(b), UCS-65, UHA-51, and UHT-60);

(3) unfired steam boiler [for example, see UW-2(c)];

(4) direct firing [for example, see UW-2(d)].

When a vessel is intended for such special services, the special service and the paragraphs of special requirements complied with shall be indicated on the Data Reports.

(e) For sample forms and guidance in their preparation, see Appendix W.

PRESSURE RELIEF DEVICES

UG-125 GENERAL

(a) All pressure vessels within the Scope of this Division, irrespective of size or pressure, shall be provided with pressure relief devices in accordance with the requirements of UG-125 through UG-137. It is the responsibility of the user to ensure that the required pressure relief devices are properly installed prior to initial operation. These pressure relief devices need not be supplied by the vessel Manufacturer. Unless otherwise defined in this Division, the definitions relating to pressure relief devices in Section 2 of ASME PTC 25 shall apply.

(b) An unfired steam boiler, as defined in U-1(g), shall be equipped with pressure relief devices required by Section I insofar as they are applicable to the service of the particular installation.

(c) All pressure vessels other than unfired steam boilers shall be protected by a pressure relief device that shall prevent the pressure from rising more than 10% or 3 psi, whichever is greater, above the maximum allowable working pressure except as permitted in (1) and (2) below. (See UG-134 for pressure settings.)

(1) When multiple pressure relief devices are provided and set in accordance with UG-134(a), they shall prevent the pressure from rising more than 16% or 4 psi, whichever is greater, above the maximum allowable working pressure.

(2) Where an additional hazard can be created by exposure of a pressure vessel to fire or other unexpected sources of external heat, supplemental pressure relief devices shall be installed to protect against excessive pressure. Such supplemental pressure relief devices shall be capable of preventing the pressure from rising more than 21% above the maximum allowable working pres-

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sure. The same pressure relief devices may be used to satisfy the capacity requirements of (c) or (c)(1) above and this paragraph provided the pressure setting requirements of UG-134(a) are met.

(3) Pressure relief devices, intended primarily for protection against exposure of a pressure vessel to fire or other unexpected sources of external heat installed on vessels having no permanent supply connection and used for storage at ambient temperatures of nonrefrigerated liquefied compressed gases,[42] are excluded from the requirements of (c)(1) and (c)(2) above, provided:

(a) the pressure relief devices are capable of preventing the pressure from rising more than 20% above the maximum allowable working pressure of the vessels;

(b) the set pressure marked on these devices shall not exceed the maximum allowable working pressure of the vessels;

(c) the vessels have sufficient ullage to avoid a liquid full condition;

(d) the maximum allowable working pressure of the vessels on which these pressure relief devices are installed is greater than the vapor pressure of the stored liquefied compressed gas at the maximum anticipated temperature[43] that the gas will reach under atmospheric conditions; and

(e) pressure relief valves used to satisfy these provisions also comply with the requirements of UG-129(a)(5), UG-131(c)(2), and UG-134(d)(2).

(d) Pressure relief devices shall be constructed, located, and installed so that they are readily accessible for inspection, replacement, and repair and so that they cannot be readily rendered inoperative (see Appendix M), and should be selected on the basis of their intended service.

(e) Pressure relief valves or nonreclosing pressure relief devices[44] may be used to protect against overpressure. Nonreclosing pressure relief devices may be used either alone or, if applicable, in combination with pressure relief valves on vessels.

NOTE: Use of nonreclosing pressure relief devices of some types may be advisable on vessels containing substances that may render a pressure relief valve inoperative, where a loss of valuable material by leakage should be avoided, or where contamination of the atmosphere by leakage of noxious fluids must be avoided. The use of rupture disk devices may also be advisable when very rapid rates of pressure rise may be encountered.

(f) Vessels that are to operate completely filled with liquid shall be equipped with pressure relief devices designed for liquid service, unless otherwise protected against overpressure.

(g) The pressure relief devices required in (a) above need not be installed directly on a pressure vessel when the source of pressure is external to the vessel and is under such positive control that the pressure in the vessel cannot exceed the maximum allowable working pressure at the operating temperature except as permitted in (c) above (see UG-98).

NOTE: Pressure reducing valves and similar mechanical or electrical control instruments, except for pilot operated pressure relief valves as permitted in UG-126(b), are not considered as sufficiently positive in action to prevent excess pressures from being developed.

(h) Pressure relief valves for steam service shall meet the requirements of UG-131(b).

UG-126 PRESSURE RELIEF VALVES[45]

(a) Safety, safety relief, and relief valves shall be of the direct spring loaded type.

(b) Pilot operated pressure relief valves may be used, provided that the pilot is self-actuated and the main valve will open automatically at not over the set pressure and will discharge its full rated capacity if some essential part of the pilot should fail.

(c) The spring in a pressure relief valve shall not be set for any pressure more than 5% above or below that for which the valve is marked, unless the setting is within the spring design range established by the valve Manufacturer or is determined to be acceptable to the Manufacturer. The initial adjustment shall be performed by the Manufacturer, his authorized representative, or an Assembler, and a valve data tag shall be provided that identifies the set pressure capacity and date. The valve shall be sealed with a seal identifying the Manufacturer, his authorized representative, or the Assembler performing the adjustment.

(d) The set pressure tolerances, plus or minus, of pressure relief valves shall not exceed 2 psi (13.8 kPa)

[42] For the purpose of these rules, gases are considered to be substances having a vapor pressure greater than 40 psia (276 kPa absolute) at 100°F (38°C).

[43] Normally this temperature should not be less than 115°F (46°C).

[44] A *pressure relief valve* is a pressure relief device which is designed to reclose and prevent the further flow of fluid after normal conditions have been restored. A *nonreclosing pressure relief device* is a pressure relief device designed to remain open after operation.

[45] A *safety valve* is a pressure relief valve actuated by inlet static pressure and characterized by rapid opening or pop action. A *relief valve* is a pressure relief valve actuated by inlet static pressure which opens in proportion to the increase in pressure over the opening pressure. A *safety relief valve* is a pressure relief valve characterized by rapid opening or pop action, or by opening in proportion to the increase in pressure over the opening pressure, depending on application. A *pilot operated pressure relief valve* is a pressure relief valve in which the major relieving device is combined with and is controlled by a self-actuated auxiliary pressure relief valve.

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for pressures up to and including 70 psi (483 kPa) and 3% for pressures above 70 psi (483 kPa).

UG-127 NONRECLOSING PRESSURE RELIEF DEVICES

(a) Rupture Disk Devices[46]

(1) General. Every rupture disk shall have a marked burst pressure established by rules of UG-137(d)(3) within a manufacturing design range[47] at a specified disk temperature[48] and shall be marked with a lot[49] number. The burst pressure tolerance at the specified disk temperature shall not exceed ±2 psi (±13.8 kPa) for marked burst pressure up to and including 40 psi (276 kPa) and ±5% for marked burst pressure above 40 psi (276 kPa).

(2) Relieving Capacity. The rated flow capacity of a pressure relief system which uses a rupture disk device as the sole relief device shall be determined by a value calculated under the requirements of (a) using a coefficient of discharge or (b) using flow resistances below.

(a) When the rupture disk device discharges directly to atmosphere and

(1) is installed within eight pipe diameters from the vessel nozzle entry; and

(2) with a length of discharge pipe not greater than five pipe diameters from the rupture disk device; and

(3) the nominal diameters of the inlet and discharge piping are equal to or greater than the stamped NPS designator of the device,

the calculated relieving capacity of a pressure relief system shall not exceed a value based on the applicable theoretical flow equation [see UG-131(e)(2) and Appendix 11] for the various media multiplied by a coefficient of discharge K equal to 0.62. The area A in the theoretical flow equation shall be the minimum net flow area[50] as specified by the rupture disk device Manufacturer.

(b) The calculated capacity of any pressure relief system may be determined by analyzing the total system resistance to flow. This analysis shall take into consideration the flow resistance of the rupture disk device, piping and piping components including the exit nozzle on the vessels, elbows, tees, reducers, and valves. The calculation shall be made using accepted engineering practices for determining fluid flow through piping systems. This calculated relieving capacity shall be multiplied by a factor of 0.90 or less to allow for uncertainties inherent with this method. The certified flow resistance[51] K_R for the rupture disk device, expressed as the velocity head loss, shall be determined in accordance with UG-131(k) through (r).

(3) Application of Rupture Disks

(a) A rupture disk device may be used as the sole pressure relieving device on a vessel.

NOTE: When rupture disk devices are used, it is recommended that the design pressure of the vessel be sufficiently above the intended operating pressure to provide sufficient margin between operating pressure and rupture disk bursting pressure to prevent premature failure of the rupture disk due to fatigue or creep.

Application of rupture disk devices to liquid service should be carefully evaluated to assure that the design of the rupture disk device and the dynamic energy of the system on which it is installed will result in sufficient opening of the rupture disk.

(b) A rupture disk device may be installed between a pressure relief valve[52] and the vessel provided:

(1) the combination of the pressure relief valve and the rupture disk device is ample in capacity to meet the requirements of UG-133(a) and (b);

(2) the marked capacity of a pressure relief valve (nozzle type) when installed with a rupture disk device between the inlet of the valve and the vessel shall be multiplied by a factor of 0.90 of the rated relieving capacity of the valve alone, or alternatively, the capacity of such a combination shall be established in accordance with (3) below;

(3) the capacity of the combination of the rupture disk device and the pressure relief valve may

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[46] A *rupture disk device* is a nonreclosing pressure relief device actuated by inlet static pressure and designed to function by the bursting of a pressure containing disk. A *rupture disk* is the pressure containing and pressure sensitive element of a rupture disk device. Rupture disks may be designed in several configurations, such as plain flat, prebulged, or reverse buckling. A *rupture disk holder* is the structure which encloses and clamps the rupture disk in position.

[47] The *manufacturing design range* is a range of pressure within which the marked burst pressure must fall to be acceptable for a particular requirement as agreed upon between the rupture disk Manufacturer and the user or his agent.

[48] The specified disk temperature supplied to the rupture disk Manufacturer shall be the temperature of the disk when the disk is expected to burst.

[49] A *lot of rupture disks* is those disks manufactured of a material at the same time, of the same size, thickness, type, heat, and manufacturing process including heat treatment.

[50] The *minimum net flow area* is the calculated net area after a complete burst of the disk with appropriate allowance for any structural members which may reduce the net flow area through the rupture disk device. The net flow area for sizing purposes shall not exceed the nominal pipe size area of the rupture disk device.

[51] The *certified flow resistance* K_R is a dimensionless factor used to calculate the velocity head loss that results from the presence of a rupture disk device in a pressure relief system.

[52] Use of a rupture disk device in combination with a pressure relief valve shall be carefully evaluated to ensure that the media being handled and the valve operational characteristics will result in opening of the valve coincident with the bursting of the rupture disk.

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be established in accordance with the appropriate paragraphs of UG-132;

(4) the space between a rupture disk device and a pressure relief valve shall be provided with a pressure gage, a try cock, free vent, or suitable telltale indicator. This arrangement permits detection of disk rupture or leakage.[53]

(5) the opening[50]provided through the rupture disk, after burst, is sufficient to permit a flow equal to the capacity of the valve [(2) and (3) above], and there is no chance of interference with proper functioning of the valve; but in no case shall this area be less than the area of the inlet of the valve unless the capacity and functioning of the specific combination of rupture disk device and pressure relief valve have been established by test in accordance with UG-132.

(c) A rupture disk device may be installed on the outlet side[54] of a pressure relief valve which is opened by direct action of the pressure in the vessel provided:

(1) the pressure relief valve will not fail to open at its proper pressure setting regardless of any back pressure that can accumulate between the pressure relief valve disk and the rupture disk. The space between the pressure relief valve disk and the rupture disk shall be vented or drained to prevent accumulation of pressure, or suitable means shall be provided to ensure that an accumulation of pressure does not affect the proper operation of the pressure relief valve.[55]

(2) the pressure relief valve is ample in capacity to meet the requirements of UG-125(c);

(3) the marked burst pressure of the rupture disk at the specified disk temperature plus any pressure in the outlet piping shall not exceed the design pressure of the outlet portion of the pressure relief valve and any pipe or fitting between the valve and the rupture disk device. However, in no case shall the marked burst pressure of the rupture disk at the specified disk temperature plus any pressure in the outlet piping exceed the maximum allowable working pressure of the vessel or the set pressure of the pressure relief valve.

(4) the opening provided through the rupture disk device after breakage is sufficient to permit a flow equal to the rated capacity of the attached pressure relief valve without exceeding the allowable overpressure;

(5) any piping beyond the rupture disk cannot be obstructed by the rupture disk or fragment;

(6) the system is designed to consider the adverse effects of any leakage through the pressure relief valve or through the outlet side rupture disk device, to ensure system performance and reliability.[56]

(7) the bonnet of a balancing bellows or diaphragm type pressure relief valve shall be vented to prevent accumulation of pressure in the bonnet.

(b) Breaking Pin Device[57]

(1) Breaking pin devices shall not be used as single devices but only in combination between the pressure relief valve and the vessel.

(2) The space between a breaking pin device and a pressure relief valve shall be provided with a pressure gage, a try cock, a free vent, or suitable telltale indicator. This arrangement permits detection of breaking pin device operation or leakage.

(3) Each breaking pin device shall have a rated pressure and temperature at which the pin will break. The breaking pin shall be identified to a lot number and shall be guaranteed by the Manufacturer to break when the rated pressure, within the following tolerances, is applied to the device:

Rated Pressure, psi (kPa)		Tolerance, Plus or Minus, psi (kPa)
Minimum	Maximum	
30 (207)	150 (1034)	5 (34)
151 (1041)	275 (1896)	10 (69)
276 (1902)	375 (2585)	15 (103)

(4) The rated pressure of the breaking pin plus the tolerance in psi shall not exceed 105% of the

[53] Users are warned that a rupture disk will not burst at its design pressure if back pressure builds up in the space between the disk and the pressure relief valve which will occur should leakage develop in the rupture disk due to corrosion or other cause.

[54] This use of a rupture disk device in series with the pressure relief valve is permitted to minimize the loss by leakage through the valve of valuable or of noxious or otherwise hazardous materials, and where a rupture disk alone or disk located on the inlet side of the valve is impracticable, or to prevent corrosive gases from a common discharge line from reaching the valve internals.

[55] Users are warned that many types of pressure relief valves will not open at the set pressure if pressure builds up in the space between the pressure relief valve disk and the rupture disk device. A specially designed pressure relief valve such as a diaphragm valve, pilot operated valve, or a valve equipped with a balancing bellows above the disk may be required.

[56] Some adverse effects resulting from leakage may include obstructing the flow path, corrosion of pressure relief valve components, and undesirable bursts of the outlet side rupture disk.

[57] A *breaking pin device* is a nonreclosing pressure relief device actuated by inlet static pressure and designed to function by the breakage of a load-carrying section of a pin which supports a pressure containing member. A *breaking pin* is the load-carrying element of a breaking pin device. A *breaking pin housing* is the structure which encloses the breaking pin mechanism. The material of the housing shall be listed in Section II and be permitted for use in this Division.

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maximum allowable working pressure of the vessel to which it is applied.

(5) The rated pressure at the specified temperature[58] shall be verified by breaking two or more sample breaking pins from each lot of the same material and the same size as those to be used. The lot size shall not exceed 25. The test shall be made in a device of the same form and pressure dimensions as that in which the breaking pin is to be used.

(c) Spring Loaded Nonreclosing Pressure Relief Device

(1) A spring loaded nonreclosing pressure relief device, pressure actuated by means which permit the spring loaded portion of the device to open at the specified set pressure and remain open until manually reset, may be used provided the design of the spring loaded nonreclosing device is such that if the actuating means fail, the device will achieve full opening at or below its set pressure. Such a device may not be used in combination with any other pressure relief device. The tolerance on opening point shall not exceed ±5%.

(2) The calculated capacity rating of a spring loaded nonreclosing pressure relief device shall not exceed a value based on the applicable theoretical formula (see UG-131) for the various media, multiplied by: K = coefficient = 0.62.

The area A (square inches) in the theoretical formula shall be the flow area through the minimum opening of the spring loaded nonreclosing pressure relief device.

(3) In lieu of the method of capacity rating in (2) above, a Manufacturer may have the capacity of a spring loaded nonreclosing pressure relief device design certified in general accordance with the procedures of UG-131, as applicable.

UG-128 LIQUID PRESSURE RELIEF VALVES

Any liquid pressure relief valve used shall be at least NPS ½ (DN 15).

UG-129 MARKING

(a) Safety, Safety Relief, Relief, Liquid Pressure Relief, and Pilot Operated Pressure Relief Valves. Each safety, safety relief, relief, liquid pressure relief, and pilot operated pressure relief valve NPS ½ (DN 15) and larger shall be plainly marked by the Manufacturer or Assembler with the required data in such a way that the marking will not be obliterated in service. The marking may be placed on the valve or on a plate or plates that satisfy the requirements of UG-119:

(1) the name, or an acceptable abbreviation, of the Manufacturer and the Assembler;

(2) Manufacturer's design or type number;

(3) NPS size _____ (the nominal pipe size of the valve inlet);

(4) set pressure _____ psi, and, if applicable per UG-136(d)(4), cold differential test pressure _____ psi;

(5) certified capacity (as applicable):

(a) lb/hr of saturated steam at an overpressure of 10% or 3 psi (20.6 kPa), whichever is greater for valves certified on steam complying with UG-131(b); or

(b) gal/min of water at 70°F (21°C) at an overpressure of 10% or 3 psi (20.6 kPa), whichever is greater for valves certified on water; or

(c) SCFM [standard cubic feet per minute at 60°F and 14.7 psia (16°C and 101 kPa)], or lb/min, of air at an overpressure of 10% or 3 psi (20.6 kPa), whichever is greater. Valves that are capacity certified in accordance with UG-131(c)(2) shall be marked "at 20% overpressure."

(d) In addition to one of the fluids specified above, the Manufacturer may indicate the capacity in other fluids (see Appendix 11).

(6) year built, or alternatively, a coding may be marked on the valve such that the valve Manufacturer or Assembler can identify the year the valve was assembled or tested;

(7) ASME Symbol as shown in Fig. UG-129.1. The pilot of a pilot operated pressure relief valve shall be plainly marked by the Manufacturer or Assembler showing the name of the Manufacturer, the Manufacturer's design or type number, the set pressure in pounds



FIG. UG-129.1 OFFICIAL SYMBOL FOR STAMP TO DENOTE THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS' STANDARD FOR PRESSURE RELIEF VALVES

[58] The specified temperature supplied to the breaking pin manufacturer shall be the temperature of the breaking pin when an emergency condition exists and the pin is expected to break.

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per square inch, and the year built, or alternatively, a coding that the Manufacturer can use to identify the year built.

On valves smaller than NPS ½ (DN 15), the markings may be made on a metal tag attached by wire or adhesive meeting the requirements of UG-119 or other means suitable for the service conditions.

(b) Safety and safety relief valves certified for a steam discharging capacity under the provisions of Section I and bearing the official Code Symbol Stamp of Section I for safety valves may be used on pressure vessels. The rated capacity in terms of other fluids shall be determined by the method of conversion given in Appendix 11. [See UG-131(h).]

(c) Pressure Relief Valves in Combination With Rupture Disk Devices. Pressure relief valves in combination with rupture disk devices shall be marked with the capacity as established in accordance with UG-127(a)(3)(b)(2) (using 0.90 factor) or the combination capacity factor established by test in accordance with UG-132(a) or (b), in addition to the marking of UG-129(a) and (f) below. The marking may be placed on the pressure relief valve or rupture disk device or on a plate or plates that satisfy the requirements of UG-119. The marking shall include the following:

(1) name of Manufacturer of valve;

(2) design or type number of valve;

(3) name of Manufacturer of rupture disk device;

(4) design or type number of rupture disk device;

(5) capacity or combination capacity factor;

(6) name of organization responsible for this marking. This shall be either the vessel user, vessel Manufacturer, rupture disk Manufacturer, or pressure relief valve Manufacturer.

(d) Pressure Relief Valves in Combination With Breaking Pin Devices. Pressure relief valves in combination with breaking pin devices shall be marked in accordance with (a) above. In addition, the rated pressure shall be marked on the breaking pin and the breaking pin housing.

(e) Rupture Disk Devices. Every rupture disk shall be plainly marked by the Manufacturer in such a way that the marking will not be obliterated in service. The rupture disk marking may be placed on the flange of the disk or on a metal tab that satisfies the requirements of UG-119. The marking shall include the following:

(1) the name or identifying trademark of the Manufacturer;

(2) Manufacturer's design or type number;

(3) lot number;

(4) disk material;



FIG. UG-129.2 OFFICIAL SYMBOL FOR STAMP TO DENOTE THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS' STANDARD FOR RUPTURE DISK DEVICES

(5) size _____ (NPS of rupture disk holder);

(6) marked burst pressure _____ psi;

(7) specified disk temperature _____ °F;

(8) minimum net flow area _____ sq in.;

(9) certified flow resistance (as applicable): 01

(a) K_{RG} _____ for rupture disk certified on air or gases; or

(b) K_{RL} _____ for rupture disk certified on liquid; or

(c) K_{RGL} _____ for rupture disk certified on air or gases, and liquid;

(10) ASME symbol as shown in Fig. UG-129.2;

(11) year built, or alternatively, a coding may be marked on the rupture disk such that the rupture disk device Manufacturer can identify the year the rupture disk device was assembled and tested.

Items (1), (2), and (5) above and flow direction shall also be marked on the rupture disk holder.

(f) Spring Loaded Nonreclosing Pressure Relief Devices. Spring loaded nonreclosing pressure relief devices shall be marked in accordance with (a) above except that the Code Symbol Stamp is to be applied only when the capacity has been established and certified in accordance with UG-127(c)(3) and all other requirements of UG-130 have been met.

UG-130 CODE SYMBOL STAMP

Each pressure relief device[59] to which the Code Symbol (see Figs. UG-129.1 and UG-129.2) will be applied shall have been fabricated or assembled by a Manufacturer or Assembler holding a valid Certificate of Authorization (UG-117) and capacity certified in accordance with the requirements of this Division.

[59] Vacuum relief devices are not covered by Code Symbol Stamp requirements.

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UG-131 CERTIFICATION OF CAPACITY OF PRESSURE RELIEF DEVICES

(a) Before the Code Symbol is applied to any pressure relief device, the device Manufacturers shall have the capacity of their devices certified in accordance with the provisions of these paragraphs. For pressure relief valves, (b) through (j) below apply and for rupture disk devices, (k) through (r) below apply except where noted.

(b)(1) Capacity certification tests for pressure relief valves for compressible fluids shall be conducted on dry saturated steam, or air, or gas. When dry saturated steam is used, the limits for test purposes shall be 98% minimum quality and 20°F (11°C) maximum superheat. Correction from within these limits may be made to the dry saturated condition. Pressure relief valves for steam service may be rated as above, but at least one valve of each series shall be tested on steam to demonstrate the steam capacity and performance.

(2) Capacity certification tests for pressure relief valves for incompressible fluids shall be conducted on water at a temperature between 40°F and 125°F (4°C and 52°C).

(c)(1) Capacity certification tests shall be conducted at a pressure which does not exceed the pressure for which the pressure relief valve is set to operate by more than 10% or 3 psi (20.6 kPa), whichever is greater, except as provided in (c)(2) below. Minimum pressure for capacity certification tests shall be at least 3 psi (20.6 kPa) above set pressure. The reseating pressure shall be noted and recorded.

(2) Capacity certification tests of pressure relief valves for use in accordance with UG-125(c)(3) may be conducted at a pressure not to exceed 120% of the stamped set pressure of the valve.

(3)(a) Pressure relief valves for compressible fluids having an adjustable blowdown construction shall be adjusted prior to testing so that the blowdown does not exceed 5% of the set pressure or 3 psi (20.6 kPa), whichever is greater.

(b) The blowdown of pressure relief valves for incompressible fluids and pressure relief valves for compressible fluids having nonadjustable blowdown shall be noted and recorded.

(4) Capacity certification of pilot operated pressure relief valves may be based on tests without the pilot valves installed, provided prior to capacity tests it has been demonstrated by test to the satisfaction of the Authorized Observer that the pilot valve will cause the main valve to open fully at a pressure which does not exceed the set pressure by more than 10% or 3 psi (20.6 kPa), whichever is greater, and that the pilot valve in combination with the main valve will meet all the requirements of this Division.

(d)(1) A capacity certification test is required on a set of three valves for each combination of size, design, and pressure setting. The stamped capacity rating for each combination of design, size, and test pressure shall not exceed 90% of the average capacity of the three valves tested. The capacity for each set of three valves shall fall within a range of ±5% of the average capacity. Failure to meet this requirement shall be cause to refuse certification of that particular pressure relief valve design.

(2) If a Manufacturer wishes to apply the Code Symbol to a design of pressure relief valves, four valves of each combination of pipe size and orifice size shall be tested. These four valves shall be set at pressures which cover the approximate range of pressures for which the valve will be used or covering the range available at the certified test facility that shall conduct the tests. The capacities based on these four tests shall be as follows.

(a) For compressible fluids, the slope W/P of the actual measured capacity versus the flow pressure for each test point shall be calculated and averaged:

$$\text{slope} = \frac{W}{P} = \frac{\text{measured capacity}}{\text{absolute flow pressure, psia}}$$

All values derived from the testing must fall within ±5% of the average value:

$$\text{minimum slope} = 0.95 \times \text{average slope}$$

$$\text{maximum slope} = 1.05 \times \text{average slope}$$

If the values derived from the testing do not fall between the minimum and maximum slope values, the Authorized Observer shall require that additional valves be tested at the rate of two for each valve beyond the maximum and minimum values with a limit of four additional valves.

The relieving capacity to be stamped on the valve shall not exceed 90% of the average slope times the absolute accumulation pressure:

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rated slope = 0.90 × average slope

for Customary units,

stamped capacity ≤ rated slope (1.10 × set pressure + 14.7) or (set pressure + 3 psi + 14.7), whichever is greater

for SI units,

stamped capacity ≤ rated slope (1.10 × set pressure + 100 kPa) or (set pressure + 20.6 kPa + 100 kPa), whichever is greater

For valves certified in accordance with (c)(2) above for Customary units:

stamped capacity ≤ rated slope (1.20 × set pressure + 14.7 or (set pressure + 3 psi + 14.7), whichever is greater

for SI units,

stamped capacity ≤ rated slope (1.20 × set pressure + 100 kPa) or (set pressure + 20.6 kPa + 100 kPa), whichever is greater

(b) For incompressible fluids, the capacities shall be plotted on log–log paper against the differential (inlet minus discharge pressure) test pressure and a straight line drawn through these four points. If the four points do not establish a straight line, two additional valves shall be tested for each unsatisfactory point, with a limit of two unsatisfactory points. Any point that departs from the straight line by more than 5% should be considered an unsatisfactory point. The relieving capacity shall be determined from this line. The certified capacity shall not exceed 90% of the capacity taken from the line.

(e) Instead of individual capacity certification as provided in (d) above, a coefficient of discharge K may be established for a specific pressure relief valve design according to the following procedure.

(1) For each design, the pressure relief valve Manufacturer shall submit for test at least three valves for each of three different sizes (a total of nine valves) together with detailed drawings showing the valve construction. Each valve of a given size shall be set at a different pressure.

(2) Tests shall be made on each pressure relief valve to determine its capacity-lift, popping and blowdown pressures, and actual capacity in terms of the fluid used in the test. A coefficient K_D shall be established for each test run as follows:

$$K_D = \frac{\text{actual flow}}{\text{theoretical flow}} = \text{coefficient of discharge}$$

where actual flow is determined quantitatively by test, and theoretical flow is calculated by the appropriate formula which follows:

For tests with dry saturated steam,

$$W_T = 51.5AP \quad **$$

NOTE: For dry saturated steam pressures over 1500 psig (10 342 kPa gage) and up to 3200 psig (22 063 kPa gage), the value of W_T, calculated by the above equation, shall be corrected by being multiplied by the following factors:

for Customary units,

$$\left(\frac{0.1906P - 1000}{0.2292P - 1061}\right)$$

for SI units,

$$\left(\frac{0.1906P - 6\,860}{0.2292P - 7\,280}\right)$$

For tests with air,

$$W_T = 356AP\sqrt{\frac{M}{T}} \quad **$$

For tests with natural gas,

$$W_T = CAP\sqrt{\frac{M}{ZT}} \quad **$$

For tests with water,

$$W_T = 2407A\sqrt{(P - P_d)w} \quad **$$

** For some of the terms of the above equation(s), it may be necessary to convert millimeters to meters to obtain a rational result in SI units.

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where

W_T = theoretical flow, lb/hr
A = actual discharge area through the valve at developed lift, sq in.
P = (set pressure × 1.10) plus atmospheric pressure, psia, or set pressure plus 3 psi plus atmospheric pressure, whichever is greater
P_d = pressure at discharge from valve, psia
M = molecular weight
T = absolute temperature at inlet, °F + 460°F
C = constant for gas or vapor based on the ratio of specific heats
$k = c_p / c_v$ (see Fig. 11-1)
Z = compressibility factor corresponding to P and T
w = specific weight of water at valve inlet conditions**

The average of the coefficients K_D of the nine tests required shall be multiplied by 0.90, and this product shall be taken as the coefficient K of that design. The coefficient of the design shall not be greater than 0.878 (the product of 0.9 × 0.975).

NOTE: All experimentally determined coefficients K_D shall fall within a range of ±5% of the average K_D found. Failure to meet this requirement shall be cause to refuse certification of that particular valve design.

To convert lb/hr of water to gal/min of water, multiply the capacity in lb/hr by 1/500.

(3) The official relieving capacity of all sizes and pressures of a given design, for which K has been established under the provisions of (e)(2) above, that are manufactured subsequently shall not exceed the value calculated by the appropriate formula in (e)(2) above multiplied by the coefficient K (see Appendix 11).

(4) The coefficient shall not be applied to valves whose beta ratio (ratio of valve throat to inlet diameter) lies outside the range of 0.15 to 0.75, unless tests have demonstrated that the individual coefficient of discharge K_D for valves at the extreme ends of a larger range is within ±5% of the average coefficient K. For designs where the lift is used to determine the flow area, all valves shall have the same nominal lift-to-seat diameter ratio (L/D).

(f) Tests shall be conducted at a place where the testing facilities, methods, procedures, and person supervising the tests (Authorized Observer) meet the applicable requirements of ASME PTC 25. The tests shall be made under the supervision of and certified by an Authorized Observer. The testing facilities, methods, procedures, and qualifications of the Authorized Observer shall be subject to the acceptance of the ASME on recommendation of a representative from an ASME designated organization. Acceptance of the testing facility is subject to review within each 5 year period.

(g) Capacity test data reports for each valve model, type, and size, signed by the Manufacturer and the Authorized Observer witnessing the tests shall be submitted to the ASME designated organization for review and acceptance.[60] Where changes are made in the design, capacity certification tests shall be repeated.

(h) For absolute pressures up to 1500 psia (10 342 kPa absolute), it is permissible to rate safety valves under PG-69.1.2 of Section I with capacity ratings at a flow pressure of 103% of the set pressure, for use on pressure vessels, without further test. In such instances, the capacity rating of the valve may be increased to allow for the flow pressure permitted in (c)(1) and (c)(3) above, namely, 110% of the set pressure, by the multiplier,

for Customary units,

$$\frac{1.10p + 14.7}{1.03p + 14.7}$$

for SI units,

$$\frac{1.10p + 100}{1.03p + 100}$$

where

p = set pressure, psig (kPa gage)

Such valves shall be marked in accordance with UG-129. This multiplier shall not be used as a divisor to transform test ratings from a higher to a lower flow.

For steam pressures above 1500 psig (10 342 kPa gage), the above multiplier is not applicable. For pressure relief valves with relieving pressures between 1500 psig (10 342 kPa gage) and 3200 psig (22 063 kPa gage), the capacity shall be determined by using the equation for steam and the correction factor for high pressure steam in (e)(2) above with the permitted absolute relieving pressure (for Customary units, 1.10p + 14.7; for SI units, 1.10p + 100) and the coefficient K for that valve design.

** For some of the terms of the above equation(s), it may be necessary to convert millimeters to meters to obtain a rational result in SI units.

[60] Valve capacities and rupture disk device flow resistances are published in "Pressure Relief Device Certifications." This publication may be obtained from the National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Avenue, Columbus, Ohio 43229.

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(i) Rating of nozzle type pressure relief valves, i.e., coefficient K_D, greater than 0.90 and nozzle construction, for saturated water shall be according to 11-2.

(j) When changes are made in the design of a pressure relief valve in such a manner as to affect the flow path, lift, or performance characteristics of the valve, new tests in accordance with this Division shall be performed.

(k) The certified flow resistance K_R of the rupture disk device used in UG-127(a)(2) shall be either $K_R = 2.4$, or as determined in accordance with (l) through (r) below.

01 *(l)* Flow resistance certification tests for rupture disk for air or gas service K_{RG} shall be burst and flow tested with air or gas. Flow resistance certification tests for liquid service K_{RL} shall be burst tested with water and flow tested with air or gas. Rupture disk for air or gas and liquid service K_{RGL} may be certified with air or gas as above, but at least one rupture disk of the number required under (o) below for each size of each series shall be burst tested with water and flow tested with air or gas to demonstrate the liquid service flow resistance.

(m) Flow resistance certification tests shall be conducted at a rupture disk device inlet pressure which does not exceed 110% of the device set pressure.

(n)(1) The flow resistance for rupture disk devices tested with nonpressure containing disk items, such as seals, support rings, and vacuum supports, is applicable for the same rupture device design without seals, support rings, or vacuum supports.

(2) A change in material for rupture disks and their nonpressure containing disk items, such as seals, support rings, and vacuum supports, is not considered a design change and does not require retesting.

(3) Additional linings, coatings, or platings may be used for the same design of rupture disk devices provided:

(a) the certificate holder has performed a verification burst test of rupture disks with the additional linings, coatings, or platings and has documented that the addition of these materials does not affect the rupture disk opening configuration; and

(b) such verification tests shall be conducted with rupture disks of the smallest size and minimum burst pressure for which the certified flow resistance with additional materials is to be used.

(o) Flow resistance certification of rupture disk devices shall be determined by one of the following methods.

(1) One Size Method

(a) For each rupture disk device design, three rupture disks from the same lot shall be individually burst and flow tested in accordance with (p) below. The burst pressure shall be the minimum of the rupture disk device design of the size tested.

(b) The certified flow resistance K_R determined in (p) below shall apply only to the rupture disk design of the size tested.

(c) When additional rupture disks of the same design are constructed at a later date, the test results on the original rupture disks may be included as applicable in the three size method described in (o)(2) below.

(2) Three Size Method

(a) This method of flow resistance certification may be used for a rupture disk device design of three or more sizes. The burst pressure shall be the minimum of the rupture disk device design for each of the sizes submitted for test.

(b) For each rupture disk device design, three rupture disks from the same lot shall be burst and flow tested in accordance with (p) below for each of three different sizes of the same design.

(c) The certified flow resistance K_R shall apply to all sizes and pressures of the design of the rupture disk device tested.

(p) A certified flow resistance K_R may be established for a specific rupture disk device design according to the following procedure.

(1) For each design, the rupture disk Manufacturer shall submit for test the required rupture disk devices in accordance with (o) above together with the cross section drawings showing the rupture disk device design.

(2) Tests shall be made on each rupture disk device to determine its burst pressure and flow resistance at a facility which meets the requirements of (f) above.

(3) Calculate an average flow resistance using the individual flow resistances determined in (p)(2) above. All individual flow resistances shall fall within the average flow resistance by an acceptance band of plus or minus three times the average of the absolute values of the deviations of the individual flow resistances from the average flow resistance. Any individual flow resistance that falls outside of this band shall be replaced on a two for one basis. A new average flow resistance shall be computed and the individual flow resistances evaluated as stated above.

(4) The certified flow resistance K_R for a rupture disk design shall not be less than zero and shall not be less than the sum of the average flow resistance plus three times the average of the absolute values of

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the deviations of individual flow resistances from the average flow resistance.

(q) Flow resistance test data reports for each rupture disk device design, signed by the Manufacturer and the Authorized Observer witnessing the tests, shall be submitted to the ASME designated organization for review and acceptance.[60]

(r) When changes are made in the design of a rupture disk device which affect the flow path or burst performance characteristics of the device, new tests in accordance with this Division shall be performed.

01

UG-132 CERTIFICATION OF CAPACITY OF PRESSURE RELIEF VALVES IN COMBINATION WITH NONRECLOSING PRESSURE RELIEF DEVICES

(a) Capacity of Pressure Relief Valves in Combination With a Rupture Disk Device at the Inlet

(1) For each combination of pressure relief valve design and rupture disk device design, the pressure relief valve Manufacturer or the rupture disk device Manufacturer may have the capacity of the combination certified as prescribed in (3) and (4) below.

(2) Capacity certification tests shall be conducted on saturated steam, air, or natural gas. When saturated steam is used, corrections for moisture content of the steam shall be made.

(3) The pressure relief valve Manufacturer or the rupture disk device Manufacturer may submit for tests the smallest rupture disk device size with the equivalent size of pressure relief valve that is intended to be used as a combination device. The pressure relief valve to be tested shall have the largest orifice used in the particular inlet size.

(4) Tests may be performed in accordance with the following subparagraphs. The rupture disk device and pressure relief valve combination to be tested shall be arranged to duplicate the combination assembly design.

(a) The test shall embody the minimum burst pressure of the rupture disk device design which is to be used in combination with the pressure relief valve design. The marked burst pressure shall be between 90% and 100% of the marked set pressure of the valve.

(b) The test procedure to be used shall be as follows.

The pressure relief valve (one valve) shall be tested for capacity as an individual valve, without the rupture disk device at a pressure 10% or 3 psi (20.6 kPa), whichever is greater, above the valve set pressure.

The rupture disk device shall then be installed at the inlet of the pressure relief valve and the disk burst to operate the valve. The capacity test shall be performed on the combination at 10% or 3 psi (20.6 kPa), whichever is greater, above the valve set pressure duplicating the individual pressure relief valve capacity test.

(c) Tests shall be repeated with two additional rupture disks of the same nominal rating for a total of three rupture disks to be tested with the single pressure valve. The results of the test capacity shall fall within a range of 10% of the average capacity of the three tests. Failure to meet this requirement shall be cause to require retest for determination of cause of the discrepancies.

(d) From the results of the tests, a Combination Capacity Factor shall be determined. The Combination Capacity Factor is the ratio of the average capacity determined by the combination tests to the capacity determined on the individual valve.

The Combination Capacity Factor shall be used as a multiplier to make appropriate changes in the ASME rated relieving capacity of the pressure relief valve in all sizes of the design. The value of the Combination Capacity Factor shall not be greater than one. The Combination Capacity Factor shall apply only to combinations of the same design of pressure relief valve and the same design of rupture disk device as those tested.

(e) The test laboratory shall submit the test results to the ASME designated organization for acceptance of the Combination Capacity Factor.[60]

(b) Optional Testing of Rupture Disk Devices and Pressure Relief Valves

(1) If desired, a valve Manufacturer or a rupture disk Manufacturer may conduct tests in the same manner as outlined in (a)(4)(c) and (a)(4)(d) above using the next two larger sizes of the design of rupture disk device and pressure relief valve to determine a Combination Capacity Factor applicable to larger sizes. If a greater Combination Capacity Factor is established and can be certified, it may be used for all larger sizes of the combination, but shall not be greater than one.

(2) If desired, additional tests may be conducted at higher pressures in accordance with (a)(4)(c) and (a)(4)(d) above to establish a maximum Combination Capacity Factor to be used at all pressures higher than the highest tested, but shall not be greater than one.

(c) Capacity of Breaking Pin Devices in Combination With Pressure Relief Valves

(1) Breaking pin devices in combination with pressure relief valves shall be capacity tested in compliance with UG-131(d) or UG-131(e) as a combination.

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(2) Capacity certification and Code Symbol stamping shall be based on the capacity established in accordance with these paragraphs.

UG-133 DETERMINATION OF PRESSURE RELIEVING REQUIREMENTS

(a) Except as permitted in (b) below, the aggregate capacity of the pressure relief devices connected to any vessel or system of vessels for the release of a liquid, air, steam, or other vapor shall be sufficient to carry off the maximum quantity that can be generated or supplied to the attached equipment without permitting a rise in pressure within the vessel of more than 16% above the maximum allowable working pressure when the pressure relief devices are blowing.

(b) Pressure relief devices as permitted in UG-125(c)(2), as protection against excessive pressure caused by exposure to fire or other sources of external heat, shall have a relieving capacity sufficient to prevent the pressure from rising more than 21% above the maximum allowable working pressure of the vessel when all pressure relief devices are blowing.

(c) Vessels connected together by a system of adequate piping not containing valves which can isolate any vessel may be considered as one unit in figuring the required relieving capacity of pressure relief devices to be furnished.

(d) Heat exchangers and similar vessels shall be protected with a pressure relief device of sufficient capacity to avoid overpressure in case of an internal failure.

(e) The official rated capacity, or the certified flow resistance and minimum net flow area, of a pressure relief device shall be that which is stamped on the device and guaranteed by the Manufacturer.

(f) The rated pressure relieving capacity of a pressure relief valve for other than steam or air shall be determined by the method of conversion given in Appendix 11.

(g) To prorate the relieving capacity at any relieving pressure greater than 1.10*p*, as permitted under UG-125, a multiplier may be applied to the official relieving capacity of a pressure relief device as follows:

for Customary units,

$$\frac{P + 14.7}{1.10p + 14.7}$$

for SI units,

$$\frac{P + 100}{1.10p + 100}$$

where

P = relieving pressure, psig (kPa gage)

p = set pressure, psig (kPa gage)

For steam pressures above 1500 psig (10 342 kPa gage), the above multiplier is not applicable. For steam valves with relieving pressures greater than 1500 psig (10 342 gage) and less than or equal to 3200 psig (22 063 kPa gage), the capacity at relieving pressures greater than 1.10*p* shall be determined using the equation for steam and the correction factor for high pressure steam in UG-131(e)(2) with the permitted absolute relieving pressure and the coefficient *K* for that valve design.

UG-134 PRESSURE SETTING OF PRESSURE RELIEF DEVICES

(a) When a single pressure relief device is used, the set pressure[61] marked on the device shall not exceed the maximum allowable working pressure of the vessel. When the required capacity is provided in more than one pressure relief device, only one pressure relief device need be set at or below the maximum allowable working pressure, and the additional pressure relief devices may be set to open at higher pressures but in no case at a pressure higher than 105% of the maximum allowable working pressure, except as provided in (b) below.

(b) For pressure relief devices permitted in UG-125(c)(2) as protection against excessive pressure caused by exposure to fire or other sources of external heat, the device marked set pressure shall not exceed 110% of the maximum allowable working pressure of the vessel. If such a pressure relief device is used to meet the requirements of both UG-125(c) and UG-125(c)(2), the device marked set pressure shall not be over the maximum allowable working pressure.

(c) The pressure relief device set pressure shall include the effects of static head and constant back pressure.

(d)(1) The set pressure tolerance for pressure relief valves shall not exceed ±2 psi (13.8 kPa) for pressures

[61] The *set pressure* is the value of increasing inlet static pressure at which a pressure relief device displays one of the operational characteristics as defined by opening pressure, popping pressure, start-to-leak pressure, burst pressure, or breaking pressure. (The applicable operating characteristic for a specific device design is specified by the device Manufacturer.)

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up to and including 70 psi (483 kPa) and ±3% for pressures above 70 psi (483 kPa), except as covered in (d)(2) below.

(2) The set pressure tolerance of pressure relief valves which comply with UG-125(c)(3) shall be within −0%, +10%.

(e) The burst pressure tolerance for rupture disk devices at the specified disk temperature shall not exceed ±2 psi (13.8 kPa) of marked burst pressure up to 40 psi (276 kPa) and ±5% of marked burst pressure 40 psi (276 kPa) and over.

UG-135 INSTALLATION

(a) Pressure relief devices intended for use in compressible fluid service shall be connected to the vessel in the vapor space above any contained liquid or to piping connected to the vapor space in the vessel which is to be protected. Pressure relief devices intended for use in liquid service shall be connected below the normal liquid level.

(b)(1) The opening through all pipe, fittings, and nonreclosing pressure relief devices (if installed) between a pressure vessel and its pressure relief valve shall have at least the area of the pressure relief valve inlet. The characteristics of this upstream system shall be such that the pressure drop will not reduce the relieving capacity below that required or adversely affect the proper operation of the pressure relief valve.

(2) The opening in the vessel wall shall be designed to provide unobstructed flow between the vessel and its pressure relief device (see Appendix M).[62]

(c) When two or more required pressure relief devices are placed on one connection, the inlet internal cross-sectional area of this connection shall be either sized to avoid restricting flow to the pressure relief devices or made at least equal to the combined inlet areas of the safety devices connected to it. The flow characteristics of the upstream system shall satisfy the requirements of (b) above. (See Appendix M.)

(d) There shall be no intervening stop valves between the vessel and its pressure relief device or devices, or between the pressure relief device or devices and the point of discharge, except:

(1) when these stop valves are so constructed or positively controlled that the closing of the maximum number of block valves possible at one time will not reduce the pressure relieving capacity provided by the unaffected pressure relief devices below the required relieving capacity; or

(2) under conditions set forth in Appendix M.

(e) The pressure relief devices on all vessels shall be so installed that their proper functioning will not be hindered by the nature of the vessel's contents.

(f) Discharge lines from pressure relief devices shall be designed to facilitate drainage or shall be fitted with drains to prevent liquid from lodging in the discharge side of the pressure relief device, and such lines shall lead to a safe place of discharge. The size of the discharge lines shall be such that any pressure that may exist or develop will not reduce the relieving capacity of the pressure relief devices below that required to properly protect the vessel, or adversely affect the proper operation of the pressure relief devices. [See UG-136(a)(8) and Appendix M.]

UG-136 MINIMUM REQUIREMENTS FOR PRESSURE RELIEF VALVES

UG-136(a) Mechanical Requirements

UG-136(a)(1) The design shall incorporate guiding arrangements necessary to ensure consistent operation and tightness.

UG-136(a)(2) The spring shall be designed so that the full lift spring compression shall be no greater than 80% of the nominal solid deflection. The permanent set of the spring (defined as the difference between the free height and height measured 10 min after the spring has been compressed solid three additional times after presetting at room temperature) shall not exceed 0.5% of the free height.

UG-136(a)(3) Each pressure relief valve on air, water over 140°F (60°C), or steam service shall have a substantial lifting device which when activated will release the seating force on the disk when the pressure relief valve is subjected to a pressure of at least 75% of the set pressure of the valve. Pilot operated pressure relief valves used on these services shall be provided with either a lifting device as described above or means for connecting and applying pressure to the pilot adequate to verify that the moving parts critical to proper operation are free to move.

UG-136(a)(4) The seat of a pressure relief valve shall be fastened to the body of the pressure relief valve in such a way that there is no possibility of the seat lifting.

[62] Users are warned that the proper operation of various rupture disk devices depends upon following the Manufacturer's installation instructions closely with regard to the flow direction marked on the device. Some device designs will burst at pressures much greater than their marked burst pressure when installed with the process pressure on the vent side of the device.

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UG-136(a)(5) In the design of the body of the pressure relief valve, consideration shall be given to minimizing the effects of deposits.

UG-136(a)(6) Pressure relief valves having screwed inlet or outlet connections shall be provided with wrenching surfaces to allow for normal installation without damaging operating parts.

UG-136(a)(7) Means shall be provided in the design of all pressure relief valves for use under this Division for sealing all initial adjustments which can be made without disassembly of the valve. Seals shall be installed by the Manufacturer or Assembler at the time of initial adjustment. Seals shall be installed in a manner to prevent changing the adjustment without breaking the seal. For pressure relief valves larger than NPS ½ (DN 15), the seal shall serve as a means of identifying the Manufacturer or Assembler making the initial adjustment.

UG-136(a)(8) If the design of a pressure relief valve is such that liquid can collect on the discharge side of the disk, except as permitted in (a)(9) below, the valve shall be equipped with a drain at the lowest point where liquid can collect (for installation, see UG-135).

UG-136(a)(9) Pressure relief values that cannot be equipped with a drain as required in (a)(8) above because of design or application may be used provided:

(a) the pressure relief valves are used only on gas service where there is neither liquid discharged from the valve nor liquid formed by condensation on the discharge side of the valve; and

(b) the pressure relief valves are provided with a cover or discharge piping per UG-135(f) to prevent liquid or other contaminant from entering the discharge side of the valve; and

(c) the pressure relief valve is marked FOR GAS SERVICE ONLY in addition to the requirements of UG-129.

UG-136(a)(10) For pressure relief valves of the diaphragm type, the space above the diaphragm shall be vented to prevent a buildup of pressure above the diaphragm. Pressure relief valves of the diaphragm type shall be designed so that failure or deterioration of the diaphragm material will not impair the ability of the valve to relieve at the rated capacity.

UG-136(b) Material Selections

UG-136(b)(1) Cast iron seats and disks are not permitted.

UG-136(b)(2) Adjacent sliding surfaces such as guides and disks or disk holders shall both be of corrosion resistant material. Springs of corrosion resistant material or having a corrosion resistant coating are required. The seats and disks of pressure relief valves shall be of suitable material to resist corrosion by the fluid to be contained.

NOTE: The degree of corrosion resistance, appropriate to the intended service, shall be a matter of agreement between the manufacturer and the purchaser.

UG-136(b)(3) Materials used in bodies and bonnets or yokes shall be listed in Section II and this Division. Carbon and low alloy steel bodies, bonnets, yokes and bolting (UG-20) subject to in-service temperatures colder than −20°F (−23°C) shall meet the requirements of UCS-66, unless exempted by the following.

(a) The coincident ratio defined in Fig. UCS-66.1 is 0.35 or less.

(b) The material(s) is exempted from impact testing per Fig. UCS-66.

UG-136(b)(4) Materials used in nozzles, disks, and other parts contained within the external structure of the pressure relief valves shall be one of the following categories:

(a) listed in Section II;

(b) listed in ASTM specifications;

(c) controlled by the Manufacturer of the pressure relief valve by a specification ensuring control of chemical and physical properties and quality at least equivalent to ASTM standards.

UG-136(c) Inspection of Manufacturing and/or Assembly of Pressure Relief Valves

UG-136(c)(1) A Manufacturer or Assembler shall demonstrate to the satisfaction of a representative from an ASME designated organization that his manufacturing, production, and testing facilities and quality control procedures will insure close agreement between the performance of random production samples and the performance of those valves submitted for Capacity Certification.

UG-136(c)(2) Manufacturing, assembly, inspection, and test operations including capacity are subject to inspections at any time by a representative from an ASME designated organization.

UG-136(c)(3) A Manufacturer or Assembler may be granted permission to apply the UV Code Symbol to production pressure relief valves capacity certified in accordance with UG-131 provided the following tests are successfully completed. This permission shall expire on the fifth anniversary of the date it is initially granted. The permission may be extended for 5 year periods if the following tests are successfully repeated within the 6-month period before expiration.

(a) Two sample production pressure relief valves of a size and capacity within the capability of an

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ASME accepted laboratory shall be selected by a representative from an ASME designated organization.

(b) Operational and capacity tests shall be conducted in the presence of a representative from an ASME designated organization at an ASME accepted laboratory. The pressure relief valve Manufacturer or Assembler shall be notified of the time of the test and may have representatives present to witness the test. Pressure relief valves having an adjustable blowdown construction shall be adjusted by the Manufacturer or Assembler following successful testing for operation but prior to flow testing so that the blowdown does not exceed 7% of the set pressure or 3 psi (20.6 kPa), whichever is greater. This adjustment may be made on the flow test facility.

(c) Should any pressure relief valve fail to relieve at or above its certified capacity or should it fail to meet performance requirements of this Division, the test shall be repeated at the rate of two replacement pressure relief valves, selected in accordance with (c)(3)(a) above, for each pressure relief valve that failed.

(d) Failure of any of the replacement pressure relief valves to meet the capacity or the performance requirements of this Division shall be cause for revocation within 60 days of the authorization to use the Code Symbol on that particular type of pressure relief valve. During this period, the Manufacturer or Assembler shall demonstrate the cause of such deficiency and the action taken to guard against future occurrence, and the requirements of (c)(3) above shall apply.

01 *UG-136(c)(4)* Use of the Code Symbol Stamp by an Assembler indicates the use of original, unmodified parts in strict accordance with the instructions of the Manufacturer of the pressure relief valve.

(a) An assembler may transfer original and unmodified pressure relief parts produced by the Manufacturer to other Assemblers provided the following conditions are met:

(1) both Assemblers have been granted permission to apply the V or UV Code Symbol to the specific valve type in which the parts are to be used;

(2) the Quality Control System of the Assembler receiving the pressure relief valve parts shall define the controls for the procurement and acceptance of those parts; and

(3) the pressure relief valve parts are appropriately packaged, marked, or sealed by the Manufacturer to ensure that the parts are:

(a) produced by the Manufacturer; and

(b) the parts are original and unmodified.

(b) However, an Assembler may convert original finished parts by machining to another finished part for a specific application under the following conditions:

(1) Conversions shall be specified by the Manufacturer. Drawings and/or written instructions used for part conversion shall be obtained from the Manufacturer and shall include a drawing or description of the converted part before and after machining.

(2) The Assembler's quality control system, as accepted by a representative from an ASME designated organization, must describe in detail the conversion of original parts, provisions for inspection and acceptance, personnel training, and control of current Manufacturer's drawings and/or written instructions.

(3) The Assembler must document each use of a converted part and that the part was used in strict accordance with the instructions of the Manufacturer.

(4) The Assembler must demonstrate to the Manufacturer the ability to perform each type of conversion. The Manufacturer shall document all authorizations granted to perform part conversions. The Manufacturer and Assembler shall maintain a file of such authorizations.

(5) At least annually a review shall be performed by the Manufacturer of an Assembler's system and machining capabilities. The Manufacturer shall document the results of these reviews. A copy of this documentation shall be kept on file by the Assembler. The review results shall be made available to a representative from an ASME designated organization.

UG-136(c)(5) In addition to the requirements of UG-129, the marking shall include the name of the Manufacturer and the final Assembler. The Code Symbol Stamp shall be that of the final Assembler.

NOTE: Within the requirements of UG-136(c) and (d): A *Manufacturer* is defined as a person or organization who is completely responsible for design, material selection, capacity certification, manufacture of all component parts, assembly, testing, sealing, and shipping of pressure relief valves certified under this Division. An *Assembler* is defined as a person or organization who purchases or receives from a Manufacturer or another Assembler the necessary component parts or pressure relief valves and assembles, adjusts, tests, seals, and ships pressure relief valves certified under this Division, at a geographical location other than and using facilities other than those used by the Manufacturer. An Assembler may be organizationally independent of a Manufacturer or may be wholly or partly owned by a Manufacturer.

UG-136(d) Production Testing by Manufacturers and Assemblers

UG-136(d)(1) Each pressure relief valve to which the Code Symbol Stamp is to be applied shall be subjected to the following tests by the Manufacturer or Assembler. A Manufacturer or Assembler shall have a documented program for the application, calibration, and maintenance of gages and instruments used during these tests.

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UG-136(d)(2) The primary pressure parts of each pressure relief valve exceeding NPS 1 (DN 25) inlet size or 300 psi (2070 kPa) set pressure where the materials used are either cast or welded shall be tested at a pressure of at least 1.5 times the design pressure of the parts. These tests shall be conducted after all machining operations on the parts have been completed. There shall be no visible sign of leakage.

UG-136(d)(3) The secondary pressure zone of each closed bonnet pressure relief valve exceeding NPS 1 (DN 25) inlet size when such pressure relief valves are designed for discharge to a closed system shall be tested with air or other gas at a pressure of at least 30 psi (207 kPa). There shall be no visible sign of leakage.

UG-136(d)(4) Each pressure relief valve shall be tested to demonstrate its popping or set pressure. Pressure relief valves marked for steam service or having special internal parts for steam service shall be tested with steam, except that pressure relief valves beyond the capability of the production steam test facility either because of size or set pressure may be tested on air. Necessary corrections for differentials in popping pressure between steam and air shall be established by the Manufacturer and applied to the popping point on air. Pressure relief valves marked for gas or vapor may be tested with air. Pressure relief valves marked for liquid service shall be tested with water or other suitable liquid. When a valve is adjusted to correct for service conditions of superimposed back pressure, temperature, or the differential in popping pressure between steam and air, the actual test pressure (cold differential test pressure) shall be marked on the valve per UG-129. Test fixtures and test drums where applicable shall be of adequate size and capacity to ensure that pressure relief valve action is consistent with the stamped set pressure within the tolerances required by UG-134(d).

UG-136(d)(5) After completion of the tests required by (d)(4) above, a seat tightness test shall be conducted. Unless otherwise designated by a Manufacturer's published pressure relief valve specification, the seat tightness test and acceptance criteria shall be in accordance with API 527.

UG-136(d)(6) Testing time on steam pressure relief valves shall be sufficient, depending on size and design, to insure that test results are repeatable and representative of field performance.

UG-136(e) Design Requirements. At the time of the submission of pressure relief valves for capacity certification, or testing in accordance with (c)(3) above, the ASME designated organization has the authority to review the design for conformity with the requirements of UG-136(a) and UG-136(b) and to reject or require modification of designs which do not conform, prior to capacity testing.

UG-136(f) Welding and Other Requirements. All welding, brazing, heat treatment, and nondestructive examination used in the construction of bodies, bonnets, and yokes shall be performed in accordance with the applicable requirements of this Division.

UG-137 MINIMUM REQUIREMENTS FOR RUPTURE DISK DEVICES

UG-137(a) Mechanical Requirements

UG-137(a)(1) The design shall incorporate arrangements necessary to ensure consistent operation and tightness.

UG-137(a)(2) Rupture disk devices having threaded inlet or outlet connections shall be designed to allow for normal installation without damaging the rupture disk.

UG-137(b) Material Selections

UG-137(b)(1) The rupture disk material is not required to conform to a material specification listed in ASME Section II. The rupture disk material shall be controlled by the Manufacturer of the rupture disk device by a specification ensuring the control of material properties.

UG-137(b)(2) Materials used in rupture disk holders shall be listed in Section II and this Division. Carbon and low alloy steel holders and bolting (UG-20) subject to in-service temperatures colder than −20°F shall meet the requirements of UCS-66, unless exempted by the following.

(a) The coincident ratio defined in Fig. UCS-66.1 is 0.40 or less.

(b) The material(s) is exempted from impact testing per Fig. UCS-66.

UG-137(b)(3) Materials used in other parts contained within the external structure of the rupture disk holder shall be one of the following categories:

(a) listed in Section II; or

(b) listed in ASTM specifications; or

(c) controlled by the Manufacturer of the rupture disk device by a specification insuring control of chemical and physical properties and quality at least equivalent to ASTM standards.

UG-137(c) Inspection of Manufacturing of Rupture Disk Devices

UG-137(c)(1) A Manufacturer shall demonstrate to the satisfaction of a representative of an ASME designated organization that its manufacturing, production, and testing facilities and quality control procedures will insure close agreement between the performance

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of random production samples and the performance of those devices submitted for Certification.

UG-137(c)(2) Manufacturing, assembly, inspection, and test operations are subject to inspections at any time by an ASME designee.

UG-137(c)(3) A Manufacturer may be granted permission to apply the UD Code Symbol to production rupture disk devices certified in accordance with UG-131 provided the following tests are successfully completed. This permission shall expire on the fifth anniversary of the date it is initially granted. The permission may be extended for five year periods if the following tests are successfully repeated within the 6 month period before expiration.

(a) Two production sample rupture disk devices of a size and capacity within the capability of an ASME accepted laboratory shall be selected by a representative of an ASME designated organization.

(b) Burst and flow testing shall be conducted in the presence of a representative of an ASME designated organization at a place which meets the requirements of UG-131(f). The device Manufacturer shall be notified of the time of the test and may have representatives present to witness the test.

(c) Should any device fail to meet or exceed the performance requirements (burst pressure, minimum net flow area, and flow resistance) of UG-127, the test shall be repeated at the rate of two replacement devices, selected and tested in accordance with (c)(3)(a) and (c)(3)(b) above for each device that failed.

(d) Failure of any of the replacement devices to meet the performance requirements of this Division shall be cause for revocation within 60 days of the authorization to use the Code Symbol on that particular type of rupture disk device design. During this period, the Manufacturer shall demonstrate the cause of such deficiency and the action taken to guard against future occurrence, and the requirements of (c)(3) above shall apply.

UG-137(d) Production Testing by Manufacturers

UG-137(d)(1) Each rupture disk device to which the Code Symbol Stamp is to be applied shall be subjected to the following tests by the Manufacturer. The Manufacturer shall have a documented program for the application, calibration, and maintenance of gages and instruments used during these tests.

UG-137(d)(2) The pressure parts of each rupture disk holder exceeding NPS 1 (DN 25) inlet size or 300 psi (2 070 kPa) design pressure where the materials used are either cast or welded shall be tested at a pressure of at least 1.5 times the design pressure of the parts. These tests shall be conducted after all machining operations on the parts have been completed but prior to installation of the rupture disk. There shall be no visible sign of leakage.

UG-137(d)(3) Each lot of rupture disks shall be tested in accordance with one of the following methods. All tests of disks for a given lot shall be made in a holder of the same form and pressure area dimensions as that being used in service. Sample rupture disks, selected from each lot of rupture disks, shall be made from the same material and of the same size as those to be used in service. Test results shall be applicable only to rupture disks used in disk holders supplied by the rupture disk Manufacturer.

(a) At least two sample rupture disks from each lot of rupture disks shall be burst at the specified disk temperature. The marked burst pressure shall be determined so that the sample rupture disk burst pressures are within the burst pressure tolerance specified by UG-127(a)(1).

(b) At least four sample rupture disks, but not less than 5% from each lot of rupture disks, shall be burst at four different temperatures distributed over the applicable temperature range for which the disks will be used. This data shall be used to establish a smooth curve of burst pressure versus temperature for the lot of disks. The burst pressure for each data point shall not deviate from the curve more than the burst pressure tolerance specified in UG-127(a)(1).

The value for the marked burst pressure shall be derived from the curve for a specified temperature.

(c) For prebulged solid metal disks or graphite disks only, at least four sample rupture disks using one size of disk from each lot of material shall be burst at four different temperatures, distributed over the applicable temperature range for which this material will be used. These data shall be used to establish a smooth curve of percent change of burst pressure versus temperature for the lot of material. The acceptance criteria of smooth curve shall be as in (d)(3)(b) above.

At least two disks from each lot of disks, made from this lot of material and of the same size as those to be used, shall be burst at the ambient temperature to establish the room temperature rating of the lot of disks. The percent change shall be used to establish the marked burst pressure at the specified disk temperature for the lot of disks.

UG-137(e) Design Requirements. At the time of the inspection in accordance with (c)(3) above, a representative from an ASME designated organization has the authority to review the design for conformity with the requirements of UG-137(a) and UG-137(b) and to reject

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or require modification of designs which to not conform, prior to capacity testing.

UG-137(f) Welding and Other Requirements. All welding, brazing, heat treatment, and nondestructive examination used in the construction of rupture disk holders and pressure parts shall be performed in accordance with the applicable requirements of this Division.

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