

GS 146-2

PRESSURE VESSELS

July 1997

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BP GROUP RECOMMENDED PRACTICES AND SPECIFICATIONS FOR ENGINEERING											
Doc. No. GS 146-2		Issue Date July 1997	Latest Amendment Date								
Document Title PRESSURE VESSELS (Replaces BP Engineering Std. 194 Parts 1 and 2)											
APPLICABILITY - No restrictions. Regional Applicability: International											
SCOPE AND PURPOSE This Guidance for Specification specifies BPs general requirements for the mechanical design, materials selection, fabrication, inspection and testing of pressure vessels. It may be used with any recognised vessel code. It comprises a general section common to all vessels and appendices which are material specific. For a particular job, it is intended that only the general section and relevant material specific appendix would be issued to vendors, and that the other material specific appendices would be omitted. It supersedes BP 194 Parts 1 and 2, and includes the requirements of BP Chemicals specification ES/ENG/350/01.											
AMENDMENTS <table border="0"> <thead> <tr> <th>Amd</th> <th>Date</th> <th>Page(s)</th> <th>Description</th> </tr> </thead> <tbody> <tr> <td colspan="4"> </td> </tr> </tbody> </table>				Amd	Date	Page(s)	Description				
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Approved for issue:- July 1997		 Rod MacFarlane DOCUMENT CUSTODIAN	 John Lambert STANDARDS ENGINEER								
CUSTODIAN (See Quarterly Status List for Contact) Pressure Vessels											
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FOREWORD

Introduction to BP Group Recommended Practices and Specifications for Engineering

The Introductory Volume contains a series of documents that provide an introduction to the BP Group Recommended Practices and Specifications for Engineering (RPSEs). In particular, the 'General Foreword' sets out the philosophy of the RPSEs. Other documents in the Introductory Volume provide general guidance on using the RPSEs and background information to Engineering Standards in BP. There are also recommendations for specific definitions and requirements.

Application

This Guidance for Specification provides a specification for purchasing pressure vessels. It replaces BP Standard 194 Parts 1 and 2. It may be used with any recognised vessel code and adopts a different form from that used previously. The general section is applicable to all vessels but information specific to different materials is included in separate appendices. Having selected the material, it is intended that the general section and the appendix for only that material would be issued to vendors and that the others would be omitted.

Text in *italics* is Commentary. Commentary provides background information which supports the requirements of the Recommended Practice, and may discuss alternative options.

This document may refer to local, national or international regulations but the responsibility to ensure compliance with legislation and any other statutory requirement lies with the user. The user should adapt or supplement this document to ensure compliance for the specific application.

Changes from Previous Edition

This edition replaces that of December 1996 and has been updated to enhance the requirements for inspection (5.2.6) and to correct an error in Appendix D (D2, 'D' dimension in mm).

Feedback and Further Information

Users are invited to feed back any comments and to detail experiences in the application of BP RPSE's, to assist in the process of their continuous improvement.

For feedback and further information, please contact Standards Group, BP International or the Custodian. See Quarterly Status List for contacts.



1. INTRODUCTION

1.1 Scope

This BP GS states BP's general requirements for the mechanical design, materials selection, fabrication, inspection and testing of pressure vessels.

It may be used with any recognised pressure vessel code but is current with:

- [BS 5500](#): 1997.
- [ASME VIII](#) Divisions 1 and 2, 1995.

Information specific to these codes is indicated either BS or ASME.

Definitions and abbreviations are given in general Appendix A. Referenced documents are given in general Appendix B.

Material specific appendices are included as follows:

<u>Appendix</u>	<u>Material</u>
AA	C, C Mn steels,
BB	Vessels internally clad in austenitic stainless steel and nickel alloys
CC	Vessels in solid austenitic stainless steel and nickel alloys
DD	Cr Mo steels
EE	Duplex stainless steels
FF	Hastelloy and zirconium
GG	Titanium

Having selected the material, it is intended that this BP GS would be issued with only the relevant material specific appendix.

1.2 Responsibilities of the manufacturer

The manufacturer shall be responsible for mechanical design, provision of materials, fabrication, testing and quality of workmanship unless agreed otherwise with BP. Approval of the manufacturer's drawings by BP, the purchaser or an inspector does not relieve the manufacturer of any of these responsibilities.

The manufacturer shall ensure that technical and QA requirements specified in the enquiry and purchase documents are applied to all materials, equipment and services provided by sub-contractors.

1.3 Information to be agreed and documented

1.3.1 Information to be specified by the purchaser

A typical vessel data sheet is given in Appendix C. This, together with any supplementary information furnished by the purchaser, shall give the following details as applicable:-

- (1) Code
- (2) Coincident static design pressures and temperatures
- (3) Transient and/or cyclic pressures and temperatures.
- (4) Required creep or fatigue life
- (5) Corrosion allowance
- (6) Required materials
- (7) Nature of contents
- (8) Installation site and environmental conditions, e.g. design wind speed, minimum ambient temperature.
- (9) Construction Category (BS), Degree of Radiographic Examination (ASME), or equivalent
- (10) Foundation details
- (11) Nozzle details and orientations
- (12) Bolt tensioning equipment
- (13) Nozzle design loads or external piping loads
- (14) Emergency external loads such as earthquake, explosion blast and impact of projectiles
- (15) Name of Inspecting Authority (BS), Inspector (ASME), or equivalent.

1.3.2 Information to be supplied by the manufacturer

1.3.2.1 With quotation

When quoting, vendors shall confirm compliance with the code and this BP GS, or give any deviations therefrom. They shall also submit a typical quality plan for review by the purchaser, a manufacturing programme and a list of proposed sub-contractors/suppliers.

1.3.2.2 During design and manufacture

Before manufacture commences, the vendor shall submit for review by the purchaser a full set of drawings, calculations, weld and heat treatment procedures.

Detailed drawings of trays, packings and internals shall be provided where applicable

When aspects of design fall beyond the scope of the code, adequate calculations shall be carried out by the manufacturer to prove the integrity of the design. These shall be submitted to BP for approval.

The manufacturer shall resubmit any revisions of drawings for further approval by the purchaser.

No modifications shall be made to the approved design without the approval of the purchaser and the Inspecting Authority (BS), Inspector (ASME) or equivalent.

1.3.2.3 On completion of construction

On completion of construction, the manufacturer shall assemble and deliver with the vessel a dossier, which shall contain as a minimum the following:-

- (a) Data sheet and list of design requirements
- (b) All drawings, including the 'as built' drawings
- (c) List of the materials used in the construction of the vessel
- (d) Material test certificates for all pressure containing parts. These shall be to [BS EN 10204:1991 3.1B](#) for vessels to [BS 5500](#), or equivalent for other codes.
- (e) Details of any heat treatments carried out by the materials supplier. Records may also be required if specified by BP.

- (f) Weld seam identification chart
- (g) Qualified welding procedures
- (h) Welders' qualifications
- (i) Radiography and other NDT records. (Radiographs may be required if specified by BP).
- (j) Record of heat treatment during manufacture
- (k) Hydraulic test certificate
- (l) Inspection certificates
- (m) Details of any deviations from code and the acceptance thereof
- (n) Nameplate rubbing or photograph
- (o) Design calculations for pressure containing parts and vessel supports
- (p) Quality Plan signed by all inspection parties
- (q) Engineering concessions
- (r) Details of weld procedure plate when appropriate
- (s) A Certificate of Compliance Form X (BS); or [Manufacturer's Data Report U-1A](#) (ASME VIII Division 1); or [Manufacturer's Data Report A-1](#) (ASME VIII Division 2); or equivalent.
- (t) Any maintenance requirements.

1.4 Quality Assurance

- 1.4.1 The manufacturer will be expected to operate a quality system to satisfy the design code and this BP GS. It should be in accordance with the relevant part of [ISO 9001](#) or equivalent.
- 1.4.2 Positive Materials Identification/Alloy verification, when required by BP, shall be specified separately.

1.5 Site fabricated vessels

For any large vessel which is to be fully or partly fabricated on site, the design, construction, inspection and testing of the vessel shall be subject to approval by BP at an early stage.

2. MATERIAL SELECTION

2.1 Materials for low temperature applications

2.1.1 The requirements for vessels with design metal temperatures lower than -60 °C shall be specified by BP.

The addition of nickel to steels improves their low temperature toughness thus: 0.5 % Ni permits LT60 duty; 1.5 % Ni LT80; 3.5 % Ni LT80/100; 5 % Ni LT120; 9Ni LT196.

2.2 Materials for elevated temperatures

2.2.1 The maximum design temperature for carbon or carbon manganese steels shall be 425 °C. For temperatures above 400 °C such steels shall be fully killed. For vessels having a design temperature exceeding 425 °C, materials shall be 1 Cr 1/2 Mo or higher alloy steel.

2.2.2 C 1/2 Mo steel shall not be used, unless specifically approved by BP. Carbon Molybdenum steels shall not be used in hydrogen service.

2.2.3 For vessels where the design stress is creep-related and based upon the stress-to-rupture of the material, the 100 000h value shall be used unless otherwise specified by the purchaser.

2.3 Materials for aggressive environments

2.3.1 General

Where vessels are to operate in aggressive environments, the materials of construction shall be as specified by the purchaser and approved by BP.

In all the services described in sub-section 2.3, it is assumed that hydrocarbon is present.

2.3.2 Wet Sour Service

Wet sour service is the sour service defined in [NACE MR0175](#) and BP Group [GS 136-1](#). Materials for wet sour service shall be in accordance with BP Group [GS 136-1](#) and in particular:-

- tensile strength of Carbon and C Mn steels shall not exceed 585 N/mm²;
- vessels shall be stress relieved;
- Z quality plate shall be used to [GS 136-1](#) Appendix G. Under conditions of severe hydrogen charging (e.g. sour water containing cyanides) as specified by BP, the plate shall be HIC resistant to Appendix H of [GS 136-1](#). In either case, plate hardness shall not exceed 248 Hv₁₀.
- hardness in the weld metal shall comply with [NACE RP 0472](#) for refinery applications.

Per 3.2.3.1 of this BP GS, branch reinforcing pads shall not be used on wet sour service. Reinforcing plate for external attachments shall be made of Z-quality plate and vented.

Materials for wet sour service need to be resistant to both sulphide stress cracking and hydrogen induced cracking (see BP Group [GS 136-1](#)). Further requirements for wet sour service are given in [EEMUA 179](#).

Hardnesses in this standard are given in Hv₁₀ as this is regarded as the most accurate method for vessel manufacture.

2.3.3 Hydrogen Service with or without hydrogen sulphide

2.3.3.1 Hydrogen service is typically defined as applying when the partial pressure of hydrogen is 5 bar(abs) or greater.

2.3.3.2 For hydrogen service, C Mn steel is acceptable for design temperatures up to 230 °C.

Above 230 °C - 260 °C, depending on the partial pressure of hydrogen, Cr Mo steel shall be used per [API Publication 941](#).

Enhanced 2 1/4 Cr 1 Mo shall be limited to 425 °C.

This is due to concerns over hydrogen damage at temperatures higher than 425 °C. Enhanced 2 1/4 Cr 1 Mo obtains its strength from heat treatment at a relatively low temperature during plate manufacture.

For design temperatures between 425 °C and 454 °C, either standard 2 1/4 Cr 1 Mo or Vanadium modified Cr Mo steels shall be used.

For design temperatures between 454 °C and 482 °C, vanadium modified steels, i.e. 2 1/4 Cr 1 Mo V or 3 Cr 1 Mo V, shall be used.

The relevant standards for the enhanced, standard and Cr Mo V grades are given in Appendix DD.

- 2.3.3.3 For hydrogen service with hydrogen sulphide concentration greater than 0.02 mol %, and design temperature above 260 °C, austenitic stainless steel (Type 321 or 347) shall be used.

This is normally a cladding on a Cr Mo base material and is required for resistance to general corrosion (high temperature sulphidation). The Cr Mo is necessary to provide both high temperature strength and resistance to hydrogen damage from any hydrogen which diffuses through the cladding.

- 2.3.4 High temperature Hydrogen Sulphide

Where hydrogen sulphide is present at high temperature without hydrogen, the following materials shall be used: solid 5 Cr 1/2 Mo; solid 9 Cr 1 Mo; solid or clad 12 Cr steel (Type 405 or 410S); or an austenitic stainless steel cladding.

This is for resistance to high temperature corrosion, typically for design temperatures in excess of 280 °C. Solid 5 Cr 1/2 Mo or 12 Cr clad carbon steel are the usual options, the final selection being based on design, sulphur content in the process stream and cost.

- 2.3.5 Naphthenic acids

For duties with oils containing Naphthenic acids and a design temperature above 220 °C, 316L cladding shall be used with 2.5 % minimum molybdenum content.

316L cladding is usually required when the Total Acid number (TAN) exceeds 0.3mg KOH/g and the fluid velocity is greater than 50m/s.

- 2.3.6 Caustic Soda

For caustic soda in sour or non-sour service, post-weld heat treatment (PWHT) of carbon steel shall be in accordance with BP [GS 136-1](#).

BP GS 136-1 contains a figure extracted from the NACE Corrosion Data Survey which gives requirements for stress relief of fabrications used on caustic soda duty.

- 2.3.7 Other aqueous environments

In certain aqueous environments containing amines, carbon steel shall be subject to PWHT per BP [GS 136-1](#) to reduce the possibility of stress corrosion cracking. For hydrofluoric acid service, material selection shall be to licensor and BP requirements.

3. DESIGN

3.1 General

3.1.1 The code shall be specified by BP.

The code to be used depends on national regulations, material, design, fabrication and cost. Some current aspects of code selection are:

- *for C Mn steel up to 340 °C, [ASME VIII](#) Division 1 generally requires a greater thickness than [BS 5500](#) because the stresses in [ASME VIII](#) Part II Section D are limited by UTS/4 rather than UTS/2.35.*
- *[ASME VIII](#) Division 2 requires a thickness which is less than Division 1 and similar to [BS 5500](#). It requires more stress analysis than [BS 5500](#).*
- *[ASME VIII](#) includes titanium, hastelloy and zirconium ; [BS 5500](#) does not.*
- *[BS 5500](#) has well regarded external pressure, nozzle and saddle design methods. It also permits greater use of ultrasonics in lieu of radiography.*

3.1.2 The design pressure shall be assumed to be acting at the top of the vessel. Design of the vessel shall take full account of static head.

3.1.3 In addition to loads from pressure, static head and weight, the following shall apply as appropriate:

(a) Wind and earthquake

It shall be assumed that they will not occur simultaneously.

In the UK, there are currently two wind codes, [BS CP3](#) Chapter V Part 2 and [BS 6399:Part 2](#), which give different results. [BS CP3](#) is to be used pending resolution of the difference.

(b) Local loads from applied moments and forces on nozzles and at attachments. These shall either be as Appendix D of this BP GS or as given by the purchaser.

For small nozzles in vessels to [BS 5500](#), the method for calculating the stresses should be [BS 5500](#) Appendix G. Similarly for vessels to [ASME VIII](#), Welding Research Council [Bulletin 107](#) should be used. For large nozzles, consideration should be given to Welding Research Council [WRC 297](#).

The stresses are determined in a similar way in [BS 5500](#) Appendix G and [WRC 107](#) but they are added differently, with [BS 5500](#) being the more conservative. This comes from extensive research showing that under combined loadings it is possible to predict reasonably accurately the size of the maximum stress but not its location.

3.1.4 With the exception of vessels in zirconium (see paragraph FF2.4), all vertical vessels shall be designed to be self-supporting without guys or braces.

3.1.5 Vertical vessels with a height-to-diameter ratio exceeding 10 shall be checked for wind induced vibration. In cases where such vibrations give rise to stresses exceeding those permitted by the design code and/or to deflections of the vessel in excess of 60 mm per 10 m of height, the vessel shell and supporting skirt shall be suitably thickened and a helical vortex spoiler fitted to the upper third of the vessel shell.

3.1.6 Unless otherwise approved by BP, all vertical vessels shall be designed to permit application of a full hydraulic test to the vessel in the vertical position in its fully corroded condition. Except where statutory requirements exist to the contrary it may be assumed that the wind loading during full hydraulic test will not exceed 25 % of the design wind load. The membrane stress in the vessel during the test shall not exceed 90 % of the specified minimum yield strength for ferritics or 90% of the 1% proof stress for austenitics.

In cases where the requirement to hydraulic test in the vertical could result in an increase in cost, vendors shall provide details in their quotation for consideration by BP.

3.1.7 Vessels shall be designed so that all necessary in-service inspection can be carried out.

3.1.8 Vessels shall be checked for transportation and erection loads where significant. They shall be checked for abnormal maintenance loads where specified.

3.1.9 The corrosion allowance shall apply equally to the exposed surfaces of all non-removable internals but not to flange gasket faces.

For fillet and seal welds on internal attachments, the corrosion allowance shall be added to the required throat thickness.

For jacketed vessels, corrosion allowances shall be applied to both the internal and the jacket side of the shell plate.

A corrosion allowance shall not be provided on vessels which are clad with a metal but shall be provided on vessels coated with a non-metal.

3.1.10 Any requirement for Design by Analysis shall be indicated by the vendor and approved by the purchaser.

In addition to a Design by Formula section for the design of conventional components, most codes have a Design by Analysis section for other components. There are two elements to Design by Analysis: analysis (to calculate stress or another quantity relevant to failure) and assessment.



For the assessment of stress, the method generally used in the codes is known as stress classification and was drawn up mainly to assess stresses calculated by thin shell discontinuity analysis; it is not ideally suited to assess results from finite element analysis. Finite element analysis provides a means of calculating stress but, depending on geometry and failure mode, there may be other means (e.g. published stress concentration factors, thin shell discontinuity analysis) which are more appropriate. In the case of buckling, shape imperfections are very significant and the method in BS 5500 Appendix M may provide the best means for determining allowable pressure for cylinders. With fatigue, weld geometry is very important and published test data may be more relevant than numerical analysis.

Before starting a design by analysis, the designer should define the failure mode and consider the combination of analysis and assessment which offers the best means of checking the component for that failure mode.

3.2 Nozzles

3.2.1 Construction details

Small branches shall comply with the requirements in Table 1.

Branches of nominal pipe size NPS 2 (DN 50) and larger shall be constructed using seamless pipe with an outside diameter of not less than 60 mm. Alternatively, branches may be constructed from long forged weld neck flanges (LFWN) of not less than 40 mm outside diameter, in which the nozzle neck and flange are forged in one piece.

For branches NPS 12 (DN 300) and larger, formed plate necks may be used. Longitudinal welds in such branches shall be 100 % radiographed.

Pipe Outside Diameter d mm	Nozzle Design
$40 \leq d < 60$ ie. NPS 1 ½ DN 40	Shall be either LFWN or as for smaller nozzles below.
$d < 40$ ie. NPS 1 1/2 DN 40 and below	Shall be either a LFWN or a seamless pipe of minimum o.d. 60 mm and min. thickness sch.160 welded to a forged reducer of the required size.

Table 1 Design of small bore nozzles

The junction between a nozzle and a shell is an important stress concentration. It is essential to match the two in a way which, without undue cost, minimises the stress concentration and permits adequate inspection.

3.2.2 Nozzle design methods

The design methods in BS 5500 Appendix F and ASME VIII UG-37 are empirical methods based on area replacement. The method in BS 5500 3.5.4 includes a calculation of the maximum stress at the nozzle and an assessment of its cyclic performance in service. It is more analytical and generally requires less reinforcement than area replacement methods.

3.2.3 Reinforcing pads

3.2.3.1 Reinforcing pads shall not be used where any of the following conditions apply:-

- (a) Operating temperature exceeds 300°C.
- (b) Operating partial pressure of hydrogen exceeds 20 bar(ga).
- (c) Operating partial pressure of hydrogen exceeds 5 bar(ga) and operating temperature exceeds 150°C.
- (d) For ferritic vessels, operating temperature is below minus 50°C.
- (e) Wet sour service.
- (f) Hydrofluoric (HF) acid service.
- (g) Design is to be for minimum internal inspection.

Reinforcing pads shall not exceed the vessel thickness.

A compensation pad is not considered a suitable way of compensating a nozzle under certain conditions. At high temperatures (as (a) above), differential thermal stresses can crack the fillet weld. Where there is a penetrating fluid (as (b) and (c) above), the fluid may permeate the nozzle weld and enter the gap between the pad and the vessel. For low temperatures (as (d) above), the fillet weld provides a stress raiser in a region where the stresses are indeterminate (as they are dependent on the fit of the pad to the shell). Where full inspection for cracking or corrosion is essential (as (e) and (f) above), the pad obstructs inspection of the nozzle weld and the shell. This also applies where a design for minimum internal inspection is required.

Reinforcing pads shall be provided with a vent hole tapped 1/4 inch API to permit an air test of the attachment welds at 1 bar(ga). The holes shall be left open during welding and PWHT. Where a reinforcing pad consists of two or more plates welded together after fitting on the vessel, a vent hole shall be provided for each sealed section. Where vessels are insulated for hot service, the vent holes shall be fitted with vent lines projecting beyond the insulation. On vessels insulated for cold service, vent lines shall not be fitted.

3.2.4 Nozzles shall meet the following requirements where applicable:-

- (a) Branches should normally be of the set-in design and shall be double welded, i.e. from both inside and outside.

- (b) In exceptional cases when set-in connections are not practicable, set-on branches may be used. In the case of set-on branches, the edges of the holes in the shell plate shall be examined to prove that the plate local to the connection is not laminated. Magnetic particle inspection (MPI) and ultrasonics shall be used on ferritic material and dye penetrant inspection (DPI) on austenitic material. The examination shall also be conducted after welding to ensure that lamellar defects have not developed during welding.
- (c) Nozzles shall not pass through weld seams. Compensation pads should not cover weld seams unless agreed by the purchaser.
- (d) Pipe couplings, socket welded, single fillet welded, studded and screwed connections are not permitted unless specified by BP.
- (e) The first flange on the bottom branch of a vertical vessel supported on a skirt should normally be located outside the skirt.
- (f) Where welds of nozzle stubs to external piping require PWHT, the minimum standoff of the stub from the outside of the vessel shall be $10 \times \sqrt{R t_a}$ unless otherwise approved by BP. (Where R = nozzle internal radius and t_a = stub thickness).
- (g) Internal pipework welded to the vessel nozzles shall be designed to the vessel code. Removable internal pipework shall be flanged close to the vessel wall and designed to an appropriate code.
- (h) Where relatively long, thin branches are unavoidable and particularly on thin walled vessels, the design shall incorporate suitable stiffening.

3.2.5 Hydraulic bolt tensioners shall be used:-

- (a) on all joints with nominal bolt diameter 2 inch and over;
- (b) on duties where the nominal bolt diameter is 1½ inch and over, and the flanges are either on hydrogen service or are Class 600 or over;
- (c) when specified by BP for nominal bolt diameter 1 inch and over.

Bolts for bolt tensioning shall be extended by the length of one nut and suitably protected by a cap during service.

Stress relaxation of bolts is a feature of any bolt tightening method. Bolt tensioners minimise stress relaxation providing an adequate number of tools is used. The optimum number of tools for hydraulic bolt tensioning is 50 % of the number of bolts. Fewer tools are sometimes used but in critical applications it should be not less than 50 % .

The purchaser should issue details of the hydraulic bolt tensioning equipment on site for the vendor to ensure that the flange design is suitable.

3.3 Manholes and inspection openings

The number and size of inspection openings shall be specified by BP. It shall as a minimum comply with [BS 470](#) and manways shall not be less than 460mm inside diameter. Where a vessel has large removable internals, the preferred size of manhole is 610 mm inside diameter.

It is strongly recommended that a manhole is provided in all vessels where corrosion, erosion or fouling may occur, and in all vessels in cyclic service subject to fatigue. Where a manhole is not feasible due to small vessel diameter, consideration shall be given to flanging the vessel head.

Where manways are in positions where access is limited (e.g. high up on tall vessels), consideration shall also be given to the size of the platform in the event that emergency treatment of personnel is required.

All internal edges on manhole and inspection openings shall be radiused to at least 3 mm.

The design of davits for handling manhole covers, trays, relief valves, etc. shall comply with any statutory requirements of the country in which they will be used. In the absence of statutory requirements, davits shall comply with [BS 5276](#) Part 1, particularly noting the hook-bolt diameters.

3.4 Gaskets

3.4.1 Gaskets shall comply with BP [GS 142-7](#).

Gaskets for manholes shall be spiral wound gaskets or as specified by the purchaser.

Two spare sets of gaskets shall be supplied for all manhole flanges and blanked nozzles.

3.5 Internal structures

3.5.1 On distillation, absorption and extraction columns, the design of internals and their attachments shall comply with BP [GS 146-1](#).

- 3.5.2 The vessel manufacturer shall furnish and install all internal support rings and other internals where specified by the purchaser.
- 3.5.3 The design of trays, tray supports or other internals welded to the vessel shall take into account the effect of differential strains which may arise due to transient temperature/pressure conditions in service as specified, during PWHT or hydraulic test.
- 3.5.4 The design of internals shall permit all reasonable internal inspection.
- 3.5.5 The design of internal fittings shall ensure that they are proof against loosening by vibration.
- 3.5.6 Any vessel internals not covered by BP [GS 146-1](#) shall meet the following requirements:-
- (a) Fixed internal rings, plates, piping supports, etc., shall have a minimum thickness equal to the greatest of:-
 - (1) Thickness for strength + 2 x Corrosion Allowance
 - (2) 3 mm + 2 x Corrosion Allowance
 - (3) 6 mm
 - (b) Coils and other internals shall, where necessary, be supported by temporary stiffeners to prevent damage during transportation and erection. These shall not be welded to the vessel.
 - (c) Removable sections shall be sized to pass through vessel manways.
 - (d) Unless otherwise specified by the purchaser, liquid outlets on vessels shall be provided with a vortex breaker.
 - (e) Where internal pads are provided, the method of welding and venting them shall be subject to approval by BP.
 - (f) Unless otherwise approved by the purchaser, single-sided fillet welds or intermittent welds shall not be used for the attachment of internals to the shell.
- Additional requirements for internal supports in clad vessels are given in Appendix BB.*
- (g) Removable internals shall be installed after any PWHT has been carried out.

3.6 Supports and external attachments

3.6.1 Vessels not larger than 1 m diameter or 2 m high may be supported on legs. Vessels subjected to severe vibrations arising through process flow, reciprocating machinery etc. shall not be supported on legs.

3.6.2 Vertical vessels shall normally be provided with a support skirt, which shall be in accordance with the following requirements:-

- (a) Subject to there being no overriding statutory requirements, vessel skirts of 2400 mm diameter or greater shall be provided with two unobstructed access openings of not less than 600 mm diameter.

When the skirt is less than 2400 mm diameter, one unobstructed access opening of 600 mm diameter shall be provided.

In some circumstances, a lockable, removable grill may be required on each opening to prevent unauthorised access.

- (b) Provision shall be made for proper ventilation of the skirt.
- (c) Pipework shall not be routed through an access opening in a skirt.
- (d) The skirt shall be attached so that its mean diameter coincides approximately with the vessel mean diameter. Attachment welds shall be continuous and shall not cover a shell to head weld.
- (e) On high temperature reactors:
- an insulated air space shall be provided at the skirt to shell junction to minimise thermal stress.
 - the attachment of the skirt to the shell shall be designed to provide adequate resistance to fatigue from the thermal stresses due to start-up and shutdown.

For this, two designs may be considered. Butt welding the skirt to an external projection on the vessel made by either weld build-up or forging. Or fillet welding the skirt to a cylindrical sleeve which is itself fillet welded to the outside of the vessel.

- (f) Anchor bolts shall be supplied in multiples of four. The minimum anchor bolt size shall be M20 diameter.

- (g) Base plate design shall be based on an allowable bearing pressure of 4.5 N/mm^2 resting on concrete. On steelwork, the appropriate bearing pressure shall be taken from the relevant steelwork code (e.g. [BS 449](#) Part 2).

- 3.6.3 Where codes do not have rules for saddle design, [BS 5500](#) Appendix G shall be used.

In essence, it is the 'Zick' method but it has been substantially improved by research in recent years.

Provision shall be made for thermal expansion of the vessel by means of slotted holes. A ventilation hole tapped 1/4 inch API shall be fitted in each saddle pad at its lowest point.

- 3.6.4 External attachments shall be of the same grade of material as the pressure shell unless agreed otherwise by BP.

Doubling plates shall be provided at any external attachments where unacceptable stresses would otherwise occur. Corners of doubling plates shall be rounded to a radius not less than 50 mm. Each pad shall contain one ventilation hole tapped 1/4 inch API in each sealed compartment.

- 3.6.5 Where stiffeners to resist external pressure are fitted, they shall be positioned at least 100 mm clear of circumferential seam welds, branches and other permanent attachments.

- 3.6.6 Lifting lugs or trunnions shall be provided on vertical vessels to facilitate handling during transport and erection at site. The load factor for their design shall be 1.5 unless otherwise agreed by BP.

For some reactors, lifting from a suitably designed nozzle may be proposed in order to avoid large permanent attachments where corrosion could occur.

- 3.6.7 Insulation supports, stiffening rings and external attachments shall be designed and constructed to prevent the channelling and holding of rainwater, which can cause under-lagging corrosion. The design of insulation supports shall be approved by BP.

With insulation support rings on vertical vessels, there shall be a continuous gap of not less than 30 mm between the vessel and the inside edge of the support ring. The standout of the outer edge of the ring shall be 10 mm less than the thickness of the insulation. The distance between rings shall be approximately 3000 mm, but not more than 3700 mm. Support brackets which are welded to the shell shall be fitted before PWHT.

For the design, supply and installation of thermal insulation, reference should be made to BP Group [RP 52-1 Thermal Insulation](#).

Water retained in insulation in the temperature range 0 - 120 °C can cause rapid general corrosion in carbon steel and stress or pitting corrosion in stainless steel. The purchaser is strongly advised to scrutinise any proposed designs of external attachments to ensure that water cannot be retained.

3.6.8 Two earthing bosses shall be provided on each vessel, and shall be in accordance with either Figure 1 or the purchaser's specification.

3.6.9 Nameplates, shall be supported from a permanent non-pressure part of a vessel, e.g. a skirt or saddle. They shall, in all cases, be mounted on a plate or bracket which stands clear of the supporting surface by approximately 40 mm.

Where a vessel comprises separate compartments, a name plate shall be provided for each compartment

Nameplates shall be of stainless steel with the required data stamped, or preferably, engraved. Lettering shall be a minimum of 4 mm high. It shall show at least the following information:-

- (a) Order number
- (b) Item number
- (c) Date of manufacture
- (d) Order placed by
- (e) Manufacturer's name
- (f) Manufacturer's serial number
- (g) Design code and its date
- (h) Construction category (BS), Degree of Radiographic Examination or equivalent.
- (i) Heat treatment
- (j) Design pressure at coincident temperature. Unless otherwise stated, the units are: bar(ga) and °C (for BS vessels) and psi(ga) and °F (for ASME).
NB: For some vessels, maximum and minimum design temperatures should be stated. More than one set of conditions may be required to fully define the operating envelope of the vessel.
- (k) Test pressure new
- (l) Test pressure corroded
- (m) Total weight empty
- (n) Any statutory markings required

Additionally a space shall be provided for a works identification number of nine digits and, as appropriate, the inspector's stamp.

3.7 Design of welds

3.7.1 All main seam welds shall be full penetration and, where possible, double sided. All nozzle to shell or head welds shall be full penetration.

3.7.2 Where required by the fatigue design rules, vessels subjected to cyclic loading shall have all butt welds ground smooth internally and externally, and all fillet welds ground so as to blend smoothly into the parent material.

3.7.3 Where a weld seam and an attachment weld intersect or lie within 40 mm of each other, an examination of the seam weld shall be carried out prior to making the attachment weld. The examination shall be for a distance of 100 mm or three times the shell thickness, whichever is the greater, from the point where the welds lie closest. The inspection shall be as shown in Table 2.

BS Construction Category (ASME Joint efficiency)	Preparation and Examination
1 (1)	Grind main weld flush and surface flaw detect (on both sides for full penetration welds). Examine with ultrasonics or X-ray. Surface flaw detect both main seam and component weld on completion.
2 (0.85) & 3 (0.7)	As above but omit ultrasonic examination.

Table 2 NDT required where welds lie within 40 mm

3.7.4 The minimum leg length of internal fillet welds shall be 5 mm plus the corrosion allowance.

4. MANUFACTURE AND WORKMANSHIP

4.1 Cutting, forming and tolerances

4.1.1 Where heads are formed in one piece from more than one plate, weld seams shall be fully radiographed before forming and again in the knuckle region after forming. 100 % surface crack detection shall be made after forming.

In general, a weld subject to forming shall have full radiographic or ultrasonic examination before forming and surface crack detection after.

4.1.2 Tolerances on vertical vessels shall be to Figure 2 and on horizontal vessels to Figure 3.



4.2 Welded joints

- 4.2.1 When the vendor has directly applicable pre-qualified welding procedures, this shall be indicated in the bid together with proposals for welding processes and techniques. The procedures may be required for review at the bid clarification stage but in any event shall be submitted for review early in the contract.

Where required by the purchaser, procedures shall be specifically qualified.

When either the material or the vendor is new to BP, it may be necessary to carry out specific qualification tests of the welding procedures. This can be time consuming, particularly if it has to be done on contract material. Where re-qualification is required, the order should state whether contract material must be used or the tests may be made on material to the same specification but purchased in advance of the contract material.

- 4.2.2 Where alloy steel vessels are welded by an automatic or semi-automatic process, the filler wire shall be of the same nominal composition as the parent plate. The addition of alloys via the flux, other than that required to make up for losses e.g. in the arc, is not permitted for any material. The filler wire shall be homogeneous and not of a self-shielding type.

Low nickel steels are usually welded with consumables of matching composition, whilst high Ni steels (5 % and 9 %) are often welded with nickel based alloy consumables.

- 4.2.3 Weld procedures shall be subject to approval by the purchaser prior to the start of fabrication.

- 4.2.4 Vessels for sour service with a design temperature lower than -30 °C require special consideration.

For sour service, NACE MR0175 limits the maximum nickel content to 1 %, thereby limiting the materials available for low temperature sour service.

- 4.2.5 When arc-air gouging of plate with a minimum specified tensile strength greater than 430 N/mm² is proposed, the procedure shall be submitted for purchaser approval. It shall include preheating, where appropriate, and allow for grinding after gouging.

- 4.2.6 For any material, the use of welding processes other than the shielded metal arc (SMAW), submerged arc (SAW) or gas tungsten inert gas (GTAW) processes, shall be subject to prior approval by the purchaser. As far as possible the submerged arc process shall be used for all main seams in carbon and ferritic alloy steels. Where this is not possible the manual metal arc process may be used.

Processes such as GMAW (Gas metal arc welding) and FCAW (Flux cored arc welding) are becoming more widely used. There is no intent to specifically exclude them but their application must be individually and carefully assessed. In particular, the high rate of metal deposition may lead to lack of fusion and the mechanical properties may not be as good as those obtained from the three welding processes above.

- 4.2.7 The use of resistance or flash butt welding techniques, such as a stud gun, for attachment of studs, pins or other fittings for the support of insulation or refractory, either internal or external, shall be approved by BP.

4.3 Surface finish and painting

- 4.3.1 External preparation, priming and painting shall be in accordance with BP [GS 106-2](#). It shall only be carried out after all pressure tests have been satisfactorily completed.
- 4.3.2 Details of any internal coating and the surface finish required shall be specified by BP.
- 4.3.3 Vessels shall be despatched clean and dry, with rust preventative on all machined surfaces.

5. INSPECTION AND TESTING

5.1 General

- 5.1.1 Vessels shall be inspected to the requirements of the code by the Inspecting Authority (BS), Inspector (ASME) or any other specified authority.

Regardless of inspection work carried out by others, BP reserves the right to carry out its own inspection.

- 5.1.2 All welders engaged in the site erection of vessels shall be performance-tested in accordance with the requirements of the code under supervision of the Inspecting Authority (BS), Inspector (ASME) or equivalent. The performance tests will normally be carried out at site.
- 5.1.3 The NDT schedule and all NDT procedures shall be subject to approval by the purchaser.

All personnel concerned with inspection, interpretation and NDT shall be qualified to at least PCN Level 2. ASNT Level 2 may be considered providing the qualification has been obtained through examination by an independent organisation. Evidence of the qualification shall be available to the purchaser for verification.



The purchaser reserves the right to test and monitor the performance of any NDT operator employed by the vendor, or his sub-supplier, and to exclude any that are deemed unsatisfactory.

Calibration certificates for NDT equipment shall be available for inspection at all times.

5.1.4 The complete length of all welds on lifting and tailing attachments (e.g. attachment of lug to pad, pad to vessel, etc.) shall be examined by NDT for surface flaws.

5.1.5 For ferritic material where the plate thickness exceeds 50 mm, ultrasonic examination of all longitudinal and circumferential seam welds shall be made in addition to radiography.

As thickness increases above 50 mm, the information available from a radiograph becomes limited. Radiography and ultrasonics detect different types of defects and can therefore be used to supplement each other.

5.1.6 Vessels requiring radiography, ultrasonics and PWHT shall be subject to radiography and ultrasonics before PWHT, and ultrasonics after.

Radiography of thick walled vessels (50 mm and above) before and after PWHT is expensive and time consuming. Ultrasonics is more appropriate for the detection of planar defects as these are more likely to propagate during PWHT. Ultrasonic examination is therefore better for the final examination of thick walled vessels in ferritic materials.

5.1.7 Radiographic examination during fabrication shall be carried out with X-ray equipment unless the use of isotopes is specifically approved by the purchaser.

5.1.8 MPI techniques liable to damage the vessel by arcing are not permitted.

For the examination of nozzles or holes, the magnetic field may be produced by the threading bar or coil techniques.

5.1.9 On ferritic vessels subject to PWHT, the shell to nozzle welds on nozzles greater than NPS 8 (DN 200) shall be subject to MPI after PWHT.

5.1.10 Any fracture mechanics assessment of a defect in the vessel shall be carried out in accordance with Appendix E of this BP GS and the assessment submitted for BP approval.

5.1.11 Vessels for duty in wet sour service shall be subject to:

- 100 % radiography;
- 100 % wet fluorescent MPI on internal welds;

- 100 % MPI on external welds.

The location of any temporary construction welds shall also be subject to MPI as above.

Final NDT shall be carried out after PWHT.

- 5.1.12 During in-service inspection of vessels for wet sour service, a coating (e.g. an inhibitor) shall be applied after the wet fluorescent dye to prevent undue hydrogen damage during re-commissioning.

Further details are given in [EEMUA 179](#).

- 5.1.13 Irrespective of code requirements, welds shall be free from all surface breaking defects.

5.2 Inspection requirements specific to BS 5500

- 5.2.1 Welders engaged on site fabrication of vessels shall be performance tested at site under representative conditions in accordance with the requirements of [BS EN 287](#) and [BS 5500](#) Enquiry Case 97, and shall be approved on the basis of X-ray examination.

- 5.2.2 Ultrasonic inspection shall be made on plates, nozzle pipe and nozzle forgings in carbon steel over 50 mm thick and in low alloy (materials in BS 5500 bands M2-M9) over 25 mm thick. This is to ensure the items are free from laminations or other injurious defects. Flanges and blank covers are exempt from these thickness limits and shall be inspected as specified by the purchaser.

Plates and pipe shall be tested in accordance with [BS 5996](#) to Acceptance Level B2/E2, but for critical applications (e.g. sour service) B4/E2 shall be required (per BP [GS 136-1](#)).

Forgings shall be tested in accordance with [BS 4124](#). Acceptance criteria shall be as follows. Any area giving an indication equal to or greater than the signal received from a 3 mm flat-bottom hole shall be cause for rejection. Multiple indications with an amplitude exceeding 50 % of the indication for the calibration hole, accompanied by a loss of back reflection exceeding 50 %, shall also be cause for rejection. Any indication which results in a complete loss of back wall echo shall be cause for rejection.

For angle beam examination, indications which are equal to or greater than those obtained from a rectangular notch 25 mm long and having a depth not greater than 5 % of the nominal wall thickness are cause for rejection.

- 5.2.3 When set-on or set-in nozzles are examined by ultrasonics, the procedure shall be in accordance with [BS 3923](#) Part 1 level 2.
- 5.2.4 Table 5.7(1) of [BS 5500](#) for radiographic acceptance levels shall apply with the following additions:
- (a) Maximum length of individual solid inclusions shall be 50 mm. The distance between individual defects shall be greater than the larger of two adjacent defects, otherwise they shall be treated as one.
 - (b) The total length of all imperfections shall be less than 10 % of the total weld length.
- 5.2.5 Table 5.7(2) of [BS 5500](#) for ultrasonics acceptance levels shall apply with the following addition: in principle, no undercut shall be allowed on equipment operating below 0 °C.
- 5.3 Inspection requirements specific to ASME Boiler & Pressure Vessel Code, Section VIII**
- 5.3.1 The acceptance standard for ultrasonics examination of forgings shall be as 5.2.2 unless otherwise specified.
- 5.3.2 MPI shall be per [ASME VIII](#) Division 1 Appendix 6 and DPI shall be per Appendix 8.
- 5.3.3 The extent of radiographic examination shall be as per [ASME VIII](#) Division 1 UW-11. The acceptance standard for full radiography shall be per UW-51 and for spot radiography UW-52.
- 5.3.4 Ultrasonic examination of welds and acceptance criteria shall be per [ASME VIII](#) Appendix 12.
- 5.4 Pressure test**
- 5.4.1 All vertical vessels shall be pressure tested in the horizontal position with suitable support. The design of vertical vessels shall enable them to be tested in the vertical.
- 5.4.2 The gaskets, joint rings and bolting, used on all flanged connections during pressure testing shall be identical to those for operation.
- 5.4.3 No repairs shall be carried out after hydraulic testing without the approval of the purchaser.

- 5.4.4 The hydraulic test fluid shall be fresh water unless prior approval has otherwise been given by the purchaser. For ferritic vessels, the minimum temperature shall not be less than 7 °C.
- 5.4.5 As soon as possible after completion of the hydraulic test, all vessels shall be drained and dried throughout.
- 5.4.6 A pneumatic leak test shall be carried out on all nozzle reinforcement pads at a pressure of 1.0 bar(ga).
- 5.5 Final Inspection**
- 5.5.1 Prior to despatch, a final inspection shall be made by the manufacturer to ensure all aspects of the Quality Plan have been complied with.

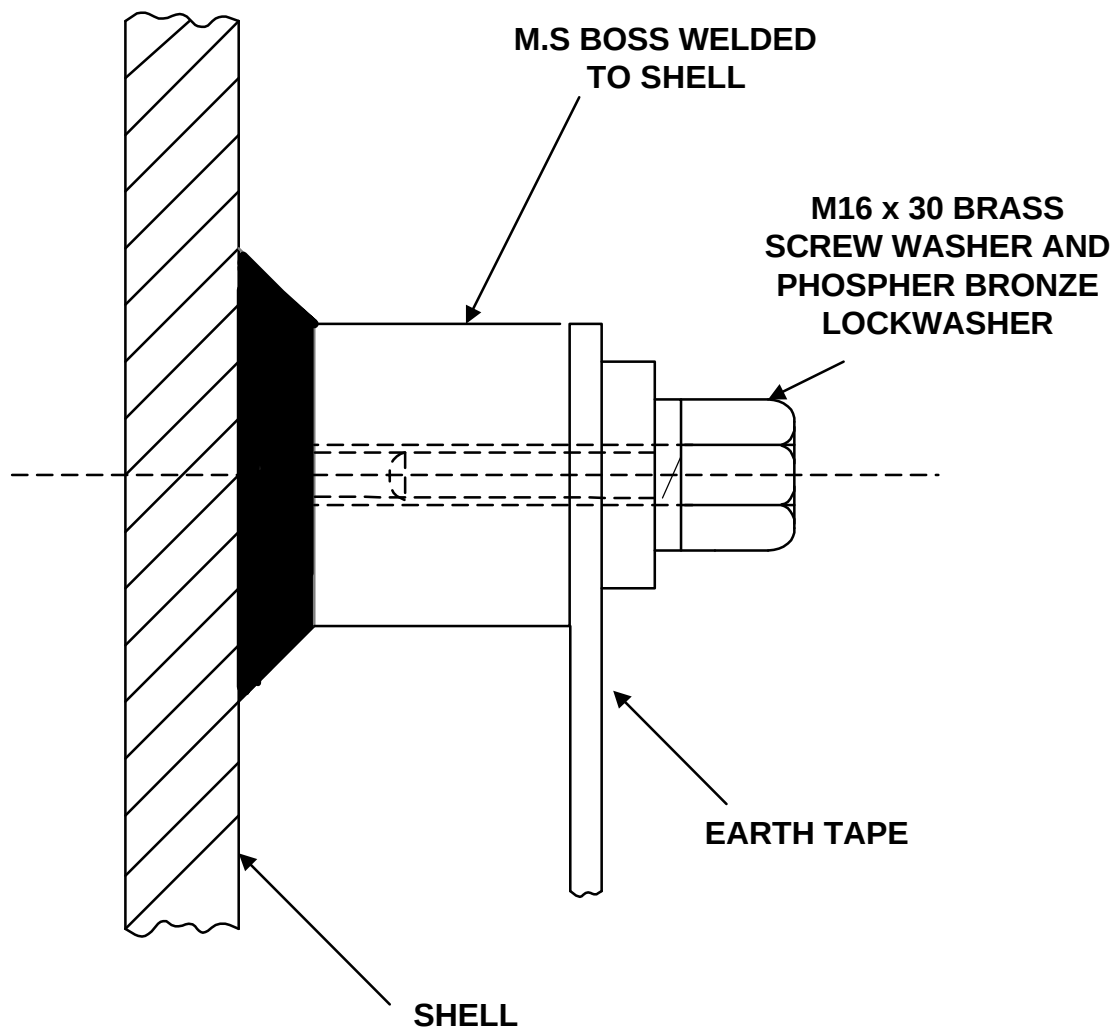


FIGURE 1
EARTHING BOSS

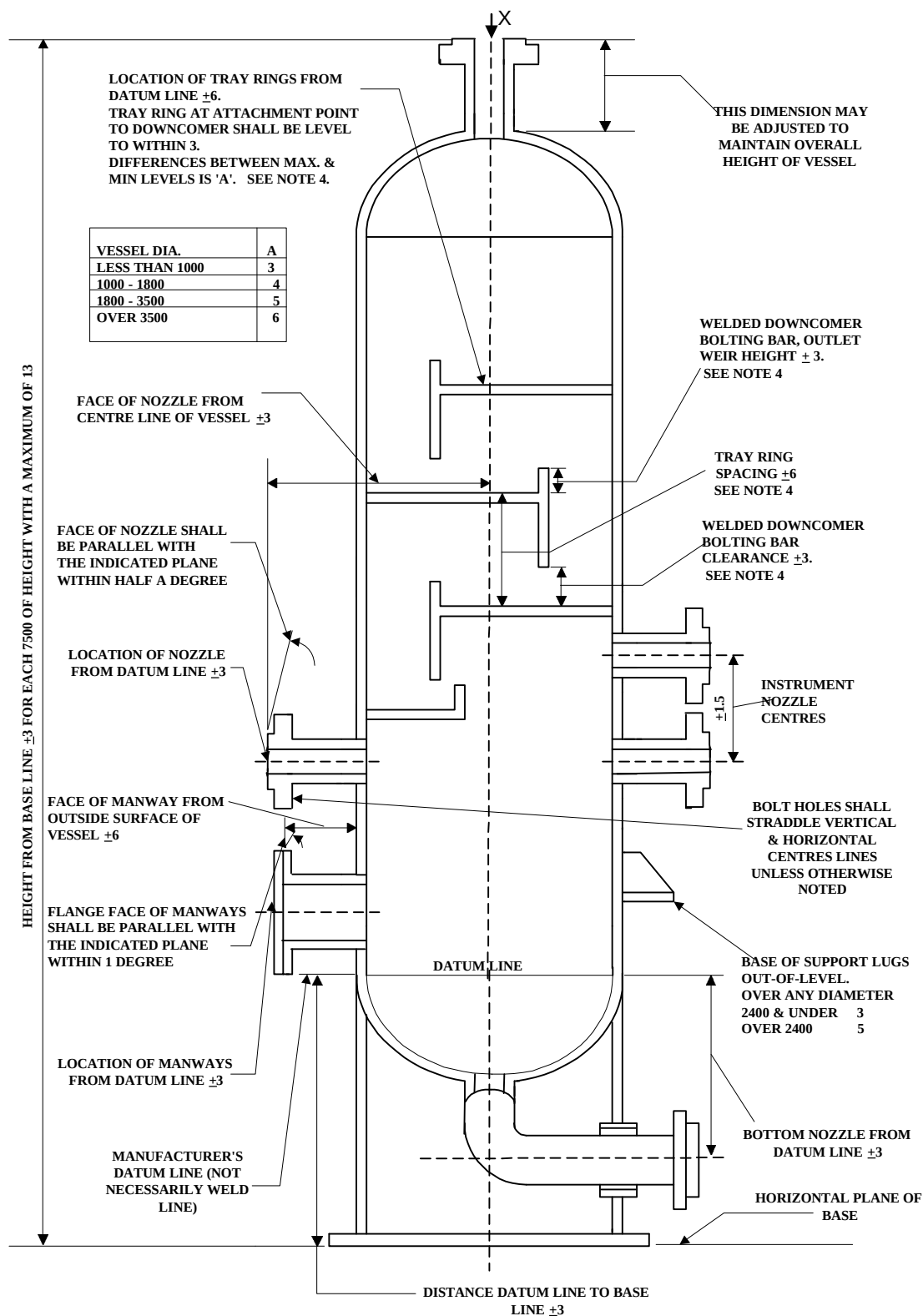
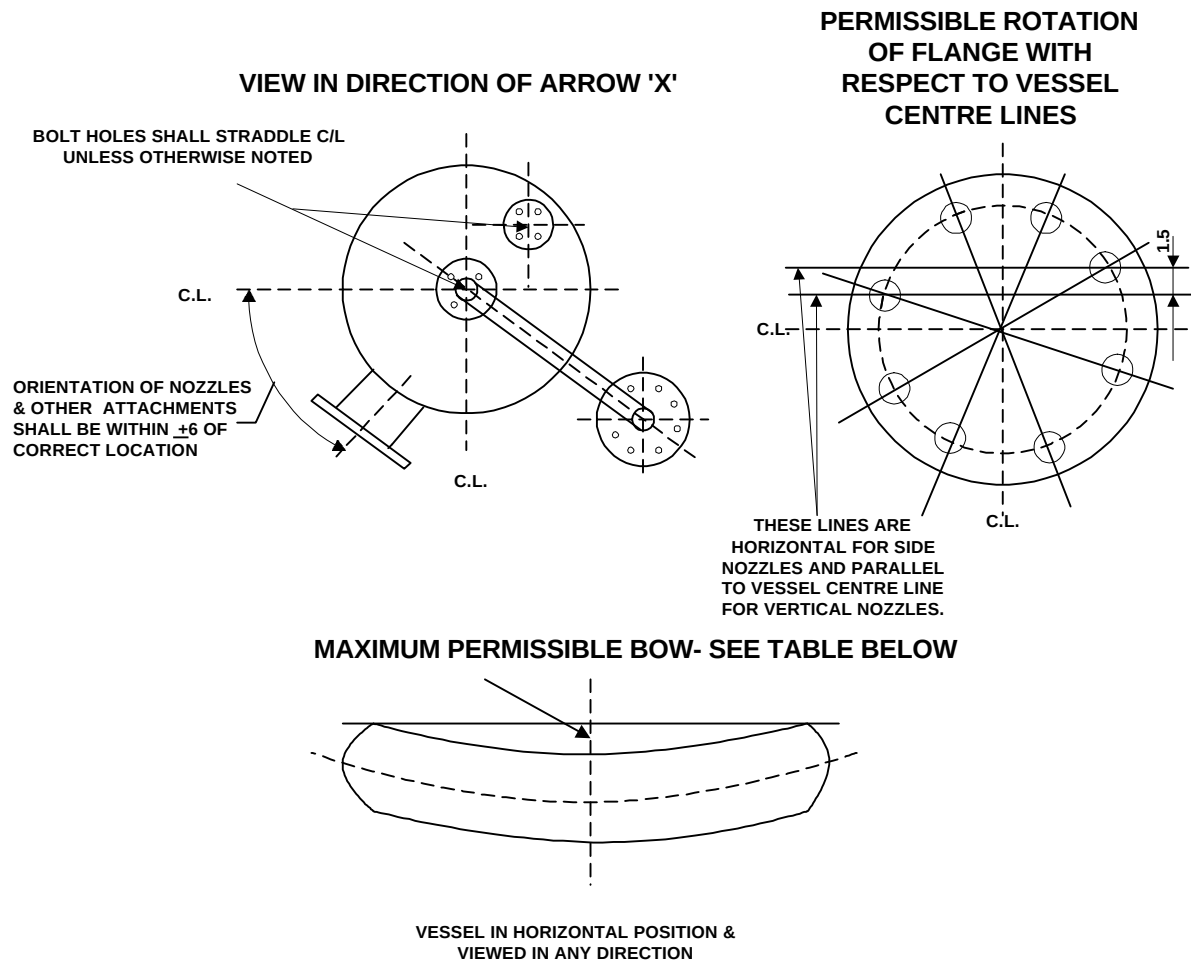


FIGURE 2 (PAGE 1 OF 2)
VERTICAL VESSELS: TOLERANCES



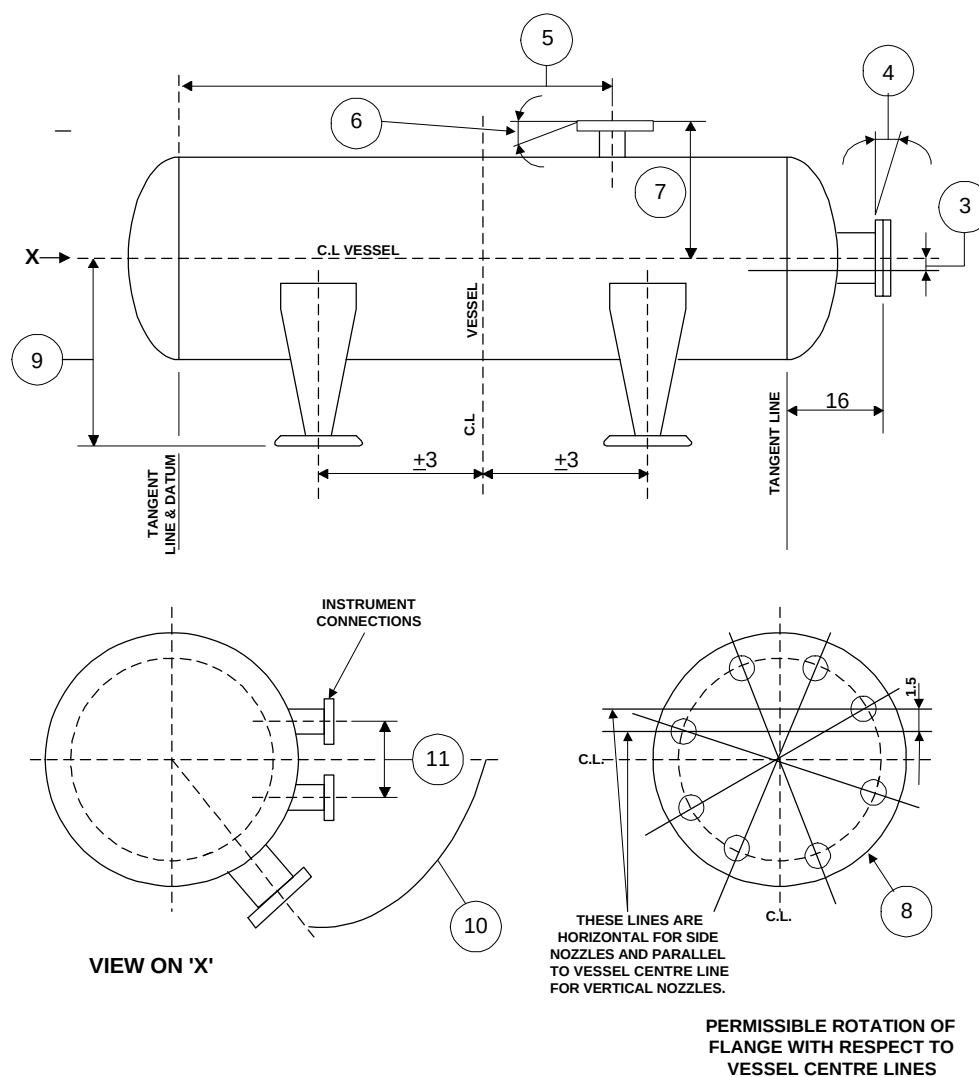
VESSEL	HEIGHT	VESSEL DIAMETER & MAX PERMISSIBLE BOW			
		600 TO 1200 INCL	OVER 1200 TO 1700 INCL	OVER 1700 TO 2300 INCL	OVER 2300
-	3000	2	2.5	2	2
3000	6000	3	5	4	3
6000	9000	4	7.5	6	4
9000	12000	5	10	8	5
12000	15000	6	12.5	10	6
15000	18000	7	15	12	7
18000	21000	8	17.5	14	8
21000	24000	10	20	16	10
24000	27000	12	22.5	18	12
30000	-	14	25	20	14

NOTES:

1. DIMENSIONS ARE IN MILLIMETRES.
2. THESE TOLERANCES SUPPLEMENT CODE TOLERANCES.
3. MACHINED FLANGE FACES SHALL BE FLAT TO WITHIN ± 0.1 .
4. THESE TOLERANCES APPLY TO THE WELDED SUPPORTS FOR INTERNALS. TOLERANCES FOR INTERNALS ARE SPECIFIED IN BP GROUP GS 146-1.

FIGURE 2 (PAGE 2 OF 2)

VERTICAL VESSELS: TOLERANCES



NOTE:

1. DIMENSIONS ARE IN MILLIMETRES.
2. THESE TOLERANCES SUPPLEMENT THE CODE TOLERANCES.
3. LOCATION OF MANWAYS FROM DATUM LINE ± 13
4. FLANGE FACE OF MANWAY SHALL BE PARALLEL WITH THE INDICATED PLANE WITHIN 1°
5. LOCATION OF NOZZLES FROM DATUM LINE ± 13
6. FACE OF NOZZLES SHALL BE PARALLEL WITH THE INDICATED PLANE WITHIN $\frac{1}{2}^\circ$
7. FACE OF NOZZLE FROM CENTRE LINE OF VESSEL ± 3
8. BOLT HOLES SHALL STRADDLE VERTICAL & HORIZONTAL CENTRE LINES UNLESS OTHERWISE NOTED.
9. DISTANCE FROM DATUM LINE TO BASE LINE ± 3
10. ORIENTATION OF NOZZLES & OTHER ATTACHMENTS SHALL BE WITHIN ± 6 OF CORRECT LOCATION.
11. INSTRUMENT NOZZLE CENTRES ± 1.5
12. MACHINED FLANGE FACES SHALL BE FLAT TO WITHIN ± 0.1

FIGURE 3

HORIZONTAL UNFIRED PRESSURE VESSELS - TOLERANCES

DEFINITIONS AND ABBREVIATIONS

Definitions

Standardised definitions may be found in the BP Group RPSEs Introductory volume.

Abbreviations

API	American Petroleum Institute
ASS	Austenitic stainless steel
ASNT	American Society for Non-Destructive Testing
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
AWS	American Welding Society
BS	British Standard
DN	Nominal pipe diameter
DPI	Dye penetrant inspection
CTOD	Crack-Tip Opening Displacement
FCAW	Flux Cored Arc Welding
FN	Ferrite Number
GMAW	Gas Metal Arc Welding
GTAW	Tungsten Inert Gas Welding
HAZ	Heat Affected Zone
HIC	Hydrogen Induced Cracking
J	A measure of fracture toughness
LFWN	Long forged weldneck flange
MPI	Magnetic particle inspection
NACE	National Association of Corrosion Engineers (US)
NDT	Non-Destructive Testing
NPS	Nominal pipe size
PCN	Personnel Certification in Non-Destructive Testing
PD	Published Document
PWHT	Post-weld heat treatment
SMAW	Shielded Metal Arc Welding
SAW	Submerged Arc Welding
TAN	Total Acid Number
TWI	The Welding Institute

LIST OF REFERENCED DOCUMENTS

A reference invokes the latest published issue or amendment unless stated otherwise.

Referenced standards may be replaced by equivalent standards that are internationally or otherwise recognised provided that it can be shown to the satisfaction of the purchaser's professional engineer that they meet or exceed the requirements of the referenced standards.

Note: This is a list of codes, standards and other documents referred to in this BP GS. A reference to these documents invokes the latest published issue or amendment unless otherwise stated.

ISO standards

ISO 9001 Quality systems - Model for quality assurance in design/development, production, installation and servicing.

British Standards

BS 427: Part 1 Method for Vickers hardness test. Part 1. Testing of metals.

BS 449 Part 2 Specification for the use of structural steel in buildings

BS 470 Inspection, access and entry openings for pressure vessels.

BS 1501: Part 1 Steels for fired and unfired pressure vessels. Plates. Part 1. Specification for carbon and carbon manganese steels.

BS 3923: Part 1 Methods for ultrasonic examination of welds. Part 1. Methods for manual examination of fusion welds in ferritic steels.

BS 4124 Methods for ultrasonic detection of imperfections in steel forgings.

BS 5276: Part 1 Pressure vessel details (dimensions). Part 1. Specification for davits for branch covers of steel vessels.

BS 5500: 1997 Unfired fusion welded pressure vessels.

BS 5996 Specifications for acceptance levels for internal imperfections in steel plate, strip and wide flats, based on ultrasonic testing.

BS 6399:Part 2 Loadings for buildings: code of practice for wind loads.

BS 7448 Part 1 Method for determination of K_{Ic} , critical CTOD and critical J values of metallic materials

BS EN 287 Parts 1& 2	Approval testing of welders, Fusion welding - Part 1 - Steels Part 2 Aluminium and aluminium alloys.
BS EN 288-3	Specification and approval of welding procedures for metallic materials - Part 3 Welding procedure tests for the arc welding of steels.
BS EN10028	Specification for flat products made of steels for pressure-purposes
-1:1993	General requirements
-2:1993	Non-alloy and alloy steels with specified elevated temperature properties
-3:1993	Weldable fine grain steels, normalized.
-4:1995	Nickel alloy steels with specified low temperature properties
BS EN 10045	Charpy impact test on metallic materials
-1	Test method (V and U notches)
BS EN 10204 : 1991	Metallic Products - Types of Inspection Documents

British Standard Codes of Practice and Published Documents

BS CP3 Chpt.V Pt.2	Code of basic data for the design of buildings, Chapter V Loading, Part 2 Wind loads.
BS PD 6493 :1991	Guidance on methods for assessing the acceptability of flaws in fusion welded structures.
BS PD 6539 : 1994	Methods for the assessment of the influence of crack growth on the significance of defects in components operating at high temperatures.

American Standards

[ASME Boiler and Pressure Vessel Code](#)

Section II	Part D Materials
Section VIII	Rules for Construction of Pressure Vessels Divisions 1 and 2
Section IX	Qualification standard for welding and brazing procedures, welders, brazers and welding and brazing operators.
ASTM A 263	Corrosion-Resisting Chromium Steel-Clad Plate, Sheet and Strip.



ASTM A 264	Stainless Chromium-Nickel Steel-Clad Plate, Sheet and Strip.
ASTM A 265	Nickel and Nickel Base Alloy Clad Steel Plate
ASTM A 387	Pressure Vessel Plates, Alloy Steel, Chromium-Molybdenum
ASTM A 578	Straight-Beam Ultrasonic Examination of Plain and Clad Steel Plates for Special Applications.
ASTM E 165	Liquid Penetrant Inspection Method.
ASTM E 562	Determining Volume Fraction by Systematic Manual Point Count.
ASTM E 813	Test Method for J_{IC} , a Measure of Fracture Toughness.
ASTM G 48	Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by the Use of Ferric Chloride Solution.
API 941	Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants.
NACE MR0175	Standard Material Requirements - Sulphide Stress Cracking Resistant Metallic Materials for Oilfield Equipment.
NACE RP 0472	Methods and Controls to Prevent In-service Cracking of Carbon Steel Welds in P-1 Materials in Corrosive Petroleum Refining Environments.

Other external publications

TWI Report 5632/18/June 93	Recommended Practice for determining volume fraction of ferrite in duplex stainless steel weldments by systematic point counting.
EEMUA publication 179:1996.	A working guide for carbon steel equipment in wet H ₂ S service.
Welding Research Council Bulletin 107	Local Stresses in Spherical and Cylindrical Shells due to External Loadings, 1965.
Welding Research Council Bulletin 297	Supplement to WRC 107, 1984.



BP Group Documents

BP RP 52-1	Thermal Insulation
BP GS 106-2	Painting of Metal Surfaces
BP GS 118-7	Fabrication of Pipework to ANSI B31.3, Part 3: Austenitic and Duplex Steel Pipework, Cupro-Nickel and Nickel Base Alloy Pipework
BP GS 136-1	Materials for Sour Service
BP GS 146-1	Distillation, Absorption and Extraction Column Internals
BP GS 142-7	Gaskets and Jointing
BP GS 142-9	Bolting for Flanged Joints (Unified Inch Series)



APPENDIX C

TYPICAL DATA SHEET FOR PRESSURE VESSELS

Nozzle Schedule							Design Data				
Mk	No off	Size	Rating	Facing	Service	Stand out	Vertical/Horizontal*	Inside Dia.	Tan/tan length		
							Design Code				
							Criticality Rating				
							Corrosion Allowance				
							Specifications				
							Design Pressures	Int.	at temp		
								Ext.	at temp		
							Min Design Temperature				
							Joint Efficiency	Shell	Heads		
							Construction Cat. (BS)				
							Stress Relief	Required	Not Req'd	*	
							Wind Loading Std		Wind Vel.		
							Wind Moment at base	Erection			
								Operating			
							Shear Force at base				
							Support	Skirt	Saddles	Legs	
									Other	*	
							Fabrication	Shop	Site	*	
							Lifting Lugs	Required	Not Req'd	*	
Painting and Insulation							Materials				
Surface	Int.						Shell				
Preparation	Ext.						Heads				
Ext. Painting							Cladding				
Int. Painting							Impact Tests	at temp.		Not Req'd	*
Fire Proofing	o/s skirt	i/s skirt	btm. head				Cladding Shear Test	Required	Not Req'd	*	
Insulation							Vessel Supports				
Weights							Attachments	Int.	Ext.		
Empty						Operating					
Test						Loose ints.					
Capacity											
Reference Drawings							Trays				
							External	Neck	Pipe	Plate	
							Nozzles/M.H.	Flg.			
							Internal	Neck	Pipe	Plate	
							Nozzles	Flg.			
							External	Neck			
							Bolting	Flg.			
							Internal	Neck			
							Bolting	Flg.			
							Gaskets	M.H.			
							Nozzles				
General Notes							Inspection Data				
1. Manway to be supplied complete with cover, stud bolts, gasket and davit.							Radiography	Full	Spot	None	*
2. Standouts of nozzles in shell are measured from centre-line vessel to flange face.							Hydrostatic Test	Shop	at temp		
3. Tray elevations are to top of support rings.							Pressures	Field	at temp		
4. Fixed internals to be supplied by vessel fabricator.							Ultrasonic Tests	Required	Not Required		*
5. Vessel to comply with local and national requirements.							Crack Detection	MPI	DPI		*
6. Flange bolt holes to straddle main vessel centre-lines.							Production Weld Tests	Required	Not Required		*
							Inspection by:				
							* Delete those not required				
JOB TITLE											
ORDER NO											
NO REQD.											
UNIT											
DATE							REV	DATE	REMARKS	BY	APP
ORIGINATING CENTRE							DATA SHEET FOR PRESSURE VESSELS				SHEET OF

Units to be: bar (ga), °C, kg, m, J (BS)
psi (ga), °F, lb, ft, ft-lb (ASME)



NOZZLE LOADS ON PRESSURE VESSELS

- D1 The standard nozzle loads to be used for vessel design shall be either from the purchaser's standard or as given below.

Pipework exerts forces and moments on a vessel due to thermal expansion, internal pressure and dead weight. On a project, pipework design usually occurs after the order for the vessel has been placed. Hence standard loads are specified as provision against the actual loads calculated later in the design of the pipework. Where the actual loads are significantly lower than the standard loads, and there is a cost benefit, the actual loads may be substituted.

Local load analysis is not required on either blind flange connections or instrument connections.

- D2
- | | |
|-------|---|
| D | Nominal diameter of nozzle (mm) |
| F_R | Positive or negative radial force (N) |
| M_L | Longitudinal moment on the cylinder (Nm) |
| M_C | Circumferential moment on cylinder (Nm) |
| M_B | Resultant bending moment on sphere (Nm) |
| P | Internal pressure of the vessel (bar(ga)) |

- D3 The effect of torsion and shear forces on the shell shall be ignored.

- D4 The loads at the intersection of the axis of the nozzle with the mid-plane of the shell shall be evaluated from the following formulae:

- (a) Radial Force (for Cylinders and Spheres)

$$F_R = \pm 20D^{1.2} + PD^{0.85}$$

The effect of both positive and negative values of the forces shall be evaluated.

- (b) Moment

- (1) For a cylinder

$$M_L = M_C = (1.75D^{1.4}) + (5.0 \times 10^{-6})PD^{2.9}$$

- (2) For a sphere

$$M_B = \sqrt{2}M_L$$

FRACTURE MECHANICS ANALYSIS

- E1 For vessels outside the creep range, [BS PD 6493](#) should be applied to assess defects for fracture, fatigue and environmental cracking. For vessels operating in the creep range, [BS PD 6539](#) should be used.
- E2 Where specified by BP, materials shall be subject to CTOD or J testing. Test procedures (e.g. to [BS7448](#) Part 1 or [ASTM E 813](#)) shall be subject to approval by BP.

For reactors and critical vessels, samples of unwelded and welded plate should be kept so that, in the event of defects being found, specific testing may be done.

IMPACT TESTING OF FERRITIC STEELS

F4. MATERIAL IMPACT TEST REQUIREMENTS

F1 Charpy testing shall be in accordance with [BS EN 10045](#) or equivalent.

Required impact test values are given in the appropriate material specific appendix of this BP GS.

All Charpy V-energy requirements refer to the minimum average value from a set of three tests, with no single value less than 75 % of the specified minimum average, irrespective of the test specimen size.

F2 The position of the impact test specimens for tests of weld metal and HAZ shall be as follow unless otherwise approved by BP:-

- (i) Weld metal centreline.
- (ii) Fusion line.
- (iii) Fusion line plus 2 mm.
- (iv) Fusion line plus 5 mm.

VESSELS IN CARBON AND CARBON MANGANESE STEELS

AA1 GENERAL

- AA1.1 Shell and head thickness, including corrosion allowance, shall not be less than 6 mm. Corrosion allowance shall be a minimum of 2 mm.
- AA1.2 For service conditions other than those defined in BP [GS 136-1](#), the maximum allowable phosphorus and sulphur content shall not exceed 0.020 % each in the ladle analysis.
- For any welded component, carbon content shall not exceed 0.25 %.
- AA1.3 Cold formed carbon steel ends shall be heat treated by normalising.
- AA1.4 Storage sphere fittings, e.g. branches and column support connections, which are welded to the sphere plates and given PWHT in the shop, shall be subject to MPI prior to despatch to site.

AA2 IMPACT TESTING

- AA2.1 The Charpy V values obtained from the testing of the weld metal and heat affected zone, as required in Appendix F of this BP GS, shall not be less than that permitted by the code for the base material.

Note the conversion of 1.5J per°C in the range 18-47J in [BS 5500](#) Appendix D.

- AA2.2 For vessels designed to operate above 0 °C, insulated or not, the following applies:-
- i) when minimum ambient temperature is minus 20 °C or below, impact testing shall be per code.
 - ii) when minimum ambient temperature is above minus 20 °C but less than 0 °C, impact testing shall not be required when either:
 - the shell thickness does not exceed that shown in Table AA.1; or
 - a set of impact tests on the weld metal of a test piece representative of a shell butt weld gives an average of 40J at 0 °C.

Heat treated condition	Maximum thickness (mm) to waive impact testing when -20 °C < min. amb. temp. < 0 °C	
	Cat. 1 (BS) or full radiog. (ASME)	Cat. 2 (BS) or spot radiog. (ASME)
As Welded	16	12
Subject to PWHT	40	30

Table AA.1 Shell thickness below which impact testing may be waived

Table AA1 permits a greater thickness for vessels with full NDE because the likelihood of defects being present which could initiate brittle fracture is smaller.

AA2.3 Vessels made in C and C Mn steel thicker than 20 mm and not subject to PWHT, are required to meet the impact test requirement below when the initial hydraulic test of the vessel will take place on site.

The requirement is: three sets of impact tests on weld metal from test pieces representative of the shell butt welds shall give an average of 40J at 0 °C.

AA3 SPECIFIC TO BS 5500

AA3.1 Nominal design stress for steels to BS EN 10028 shall be derived using BS 5500 Appendix K.

BS1501 Part 1 has been superseded by BS EN 10028 -1 (General requirements), -2 (Non-alloy and alloy steels) and -3 (Fine grain steels). However, steels to BS 1501 are still obtainable and the design stresses remain in BS 5500.

VESSELS INTERNALLY CLAD IN AUSTENITIC STAINLESS STEEL AND NICKEL ALLOYS

BB1. TERMS

In this appendix, the following terms are used:

‘clad plate’ is plate which has been purchased by the vessel fabricator already clad;
‘weld overlay’ refers to the process in which most of the cladding is applied by weld deposit during vessel fabrication; and
‘cladding re-instatement’ refers to the process used on all clad vessels in which small areas at nozzles and attachments, where the cladding has been removed for welding of the base material, are re-clad by welding.

BB2. DESIGN

- BB2.1 Design calculations for clad vessels shall exclude the lining thickness.
- BB2.2 Internal fillet welds shall be kept to the minimum in clad vessels. When the design temperature is greater than 300 °C, full penetration welds shall be used in preference to fillet welds wherever possible.
- BB2.3 In reactor vessels with design temperature above 300 °C (e.g. hydrocrackers and hydrofiners), major supports for catalyst beds shall comprise integral rings rather than 'footstep' brackets. The rings shall be made either by forging of the vessel strake or by weld build-up.
- This is to avoid the stress concentrations which occur with large intersecting fillet welds and can cause in-service cracking.*
- On such reactors, flanges shall be raised face and gaskets shall be graphite filled spiral wound. Ring type joints shall not be used.
- BB2.4 On vessels with weld overlay, internals may be welded to the overlay without stripping back to the base material.
- BB2.5 On vessels made from clad plate, lightly loaded attachments (e.g. tray support rings) may be welded directly to the cladding without stripping back to the base material providing:-
- the weld is essentially unidirectional (eg. at a tray support ring) rather than multi-directional (eg. at a bracket); and
 - the area is checked with ultrasonics for lack of bond prior to welding.

Where these conditions are not met, or large loadings are to be applied to the attachment, the cladding shall be cut back. The attachment shall be directly welded to the shell by an appropriate procedure before cladding re-instatement.

BB2.6 Clad nozzles may be manufactured from clad plate or by weld overlay. All internal surfaces of the nozzle and the flange face shall be clad. Loose linings are not permissible.

BB2.7 Small diameter, solid alloy nozzles may be used instead of clad nozzles when the design temperature is less than 300 °C. Above this, a check of the thermal stresses shall be made before solid nozzles are used on clad vessels.

BB3. CLAD PLATE

BB3.1 Clad plate shall be manufactured by a process such as roll bonding or explosive cladding. A continuous metallurgical bond shall be achieved between the base material and the alloy cladding.

Clad plates shall conform to one of the following ASTM specifications: [A 263](#) for chromium steel cladding; [A 264](#) for austenitic stainless steel (ASS) cladding and [A 265](#) for nickel alloy cladding.

BB3.2 An ultrasonic check of the bond between the alloy cladding and the base plate shall be carried out to acceptance level S7 of [ASTM A578](#). 100 % of the interfacial area shall be examined.

Acceptance level S7 requires that unbonded areas which cannot be encompassed within a 25 mm circle shall be repaired. This is subject to a maximum area of 1.5 % of the clad surface. Level S7 is more stringent than S6 but this is usually cost effective.

BB3.3 When specified by BP, the surface of the cladding shall be subject to DPI in accordance with [ASTM E165](#). Relevant linear or rounded defect indications are not acceptable.

BB3.4 Following forming and any associated heat treatment, the knuckle region of heads pressed or spun from alloy clad plate shall be subject to a repeat of the ultrasonic examination detailed in BB3.2. DPI to BB3.3 shall also be performed.

BB4. WELD OVERLAY AND CLADDING RE-STATEMENT

BB4.1 General

- BB4.1.1 Weld cladding shall generally consist of a minimum of two layers of weld metal. The initial layer may be deposited with a more highly alloyed welding consumable than that employed for the subsequent layer(s) in order to take into account dilution of the cladding by the base material. Fabricators offering the use of a single layer overlay will be required to produce substantial metallurgical and analytical evidence of the acceptability of their overlaying procedures. Acceptance of any single layer overlaying technique shall be at the discretion of BP.

Certain low dilution overlay welding techniques i.e. submerged arc strip and electroslag overlaying, may be capable of achieving the required overlay analysis in a single layer.

- BB4.1.2 Cladding re-instatement shall be by welding. Covering by a fillet welded strip is not acceptable.

- BB4.1.3 For any weld cladding, the welding process shall not transfer alloying elements via the flux to achieve the specified weld metal composition.

- BB4.1.4 Each batch of welding consumables, including each batch of submerged arc or electroslag flux, shall be tested in accordance with the approved weld overlay procedure to ensure that the resultant overlay will comply with the specified microstructure and chemical analysis.

- BB4.1.5 The surface of weld cladding should be essentially smooth in the as-welded condition. Adjacent weld beads shall fuse and blend to create a flat surface without any interbead grooving.

It is important that the weld clad surface should be as smooth as possible to minimise the retention of dye penetrant fluids in surface irregularities. While penetrant retention can be dealt with during vessel manufacture, excessive retention during routine in-service inspection can lead to unnecessarily prolonged interpretation and jeopardise shutdown schedules.

- BB4.1.6 For all service duties, the maximum hardness of the weld deposited overlay shall comply with the requirements of [NACE MR0175](#) unless specified otherwise by the purchaser.

Unless more stringent requirements apply, the maximum base material hardness shall be 248 Hv₁₀ for sour service and 325 Hv₁₀ for non-sour service.

BB4.2 Chemical composition and ferrite check

- BB4.2.1 With ASS, the chemical composition of the final surface on both weld overlay and cladding re-instatement shall comply with that of the corresponding AWS welding consumable classification.
- BB4.2.2 The welding consumable composition for ASS cladding reinstatement shall match that of the alloy cladding except that type 304L cladding shall be reinstated with a type 308L or type 347 consumable.
- BB4.2.3 Welding consumables used for all ASS weld overlays that are subject to PWHT shall be selected to minimise sigma phase formation during the heat treatment. The ferrite content of ASS overlays shall be in the range 3 - 8 % in the as-welded and in the post-weld heated condition.
- BB4.2.4 For cladding re-instatement on 13 Cr steel clad vessels, an ASS consumable of the 309 type shall generally be used.
- BB4.2.5 Welding consumables for cladding re-instatement on nickel alloy clad vessels shall be agreed with the purchaser.

BB4.3 Qualification of weld procedures

- BB4.3.1 Qualified welding procedures for weld overlay and cladding re-instatement shall be submitted to the purchaser for approval. Once approved, no changes to the essential variables shall be made without prior approval by the purchaser.
- BB4.3.2 Welding procedures shall be qualified in accordance with [ASME IX](#) and the test plate subject to DPI to the requirements of BB4.4.3 as applied in production. For weld overlay, the procedures shall also be subject to the ultrasonic examination of BB4.5.3.
- BB4.3.3 A macro section of the overlay shall be prepared and a series of hardness measurements (Hv₁₀) shall be made across the interface at three separate locations.
- BB4.3.4 With ASS overlays, the ferrite content shall be determined. Measurement shall be by metallographic determination and an instrumental technique. The chemical analysis results shall be used to calculate the ferrite content per the Schaeffler-DeLong diagram.
- BB4.3.5 The achievement of the required weld overlay thickness shall be demonstrated during procedure qualification.
- BB4.3.6 The need for any corrosion testing on the welding procedure qualification will be specified by the purchaser.

BB4.4 Inspection - general

- BB4.4.1 The ferrite content of all ASS weld deposited overlays shall be directly measured by an instrument approved by the purchaser. Secondary standard Ferrite Number (FN) blocks shall be available to confirm the calibration of the equipment.

Ferrite measurements shall be made adjacent to all analytical checks on the as-deposited weld metal. These measurements shall be repeated following any PWHT.

- BB4.4.2 Overlay thickness shall be monitored during production by means of mechanical callipers and/or ultrasonic testing.

- BB4.4.3 The surface of all weld deposited cladding shall be subject to 100 % DPI in accordance with [ASTM E 165](#) following any PWHT, but prior to hydraulic testing. Materials for the DPI shall be halogen free.

The acceptance standard shall be: the surface shall be free from cracks, fissures or other linear indications. Any individual rounded indication shall not exceed 1.5 mm in diameter. The sum of the diameters of rounded indications in any 100 mm diameter circle shall not exceed 4.5 mm.

BB4.5 Inspection - specific to weld overlay

- BB4.5.1 The surface of weld overlay shall be subject to chemical analysis; the technique and equipment used shall be subject to approval by the purchaser.

A minimum of two checks shall be made in each shell course and each head with a minimum of one check for each 5 m length of main seam. A minimum of one check shall also be made at each nozzle attachment weld. The test locations shall be selected by the purchaser.

- BB4.5.2 For ASS weld overlay, 10 % of the analytical checks in BB4.5.1, subject to a minimum of two samples, shall be performed on a bulk sample removed from the weld deposit. The chemical analysis shall be used to calculate the ferrite content per the Schaeffler-DeLong diagram in order to meet the limit in BB4.2.3.

- BB4.5.3 Weld deposited overlay shall be subject to ultrasonic examination in accordance with [ASTM A 578](#) primarily to establish the presence of any lack of fusion between the weld deposit and the base material.

10 % of the overlay deposited during each shift shall be examined. Any area of lack of fusion or other defect that cannot be contained within a 25 mm diameter circle shall be cause for rejection and 100 % of the overlay completed during the shift by the equipment/operator concerned shall be examined. Defects shall be repaired by an approved procedure and re-examined.

BB4.6 Inspection - specific to cladding re-instatement

BB4.6.1 Cladding re-instatement at main seam, nozzle and internal attachment welds shall be subject to chemical analysis; the technique and equipment used shall be subject to approval by the purchaser.

A minimum of one check analysis shall be made for each 5 m length of seam weld and one check shall be made at each nozzle and each internal attachment weld. The test locations shall be selected by the purchaser.

BB5. TESTING

BB9.1 For ASS vessels, the test fluid shall not contain more than 30 ppm chlorides. Providing the vessel is thoroughly washed out using chloride free water as soon as testing is complete, a chloride content of up to 100 ppm may be permitted subject to approval by the purchaser.

BB9.2 ASS vessels shall be dried within 48 hours of draining, using swabs or a flow of air at ambient temperature. Heat shall not be applied.

BB10. HIGH TEMPERATURE EMBRITTLEMENT IN SERVICE

BB10.1 12 Cr clad vessels subject to long term exposure at high temperature (circa 400 °C) may embrittle. Before any welding for repairs or modification is undertaken on such vessels, the following shall be carried out:

- the design of the repair or modification shall be reviewed to ensure that residual stress from the welding is minimised;
- the base material shall be kept above an appropriate minimum temperature (in excess of 20 °C) until the vessel returns to service.
- where possible, a hardness survey should be made across a section of the clad plate and the impact properties in the base material checked.



The cladding itself may embrittle or there may be an embrittled region (of high hardness) in the base material due to migration of carbon from the base material to the stainless steel. Either can lead to cracking.

VESSELS IN SOLID AUSTENITIC STAINLESS STEEL AND NICKEL ALLOYS

- | | |
|------|---|
| CC1 | Corrosion allowance shall be zero unless specified otherwise. Shell and head thicknesses shall not be less than 4 mm. |
| CC2 | Formed heads in ASS shall be solution annealed after forming; in nickel alloys, heat treatment shall be individually specified by BP. |
| CC3 | PWHT of ASS vessels shall only be with BP approval. |
| CC4 | The top 600 mm of the vessel skirt shall be in alloy material; the rest may be carbon steel. |
| CC5 | The ferrite content of ASS weld metal shall be in the range 3 - 8 %. |
| CC6 | The ferrite content of ASS weld metal shall be directly measured by an instrument approved by the purchaser. Secondary standard Ferrite Number (FN) blocks shall be available to confirm the calibration of the equipment. |
| CC7 | The extent of DPI on welds shall be specified by the purchaser. Welds shall be free from cracks and fissures. Materials for DPI shall be halogen free. |
| CC8 | The test fluid for ASS vessels shall not contain more than 30 ppm chlorides. Providing the vessel is thoroughly washed out using chloride free water as soon as testing is complete, a chloride content of up to 100 ppm may be permitted subject to purchaser approval. |
| CC9 | ASS vessels shall be dried within 48 hours of draining, using swabs or a flow of air at ambient temperature. Heat shall not be applied. |
| CC10 | ASS vessels which operate in the range 51 - 120 °C shall be painted externally per BP Group Document GS 106-2 .

<i>This is to avoid chloride stress corrosion cracking. Consideration should also be given to the use of more resistant materials.</i> |
| CC11 | Insulated ASS vessels operating below 50 °C shall be painted externally to BP Group Document GS 106-2 .

<i>This is to avoid pitting corrosion in the event that the insulation becomes wetted with aqueous chloride solutions.</i> |

APPENDIX DD

VESSELS IN Cr Mo STEELS

DD1 The grades of material to which this appendix applies are shown in Table DD1.

	BS 5500	ASME II Part D
1 1/4 Cr 1/2 Mo	BS1501-622	A-387 11 Cl 1 A-387 11 Cl 2
2 1/4 Cr 1 Mo	BS1501-622	A-387 22 Cl 1 A-387 22 Cl 2
Enhanced 2 1/4 Cr 1 Mo	Enquiry Case 5500/73	Code Case 1960-1
2 1/4 Cr 1 Mo 1/4 V	-	Code Case 2098-1
3 Cr 1 Mo 1/4 V	-	A-336 F3V

Table DD.1 BS & ASME specifications for Cr Mo steels

DD2 For all grades, residual elements in the parent materials shall be controlled such that:-

$$J = (Si + Mn) \times (P + Sn) \times 10,000 < 100$$

where Si, Mn etc. are the compositions of each element in weight %;

Cu = 0.2 % max and Ni = 0.3 % max.

In weld metal, the following shall apply:

$$X = (10P + 5Sb + 4Sn + As) \times 100 < 15$$

where P, Sb etc. are the compositions of each element in weight %;

Charpy V impact testing of plate, forgings, weld metal and heat affected zone shall give 55J avg. energy absorption, 40J min. at -20 °C.

For enhanced 2 1/4 Cr 1 Mo, the different Charpy V value here from that in BS 5500 EC 73 merely to conform with the step cooling test in DD4 below.

Maximum hardness in base metal, weld metal and heat affected zone shall be 235 Hv₁₀.

The chemical analysis limitations ensure good resistance to creep embrittlement for 1 1/4 Cr 1/2 Mo and to temper embrittlement for 2 1/4 Cr 1Mo. The impact and

hardness values confirm adequate toughness in zones which, if incorrectly welded or heat treated, can be brittle. Samples for mechanical test shall be given a PWHT for a period equal to three times that required for the vessel. This is to permit one heat treatment of a vessel section, one for a closing seam and one in the event of a repair. 235 Hv₁₀ (not 248) is the internationally recognised value.

DD3 Material to A-387 shall be purchased either normalised and tempered or quenched and tempered.

For 1 1/4 Cr 1/2 Mo for high temperature service, Class 1 is preferred.

Class 1 has better resistance to creep embrittlement. In addition, optimum resistance to long term creep embrittlement is obtained by minimising impurity levels, applying a relatively high PWHT temperature and minimising stress raisers at welds.

For 2 1/4 Cr 1 Mo, both classes 1 and 2 are acceptable but the measured tensile strength of the plate shall not exceed 690 N/mm².

With 2 1/4 Cr 1 Mo, crack propagation in hydrogen service is much more rapid if the tensile strength is above 690 N/mm².

DD4 With both enhanced and normal 2 1/4 Cr 1 Mo, the resistance of the base metal and weld deposit to temper embrittlement shall be checked by a step cooling test. Samples are heat treated for: 1h at 595 °C; 15h at 540 °C; 24h at 525 °C and 60h at 495 °C. The initial 55J Charpy V transition temperature + 2.5 x the increase in that temperature shall be less than 10 °C.

Steel suppliers should have results available from previous tests on comparable material. If not, testing on contract material may be necessary. However, for each vessel, step cooling tests of the weld metal shall be made. Every batch of weld consumable shall be tested.

DD5 With both enhanced and normal 2 1/4 Cr 1 Mo, welds shall have a dehydrogenation heat treatment for 3h at 300 °C immediately after welding.

VESSELS IN DUPLEX STAINLESS STEEL

EE1. SCOPE

- EE1 This appendix includes additional requirements for the design, fabrication and testing of vessels manufactured from duplex stainless steel.

EE2. DESIGN

- EE2.1 No corrosion allowance is required.
- EE2.2 The nominal design stress shall be taken from [BS 5500](#) Enquiry Case 87 or [ASME II](#) Part D.

In the event that nominal design stresses need to be determined from [BS 5500](#) Appendix 'K' of [BS 5500](#), they shall be evaluated using paragraph K.3.2 (ferritic factors) and $R_{p0.2}$ shall be used in place of R_e or $R_{e(T)}$.

EE3. MATERIAL

- EE3.1 Material manufacturers shall be subject to approval by the purchaser.
- EE3.2 All materials shall be delivered solution annealed and shall be rapidly cooled in air or water. The plates shall be pickled to remove any scaling.
- EE3.3 To confirm the mechanical properties of the material, tensile tests shall be carried out at room temperature and at the maximum design temperature, when this is in excess of 50 °C.
- EE3.4 Irrespective of the design temperature, Charpy V impact tests shall be carried out.

When the minimum design temperature is ≥ 0 °C, the impact tests shall be performed at 0 °C and the acceptance criteria shall be 45 J average, with a minimum of 34 J.

When the minimum design temperature lies below 0 °C, the impact tests shall be performed at -50 °C and the acceptance criteria shall be 45 J average, with a minimum of 34 J.

Impact testing at -50°C for a minimum design temperature of -30°C will provide a margin of safety similar to that provided in [BS 5500 Appendix D](#) for ferritic steels in the bands MO-M4.

EE3.5 The microstructure of the material shall be free from grain boundary carbides and no sigma, chi or Laves' phases shall be present after solution heat treatment. Metallographic examination at not less than 400X magnification shall be undertaken to confirm freedom from such phases.

The microstructure of the material shall have a ferrite austenite balance strictly in accordance with the manufacturer's specification when measured in accordance with [ASTM E562](#) and have a maximum hardness of 280 Hv₁₀.

EE4. FABRICATION

EE4.1 Duplex stainless steels shall be segregated from carbon, carbon manganese and low alloy steels during fabrication. Mechanical working equipment shall be thoroughly cleaned and precautions taken to ensure that contaminants are not rolled or pressed into the surface at any stage of fabrication.

EE4.2 Dished heads, whether hot formed or cold formed, shall be solution heat treated. When high levels of cold deformation are induced, such as in the knuckle region, consideration should be given to the need for intermediate solution heat treatments in order to prevent cracking.

Solution heat treatment shall consist of heating the head rapidly to a temperature generally in excess of 1,020 °C, a hold period and then rapid cooling in air or water. The solution heat treatment temperature and hold period vary depending on the grade of material and guidance should be sought from the steel supplier.

The pickling and passivation method to be used for the removal of oxide scale produced in heat treatment shall be subject to approval by the purchaser. The inside and outside surfaces of the knuckle area shall be 100 % inspected by dye penetrant examination to [ASTM E 165](#). No significant linear or rounded indications are acceptable.

EE4.3 To confirm the properties of duplex stainless steel heads, test samples shall be subjected to similar levels of mechanical working and heat treatment. These samples shall be subject to tensile and impact testing as specified in EE3.3 and EE3.4. Metallographic and hardness assessment in accordance with EE3.5 shall also be undertaken.

EE5. WELDING

- EE5.1 Welding procedures shall be qualified for the specific grade, UNS number or trade name of the duplex alloy.
- EE5.2 Details of specific consumables to be used, together with details of the supplier, shall be subject to approval by the purchaser as part of welding procedure approval.
- EE5.3 When formulating welding procedures the possibility of delayed hydrogen cracking should be recognised. Appropriate steps, such as consumable drying in accordance with manufacturers recommendations or low temperature preheating, i.e. 50 °C, must be taken to restrict the hydrogen potential of the welding technique.
- EE5.4 All welding procedures shall be qualified in accordance with [BS EN 288-3](#) or [ASME IX](#). In addition, the requirements outlined below shall also be met.
- EE5.5 All welding procedures shall be subject to Charpy V impact testing. For material thicknesses up to 20 mm, the specimens shall be cut so that one face of the specimen is substantially parallel to, and within 3 mm of, the top surface of the weld. At thicknesses greater than 20 mm, two sets of specimens shall be taken to sample the root and cap regions. Specimens shall, as a minimum, be notched on the weld metal centre line, at the fusion boundary and at the fusion boundary plus 2 mm position. Test temperature and impact values for all regions of the weld shall be as indicated by EE3.4.
- EE5.6 A transverse section taken across the weldment shall be subject to metallographic evaluation
- The etchant used shall enable the ferrite, austenitic and any sigma phase present to be clearly identified. The ferrite-austenite balance shall be determined by a systematic point counting procedure, as detailed in [TWI Report 5632/18/JUNE93](#). The phase balance shall be measured: on both sides of the weld in the root HAZ; in the root weld metal; at the HAZ and in the weld centre at mid-thickness and cap positions.
- Acceptable ferrite levels shall lie in the range 35 - 65 %.
- EE5.7 Hardness measurements (Hv₁₀) shall be performed on all procedures. Hardness traverses shall sample the HAZ and weld metal in the root, mid thickness and cap regions. The maximum hardness shall comply with [NACE MR0175](#) for all duties (not just sour service duties).

EE5.8 [ASTM G 48](#) corrosion testing may be required as an integral part of the welding procedure qualification. In some instances, this requirement will be imposed as an additional means of quality control depending on the grade of duplex stainless steel and the specific application.

The purchaser will define the need for any corrosion testing and the acceptance criteria.

EE5.9 Welds shall be cleaned by hand held stainless steel wire brushes. Rotary wire brushes or other power tools shall not be used for surface cleaning.

EE5.10 Additional requirements for the fabrication of duplex stainless steel pipework are contained in BP [GS 118-7](#).

EE5.11 Materials for DPI of austenitic and duplex stainless steels shall be halogen free.

EE6. PAINTING

EE6.1 Painting requirements for duplex stainless steel vessels shall be specified by BP

VESSELS IN HASTELLOY AND ZIRCONIUM**FF1. MATERIAL REQUIREMENTS**

- FF1.1 The trade name 'Hastelloy' has been used for the generic group of nickel-chrome-molybdenum and nickel-molybdenum alloys. Vessel data sheets shall state the relevant ASTM numbers and the trade names.
- FF1.2 Only the top 60 mm of vessel skirts need be of the same material specification as the pressure components. The remainder of the skirt being ferritic steel.
- FF1.3 Saddles may be ferritic steel although any attachment directly onto the pressure part shall be fabricated from the same material specification as the vessel, ie hastelloy to hastelloy and zirconium to zirconium.

FF2. DESIGN REQUIREMENTS

- FF2.1 The minimum shell and head thickness, inclusive of corrosion allowance, shall be 5 mm.
- FF2.2 On hastelloy and zirconium vessels, the nozzle design shall be a lap joint with a 321 stainless steel backing flange.
- FF2.3 Blind flanges on hastelloy and zirconium vessels shall have a minimum of 3 mm finished thickness of corrosion resistant material permanently attached to a carbon steel backing plate. The vessel item number shall be hard stamped on the edge of the backing plate for identification purposes along with the words 'CLAD BLIND'. The blind shall be supplied with a chain attaching the cover to the nozzle flange.
- FF2.4 Vertical vessels in zirconium may be designed to be supported by guys or braces.

FF3. MANUFACTURE AND WORKMANSHIP

- FF3.1 General
- FF3.1.1 The cutting, forming and heat treatment procedure of all hastelloy and zirconium materials shall be submitted to the purchaser for approval before fabrication commences.
- FF3.1.2 Prior to the forming of hastelloy and zirconium plates, working surfaces of the material and tools shall be completely free of ferrous chips, scale,

dirt and other foreign matter. It is essential that there is no metal contamination from tools and machines.

- FF3.1.3 Where hastelloy materials have been hot-formed or subject to cold forming they shall be re-solution heat treated within the recommended temperature range of the particular alloy.
- FF3.1.4 On hastelloy and zirconium vessels temporary or permanent fabrication or erection aids, if used, shall be of matching hastelloy and zirconium alloy composition.
- FF3.1.5 The direct welding of carbon steel or stainless steel attachments to hastelloy and zirconium vessels is not permitted.
- FF3.2 Welding
- FF3.2.1 Welding of hastelloy materials welding shall be carried out using SAW, SMAW or GTAW. Other welding processes shall be subject to prior approval by the purchaser. For welding zirconium, GTAW only is permitted.
- FF3.2.2 Welding materials shall be selected to produce welds with an identical nominal composition to the parent plate.
- FF3.2.3 All welding shall be carried out using properly approved qualified operators and procedures.
- FF3.2.4 The use of resistance flash-butt welding techniques, such as a stud gun, for the attachment of studs or other fittings required for the support of insulation or refractories either internal or external to a vessel is not permitted.
- FF3.2.5 Weld defects in hastelloy or zirconium type materials shall be removed by grinding and machining. Air-arc gouging shall not be used.
- FF3.3 Welding Procedures
- FF3.3.1 Weld procedures for hastelloy and zirconium alloys shall be qualified in accordance with [ASME IX](#).
- FF3.3.2 Control of heat input is of prime importance when welding hastelloy materials. Stringer bead deposition of weld metal shall be utilised with minimal use of weaving.
- FF3.3.3 Pre-heat for hastelloy materials shall only be used except to remove moisture from the base metal surface.

Interpass temperatures for hastelloy materials shall be limited to 100°C. Additional cooling methods may be used between weld passes to speed up the welding operation. When attaching external attachments to thin wall vessels, additional cooling on the inside of the vessel should be used to minimise heat affected zone effects.

FF3.3.4 Wherever possible all welding shall be carried out in the flat downhand position. Vertical welding with SMAW especially with hastelloy B2 should be avoided because of possible inadequate slag protection of the weld pool.

FF3.3.5 Zirconium is a reactive metal which is easily embrittled, particularly when welded, unless specific precautions are taken.

Grinding shall be such as to avoid contamination and to avoid temperatures exceeding 315 °C.

Welding shall be performed with the base metal above 15 °C. The interpass temperature shall not exceed 110 °C.

Welding shall be in an inert atmosphere chamber or with supplementary inert gas cover on the whole weld including the underside of the welded area.

The shielding and backing gases shall be high purity helium or argon (99.998 % pure). Inert gas cover shall remain until the weld has cooled sufficiently to prevent rejectable discolouration when exposed to air.

The as-deposited weld metal surface and the adjacent 1 mm of base material shall have a shiny silver or light straw appearance after all weld runs. Any dark straw, blue, black or grey colouration necessitates that sufficient metal shall be removed to ensure the removal of all contamination. The weld surface shall not be ground or dressed until the as welded surface has been inspected for discolouration.

Welding procedures and welders shall be qualified to [ASME IX](#) or equivalent, except that two bend tests shall be completed and tested to the requirements of [ASME IX](#) in addition to radiography for welder qualification. Welding procedures shall be approved by the purchaser prior to manufacture commencing.

FF4. INSPECTION AND TESTING

FF4.1 All welds and HAZ in vessels constructed in hastelloy and zirconium materials shall be subject to 100 % DPI internally and externally. The acceptance standard shall be in accordance with the design code.



- FF4.2 On hastelloy B-2 vessels, where attachment welds are deposited on the outside of the vessel walls, the corresponding areas on the process side shall be subject to DPI.
- FF4.3 All hastelloy and zirconium vessels shall be subject to 'Full' X-ray as defined by [ASME VIII](#).

VESSELS IN TITANIUM

GG1. PROHIBITED DUTIES

- GG1.1 Titanium shall not be used where methanol could be present in the process or in conjunction with cupro-nickel or any other material with which it is not galvanically compatible.

GG2. DESIGN

- GG2.1 Any carbon steel fabrications in contact with solid titanium, e.g. saddle supports, shall be electrically insulated from the titanium.

In the presence of salt water, titanium forms a strong galvanic cell with many materials including carbon steel. Hence the need for electrical insulation.

With titanium, there is no risk of incendive sparking i.e. a falling object causing a spark. Simple trials have shown that sparks are not generated when steel strikes titanium. The plate material is regularly and safely cut during fabrication with burners using oxy-fuel. It can combust when it is in fine particles and hot (e.g. machine cuttings) but such incidents are few. However, once alight, it burns with an intense heat and thick white smoke.

- GG2.2 Clad plate shall be either entirely explosion bonded or explosion bonded to the backing plate and then rolled as a laminate.

Where design pressure and diameter are small, it may be cheaper to use solid titanium but otherwise clad is cheaper.

- GG2.3.1 After all nozzle welding is completed and again after hydraulic testing, all welds in sleeve linings of nozzles shall be tested with dry air (1.5 bar(ga) minimum) applied behind the linings and soap suds. Any indication of air leakage shall be considered unacceptable.

- GG2.3.2 Nozzles made from clad plate shall have vent holes to provide access for purging at the rear of the plate.

- GG2.3.3 Vendors shall indicate their preferred method of cladding the nozzle crotch in their quotation.

- GG2.4 Flanges shall only be clad with titanium by means of a machined shrunk fit insert.

GG3. FABRICATION

- GG3.1 A clean area or a separate fabrication facility shall be created. Tools and brushes shall be stainless steel. Rolls shall be cleaned and covered



to prevent contamination of the titanium. A minimum of 1.5 mm shall be ground from any cut face in titanium. Before welding, all edge preparations and filler wires shall be degreased with acetone. The vendor shall submit a cleanliness procedure for approval.

Cleanliness is essential in the fabrication of titanium. There must be no contact with either iron particles or methanol.

GG3.2 All weld procedures shall be qualified prior to starting fabrication. Prequalified weld procedures may be accepted provided they have been witnessed by an independent third party.

The maximum hardness in the weld metal shall be as shown in Table GG1. To ensure an adequate margin for an increase in hardness during welding, the plate shall be purchased to the values shown.

	Weld max. hardness	Plate max.hardness
Grade 2	200 Hv ₅	170
Grade 3	200 Hv ₅	190

Table GG1 Maximum permitted hardness of weld metal and plate

GG3.4 All welding shall use gas shielding on both sides of the joint. Only high purity (99.998 %) argon and/or helium shall be used. Gas purity shall be checked regularly and dew point shall be below -51 °C.

GG3.5 Welds shall be visually inspected on completion; any colour greater than light straw shall not be accepted.

GG3.6 In addition to primary shielding of the weld pool, secondary shielding i.e. back purging shall be used until the titanium surface temperature falls below 300 °C.

GG3.7 The procedure for the forming or heat treatment of all components in titanium shall be submitted for purchaser approval.

GG3.8 Unless otherwise agreed, thin heads in solid titanium shall be cold formed without any further heat treatment. Heads in clad plate shall be warm pressed at about 600 °C without any further normalising treatment.

GG3.9 In addition to DPI after welding, all titanium welds in clad shells, shall be dye penetrant checked after hydrotest.

All welds in loose sleeve linings shall be tested using soapy water with dry air applied behind the linings.