

DEP SPECIFICATION

UNFIRED PRESSURE VESSELS

DEP 31.22.00.31-Gen.

February 2014

DESIGN AND ENGINEERING PRACTICE

DEM1



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1. INTRODUCTION

1.1 SCOPE

This DEP specifies requirements and gives recommendations for the construction of metallic pressure vessels designed for an internal pressure or designed for full vacuum. This DEP also applies to pressure vessels that are components of packaged equipment units. DEP 31.22.00.30-Gen Equipment Criticality in Pressure Vessel Design provides the guidance in setting the Equipment Criticality used in this DEP.

This DEP, accompanied by a completed data sheet (and, where necessary, additional technical notes), is intended be used for purchasing pressure vessels in accordance with ASME Section VIII, EN 13445, PD 5500 and GB150. All or parts of this DEP may also form part of the construction specification.

The following are excluded from the scope of this DEP:

- Pressure vessels fabricated by brazing
- Pressure vessels or pressure vessel parts fabricated by casting

This DEP contains mandatory requirements to mitigate process safety risks in accordance with Design Engineering Manual (DEM) 1 – Application of Technical Standards.

This DEP supersedes the following withdrawn DEPs:

DEP 31.22.10.32-Gen.	Pressure vessels; amendments/supplements to PD 5500
DEP 31.22.11.32-Gen.	Unfired pressure vessels (amendments/supplements to EN 13445)
DEP 31.22.20.31-Gen.	Pressure vessels (based on ASME section VIII)
DEP 31.22.31.31-Gen.	Pressure vessels (Based on Chinese Code GB150-1998)

This is a revision of the DEP of the same number dated February 2013; see (1.5) regarding the changes.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by Shell GSI, the distribution of this DEP is confined to Shell companies and, where necessary, to Contractors and Manufacturers/Suppliers nominated by them. Any authorised access to DEPs does not for that reason constitute an authorisation to any documents, data or information to which the DEPs may refer.

This DEP is intended for use in facilities related to oil and gas production, gas handling, oil refining, chemical processing, gasification, distribution and supply/marketing. This DEP may also be applied in other similar facilities.

When DEPs are applied, a Management of Change (MOC) process shall be implemented; this is of particular importance when existing facilities are to be modified.

If national and/or local regulations exist in which some of the requirements could be more stringent than in this DEP, the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable with regards to the safety, environmental, economic and legal aspects. In all cases, the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned, the objective being to obtain agreement to follow this DEP as closely as possible.

1.3 DEFINITIONS

1.3.1 General definitions

The **Contractor** is the party that carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project or operation of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party that manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party that initiates the project and ultimately pays for it. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The capitalised term **SHALL [PS]** indicates a process safety requirement.

The word **should** indicates a recommendation.

1.3.2 Specific definitions

Term	Definition
controlled bolting	Controlled tightening of the bolted connection with the use of torque wrenches, hydraulic torquing equipment or bolt tensioning.
creep service	Operation in the temperature range where time dependant properties of the materials may require consideration. See (5.9)
CUI	corrosion under insulation
cyclic service	Service in which pressure equipment is subject to frequent fluctuations in pressure and/or temperature, mechanical vibration or external loading that may lead to damage from fatigue.
EEA	European Economic Area
fluid group	See Pressure Equipment Directive PED (for vessels destined for EEA)
hazard category	See Pressure Equipment Directive PED (for vessels destined for EEA)
hydrogen charging services	Services in which atomic hydrogen exists in the steel. Services include wet hydrogen sulphide or sour, hydrofluoric acids or hydrogen service.
hydrogen service (H₂ service)	Service in which the hydrogen partial pressure is greater than 700 kPa absolute (100 psia) at any temperature. See also API RP 941, Figure 1.
Maximum Allowable Pressure (MAP)	Calculated allowable pressure, using the entire new (non-corroded) thickness at ambient temperature, including the full corrosion allowance.
Maximum Allowable Working Pressure (MAWP)	Maximum internal gage pressure permissible at the top of the completed vessel in its normal operating position at the designated coincident design temperature for that pressure using the entire new (non-corroded) thickness minus the full corrosion allowance.
Maximum Allowable External Working Pressure (MAEWP)	Maximum external pressure permissible acting on the completed vessel in its normal operating position at the designated coincident design temperature for that pressure using the entire new (non-corroded) thickness minus the full corrosion allowance.

non-corrosive service	Vessel service where there is expected to be no corrosion of the vessel materials and where no corrosion allowance is required.
PED	Pressure Equipment Directive (97/23/EC)
pressure vessel	Vessel used for containing, storing, distributing, processing or otherwise handling an expansible fluid under pressure. This excludes rotating or reciprocating equipment, fired heaters, and piping.
PWHT	Post weld heat treatment; aimed at reducing hardness and residual stresses in welds.
very toxic (substances)	Substances that are very hazardous for the environment or human health, as specified in DEP 01.00.01.30-Gen. (which also references databases of "toxic" substances).
Shell Vessel Category	Categorization of pressure vessels into 3 categories for the purpose of this DEP with Category 1 being the most restrictive and 3 being the least restrictive.

1.3.3 Abbreviations

Term	Definition
CE	European Economic Area conformance marking
CUI	corrosion under insulation
ERW	electric resistance welded
ITP	inspection and test plan
MT	magnetic particle
NDE	non-destructive examination
PED	pressure equipment directive
PT	penetrant testing
RT	radiographic testing
PQR	Procedure Qualification Record
TSA	thermal sprayed aluminium
UT	ultrasonic testing
VT	visual testing
WPS	Weld Procedure Specification

1.4 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section number is shown in brackets (). Other documents referenced by this DEP are listed in (10).

1.5 SUMMARY OF MAIN CHANGES

This DEP is a minor revision of the DEP of the same number dated February 2013. The following are the main, non-editorial changes.

Section/Clause	Change
1.1	updated sentence describing DEP 31.22.00.30-Gen.
1.1	moved sentence "Vessels built to other standards. . . ." to (2.2)
2.2	added sentence "Vessels built to other standards. . . ." from (1.1)

Section/Clause	Change
2.3.1	changed to refer to data/requisition sheet DEP 31.22.00.98-Gen.
4.2.1	changed to refer to Table 3.7 and Table 4.7 in DEP 30.10.02.11-Gen.
5.13.10	added this sentence to clause "Nozzles shall avoid circumferential and longitudinal weld seams by the greater of 50 mm (2 in) or 2*t _{min} ."
5.13.10 item a	clarified dimensions in Figure 5.1.
5.13.17 item c	changed to vessel requisition sheets DEP 31.22.00.98-Gen.
5.15.3	removed word "typically"
6.2.2 item d	clarified wording for Double fillet weld construction
6.2.2 item e	added "vacuum rings"
10	added and deleted several references
A1 item e	added "or clad" to second sentence
A2.1	added sentence and updated Figure A2.1 and A2.2 tolerances
A3.2.3 item h	added to clause "Note that forces and moments may act in any combination and direction concurrently with - internal or external - pressure. The designer shall account for the worst condition."

1.6 COMMENTS ON THIS DEP

Comments on this DEP may be submitted to the Administrator using one of the following options:

Shell DEPs Online (Users with access to Shell DEPs Online)	Enter the Shell DEPs Online system at https://www.shelldeps.com Select a DEP and then go to the details screen for that DEP. Click on the "Give feedback" link, fill in the online form and submit.
DEP Feedback System (Users with access to Shell Wide Web)	Enter comments directly in the DEP Feedback System which is accessible from the Technical Standards Portal http://sws.shell.com/standards . Select "Submit DEP Feedback", fill in the online form and submit.
DEP Standard Form (Other users)	Use DEP Standard Form 00.00.05.80-Gen. to record feedback and email the form to the Administrator at standards@shell.com .

Feedback that has been registered in the DEP Feedback System by using one of the above options will be reviewed by the DEP Custodian for potential improvements to the DEP.

1.7 DUAL UNITS

This DEP contains both the International System (SI) units, as well as the corresponding US Customary (USC) units, which are given following the SI units in brackets. When agreed by the Principal, the indicated USC values/units may be used.

2. GENERAL

2.1 MANUFACTURER/SUPPLIER

Pressure vessels shall be purchased only from Manufacturers/Suppliers accepted by the Principal.

2.2 CODE OF CONSTRUCTION

Pressure vessels shall be designed and fabricated in accordance with the applicable code of construction for the jurisdiction where the vessel is to be put in service. Pressure vessels shall be registered in accordance with the applicable local regulations.

Section (9) of this DEP provides the specific requirements for vessels constructed to each of the listed pressure vessel codes, specifically ASME Section VIII, EN 13445, PD 5500 and GB150. Vessels built to other standards, for example, the Australian standard SAI AS 1210, the German standard AD Merkblätter, or another regionally established unfired pressure vessel standard, shall comply with sections (1 to 8) of this DEP.

2.3 DRAWINGS AND FINAL DATA

2.3.1 Data sheets and design specification

The Principal's data/requisition sheet DEP 31.22.00.98-Gen. shall be completed for each pressure vessel.

The Manufacturer's/Supplier's documentation for each pressure vessel shall include the Code Data Report and shall also be in accordance with DEP 31.22.10.35-Gen.

For applications in the European Economic Area where the Pressure Equipment Directive (PED) is mandatory, the Principal is responsible for providing the Manufacturer/Supplier with a specification of the normal and transient/adverse conditions under which the vessel is to operate. Moreover, the owner is obliged to participate in and/or provide information for a hazard analysis. The input provided by the Principal shall be restricted to information that is directly relevant to the vessel's integrity.

2.3.2 General drawings

The general arrangement, assembly or outline drawing(s) shall contain the following information:

- a. Code of Construction, edition year,
- b. References to supplementary drawings, standards and specifications
- c. Equipment tag number
- d. Shell Vessel Category
- e. PD-5500 Vessel Category as applicable
- f. Primary vessel dimensions
- g. Operating and design pressures and temperatures of all services for which the vessel is designed including number of cycles if designed for fatigue
- h. Environmental data
 - Wind speed
 - Earthquake data
- i. Blast loadings if required for the specific application
- j. Corrosion allowances for shell, heads, nozzles, manways, and all supports and other accessories
- k. Nozzle ref/mark, size, rating, reinforcing pads and locations, reference datum for dimensions, fixed end/point of supports with allowable loads

- l. PWHT requirements
- m. Weld joint efficiencies where applicable
- n. Design pressures and temperatures of all services for which the vessel is designed including number of cycles if designed for fatigue
- o. Lower design temperature(s) with coincident pressure(s)
- p. Field pressure test pressure at top of vessel
- q. Shop pressure test pressure and orientation of vessel
- r. Test fluid properties
 - Product and its composition
 - Temperature
 - Density
- s. Insulation type and thickness
- t. Coating requirements
- u. Weights; shipping, operating, water full with all internals
- v. Centre of gravity location
- w. Lifting arrangements

2.3.3 Fabrication drawing(s)

The detailed fabrication drawing(s) shall contain the following information:

- a. Full dimensions of all parts and sub-assemblies shown including necessary tolerances and any finishing requirements
- b. Complete identification of materials, including bolting and gaskets
- c. Complete identification of internal materials supplied by the Manufacturer, including gaskets.
- d. Location of all circumferential and longitudinal joints
- e. Details of weld preparations and welding procedure numbers
- f. Details of internal cladding/overlay where applicable
- g. Impact test requirements
- h. Heat treatment details, including temperature of PWHT, time at temperature, heatup and cooldown rates
- i. General remarks on fabrication, assembly and testing as appropriate
- j. Installed bolt torque and bolt stress for body flanges
- k. Extent and location of all nondestructive examination (NDE)
- l. Cleaning, surface preparation, painting and marking requirements
- m. Nozzle schedule including the mark number, quantity, size, rating, facing, and type. Nozzle orientation and elevation shall be provided. The mark number shall match that shown on equipment data sheet.

2.4 OVERPRESSURE PROTECTION

Pressure vessels shall be protected from overpressure in accordance with DEP 80.45.10.11-Gen.

2.5 SURVEILLANCE REQUIREMENTS

Surveillance requirements shall be established for each pressure vessel constructed in accordance with Table 3.3. The requirements shall be established by the Principal, or by the Contractor with the approval of the Principal based on the Shell Vessel Category in (3).

Surveillance requirements identified by the Principal or the Contractor shall be incorporated into the Manufacturer's/Supplier's ITP. Third party inspection, notified bodies and local jurisdiction requirements shall also be included in the ITP. The Manufacturer/Supplier shall submit the Inspection and Test Plan (ITP) for review and approval in accordance with the surveillance sheet requirements.

For applications in the European Economic Area where the Pressure Equipment Directive (PED) is mandatory, a "Notified Body" shall be involved.

3. VESSEL CATEGORIES

3.1 GENERAL

Pressure vessels manufactured to this DEP shall be segregated in to 3 different vessel categories through the use of DEP 31.22.00.30-Gen. This categorization is on the basis of equipment criticality, which includes:

- a. Operational Risk – Loss of production and loss of containment including environmental and people risks
- b. Design Complexity – High operating temperatures and pressures, potentially high corrosion rates, hydrogen service
- c. Fabrication Complexity – Complex materials of fabrication, heavy wall, complex internals, PWHT requirements, clad vessels

The vessel categories will be:

Category 1	Highest category, associated with potentially high operational, design or fabrication risk. Warrants the most stringent design and fabrication requirements.
Category 2	Medium category, associated with potentially moderate operational, design or fabrication risk. Warrants some special design and fabrication requirements.
Category 3	Lowest category, associated with reduced operational, design or fabrication risk. Standard design and fabrication requirements are sufficient.

3.2 SPECIFIC DESIGN REQUIREMENTS BASED ON SHELL VESSEL CATEGORY

Based on the Shell Vessel Category as evaluated using DEP 31.22.00.30-Gen., Table 3.1 indicates the minimum design and fabrication requirements for each of the vessel categories. This table outlines only the areas where there are different requirements based on the Vessel Category. These requirements are in addition to the requirements specified in the balance of this DEP.

Table 3.1 Design requirements based on Shell Vessel Category

	Category 1	Category 2	Category 3
Nozzle reinforcement, see (5.13.14)	Integral reinforcement	Reinforcing pad or Integral	Reinforcing pad or Integral
Nozzle attachment	Set in	Set in or set on meeting the requirements of (5.13.11) or (5.13.12)	Set in or set on meeting the requirements of (5.13.11) or (5.13.12)
Flange tightening	Controlled bolting	Controlled bolting	Controlled bolting for class 300 or higher
Nozzle loads	As specified on the vessel data sheet or as per (Appendix 3), if not specified	As specified on the vessel data sheet or as per (Appendix 3), if not specified	As specified on the vessel data sheet or as per (Appendix 3), if not specified
Minimum nozzle size	DN 40 (NPS 1½)	DN 40 (NPS 1½)	DN 40 (NPS 1½) except DN 20 (NPS ¾ in) in non-toxic, non-flammable, non cyclic and non-vibrating service

	Category 1	Category 2	Category 3
Minimum nozzle schedule for nozzles DN 80 (NPS 3) or less	Schedule 80, schedule 160 in CUI temperature range ¹ without TSA	Schedule 80, schedule 160 in CUI temperature range ¹ without TSA	Schedule 80
Weld types, see (Appendix 6)	Full penetration welds with no voids	Full penetration welds with no voids	Full penetration welds with no voids for primary pressure boundary. Double fillet weld construction only permitted in secondary pressure boundaries (e.g., slip-on flanges), but not in hydrogen charging or cyclic service.
Support and lifting lugs repads	Yes	Yes	No
Socketwelds	No	No	Socket welds only permitted for nozzle connection to nozzle flanges DN 40 (NPS 1.5) or less in size in non-toxic, non-hydrogen charging, non-cyclic and non-corrosive service.
Threaded connections	No	No	Threaded connections DN 40 (NPS 1½) or less are only permitted for nozzle connections in non cyclic, clean air or clean water service
Flange type	Weld neck	Weld neck Lap in non-sour, non-cyclic service <440 °C [825 °F] (Limited to high alloy vessel material with CS backing flange)	Weld neck Lap or slip-on in non-hydrogen charging service. (Lap joints limited to high alloy vessel material with CS backing flange, slip-on limited to class 150). See (6.2).
ERW pipe for nozzles	No	No	Yes in non-corrosive service

NOTES: CUI temperature range is the operating temperature of a vessel between -5 °C (25 °F) and 175 °C (350 °F). See (5.13.3)

3.3 NDE REQUIREMENTS BASED ON SHELL VESSEL CATEGORY

See also (7). If the code of construction requirement is more stringent than Table 3.2, then the code requirements shall be followed.

Table 3.2 Minimum NDE requirements based on Shell Vessel Category

Joint type	NDE method	Category 1	Category 2	Category 3
All Welds	Production hardness	DEP 30.10.60.18-Gen.	DEP 30.10.60.18-Gen.	DEP 30.10.60.18-Gen.
All Welds	VT	100 %	100 %	100 %
Longitudinal and circumferential butt joints	RT or UT ¹ MT or PT	100 % 100 % ^{3,4}	100 % 100 % ^{3,4}	10 % ² 10 % ^{3,4}

Joint type	NDE method	Category 1	Category 2	Category 3
Nozzle attachment weld inspection	RT or UT ¹ MT or PT	100 % 100 %	100 % 100 %	20 % 20 %
Integral clad plate ⁵	UT clad bond	ASTM A578	ASTM A578	N/A
Overlay weld	PT	100 %	100 %	N/A
Lifting lugs and supports	MT or PT	100 %	100 %	100 %
Non-pressure attachments	MT or PT	100 %	100 %	10 %
Weld inspection prior to PWHT		Yes	Yes	optional
Forging UT inspection		100 %	100 %	As per code of construction

- NOTES:
1. UT (utilizing continuous data recording) in lieu of RT preferred for ferritic materials optional < 38 mm (1.5 in), mandatory 38 mm (1.5 in) and thicker. For austenitic stainless steels, this requirement shall only apply when specified or approved by the Principal.
 2. If more economic, substitute 100 % to increase joint efficiency factors.
 3. Also inspect 100 % after working if worked >5 %.
 4. 100 % wet fluorescent MT is mandatory for carbon steel pressure containment and attachment welds exposed to the process in wet H₂S service or hydrofluoric acid service.
 5. See appendix 1 for specific requirements on Integral clad plate.

3.4 SURVEILLANCE REQUIREMENTS BASED ON SHELL VESSEL CATEGORY

Based on the Vessel Category as evaluated using DEP 31.22.00.30-Gen., Table 3.2 indicates the minimum surveillance requirements for each of the vessel categories. The Surveillance Form in (Appendix 5) shall be filled out for each vessel. Table 3.3 is the minimum surveillance requirements and additional restrictions, reviews and hold points may be added to the surveillance form based on the specific requirements for the vessel being fabricated.

This table is not intended to restrict any ongoing routine monitoring and process inspection by the Contractor, Principal, or their third party inspectors.

Table 3.3 Minimum surveillance requirements based on Shell Vessel Category

	Hold/Witness/ Review	Category 1	Category 2	Category 3
Pre fabrication meeting	H	Principal	Principal	Contractor
Design Calculations and drawings	H	Principal	Contractor	Contractor
Bill of Material	H	Principal	Contractor	Contractor
Materials and/or Sub-Component, prior to order placement	H	Principal	Contractor	Manufacturer
Material Test Reports	H	Principal	Contractor	Contractor
Materials Receiving/Tagging Records including PMI (as applicable)	R	Principal	Contractor	Contractor
WPS/PQR's	H	Principal	Contractor	Contractor
Welder qualifications	R	Contractor	Manufacturer	Manufacturer

	Hold/Witness/ Review	Category 1	Category 2	Category 3
Weld QA/QC	R	Contractor	Contractor	Manufacturer
Material defect repairs	H	Principal	Principal	Contractor
Weld defect repairs	H	Principal	Contractor (R)	Contractor (R)
NDE procedures	H	Principal	Contractor	Manufacturer
UT in lieu of RT scan plan and UT procedure	R	Principal	Principal	Contractor
NDE personnel qualifications	R	Contractor	Contractor	Manufacturer
NDE results	R	Contractor	Contractor	Contractor
Heat treatment procedures, including U-bend heat treatment (as applicable)	H	Principal	Contractor	Contractor
Heat treatment results, including U-bend heat treatment (as applicable)	R	Contractor	Contractor	Manufacturer
Fabrication procedures	R	Principal	Contractor	Contractor
Tube-end Joining Mock- up (as applicable)	H	Principal	Contractor	Contractor
Tube-end Expansion (wall reduction)	R	Contractor	Contractor	Manufacturer
Final Tube Bundle Assembly	H	Principal	Contractor	Contractor
Tube Bundle Insertion	H	Principal	Contractor	Contractor
Production Impact Test results	R	Principal	Contractor	Contractor
Tube-end Leak Testing Results (as applicable)	R	Contractor	Contractor	Contractor
Dimensional verification	R	Contractor	Contractor	Manufacturer
Workmanship	R	Contractor	Contractor	Contractor
Pressure testing	H	Contractor	Contractor	Manufacturer
Internals Painting	H	Contractor	Contractor	Manufacturer
Cleaning and painting	H	Contractor	Contractor	Manufacturer
Final documentation	R	Principal	Contractor	Contractor
Prep for shipment	R	Contractor	Contractor	Manufacturer
Release for shipment	H	Contractor	Contractor	Contractor

Contractor means third party engineering Contractor.

Manufacturer or Contractor may be through a 3rd party inspector.

4. MATERIALS, BOLTING, CORROSION ALLOWANCE AND CLADDING

4.1 MATERIALS

- 4.1.1 Materials selection shall be in accordance with the project material selection report, the design code, and DEP 30.10.02.11-Gen., including the additional requirements specified in the Notes therein. The selected materials standard (and the afore-mentioned Notes) shall be indicated on the data/requisition sheets.
- 4.1.2 Material selected for non-pressure parts that are welded to the pressure retaining envelope of the pressure vessel shall be code approved and of the same material type/group as the pressure retaining envelope.
- 4.1.3 Potential for brittle fracture SHALL [PS] be determined through the use of DEP 30.10.02.31-Gen.
- 4.1.4 Material selection for pressure vessels in H₂S containing environments (sour service) in Upstream applications shall be in accordance with DEP 30.10.02.15-Gen. Additional material selection information for upstream facilities is included in DEP 39.01.10.12-Gen.
- 4.1.5 Material selection and fabrication requirements for pressure vessels in wet H₂S service in downstream applications shall be in accordance with DEP 30.10.02.17-Gen.
- 4.1.6 Quench and tempered ferritic materials shall not be used without approval of the Principal and shall only be considered for Shell vessel category 1.
- 4.1.7 Micro-alloyed steels or high strength low alloy steels, having a minimum specified tensile strength greater than 510 N/mm² (74 ksi) shall not be used without the approval of the Principal and shall only be considered for Shell Vessel Category 1.
- 4.1.8 Electric resistance welded (ERW) pipe or tube shall not be used for pressure retaining parts such as shells or nozzle necks. Heat exchanger tubes are not subject to this restriction. ERW pipe may be used for nozzles for Shell Vessel Category 3 equipment in non-corrosive service.
- 4.1.9 Materials selection for hydrogen service SHALL [PS] be in accordance with API RP 941. The maximum operating conditions (temperature and hydrogen partial pressure) SHALL [PS] be at least 28 °C (50°F) below and 1.7 bar (25 psi) to the left of the applicable material curve of API RP 941, Figure 1. This requirement also applies to the carbon and low alloy pressure boundary material of vessels built with a corrosion resistant cladding or overlay.
- 4.1.10 Cr-Mo materials SHALL [PS] meet the requirements of (Appendix 4) of this DEP. See also DEP 30.10.02.32-Gen. and DEP 30.10.02.36-Gen.

4.2 BOLTING

- 4.2.1 Bolts used externally for pressure vessel flanges, including nozzle flanges and manways with installed blind flanges, shall be selected from DEP 30.10.02.11-Gen. in accordance with Table 3.7 and 4.7. Where possible, bolts used to attach piping to nozzle flanges shall be consistent with the piping class of the attached piping.
- 4.2.2 Stud bolts and nuts shall be completely threaded in accordance with ANSI B1.1. Sizes 25 mm (1 in) and smaller shall be Coarse Thread Series (UNC) and sizes larger than 25 mm (1 in) shall be 8-Thread Series (8 UN). Threads shall be machine cut or rolled.
- 4.2.3 The stud bolt length shall be determined as shown in ASME B16.5 or ASME B16.47. Where specified, studs 50 mm (2 in) diameter and larger shall be the larger of one nut thickness or 40 mm (1½ in) longer than normal to permit use of a bolt tensioner. Bolt pitch, length and flange hub details shall allow for the use of bolt tensioning equipment where specified.
- 4.2.4 Bolts coated with zinc or cadmium shall not be used. Nickel-zinc, aluminium coatings or suitable non-metallic coatings are permitted.

- 4.2.5 Nuts shall be semi-finished, heavy, hexagon. Nuts shall have a height equal to the bolt diameter. Nuts coated with zinc or cadmium shall not be used. Nickel-zinc, aluminium coatings or suitable non-metallic coatings are permitted.

Table 4.1

Application	Bolt material [ASTM designation]	Nut material [ASTM designation]	Allowable design temperature range	Diameter range (inch)
General service	A193-B7	A194-2H	-40 °C to 400 °C (-40 °F to 750 °F)	$\frac{1}{2} \leq d \leq 4$
Sour service	A193-B7M	A194-2HM	-48 °C to 400 °C (-55 °F to 750 °F)	$\frac{1}{2} \leq d \leq 2 \frac{1}{2}$
Low temperature service	A320-L7	A194-4	-101 °C to 400 °C (-150 °F to 750 °F)	$\frac{1}{2} \leq d \leq 2 \frac{1}{2}$
	A320-L43	A194-4	-101 °C to 343 °C (-150 °F to 649 °F)	$2 \frac{1}{2} \leq d \leq 4$
Low temperature sour service	A320-L7M	A194-7M	-73 °C to 343 °C (-100 °F to 649 °F)	$\frac{1}{2} \leq d \leq 2 \frac{1}{2}$
High temperature, low alloy flanges	A193-B16	A194-4	-29 °C to 525 °C (20 °F to 977 °F)	$\frac{1}{2} \leq d \leq 4$
High temperature, low alloy flanges	20CrMoVTiB4-10	20CrMoVTiB4-10	-29 °C to 550 °C (-20 °F to 1020 °F)	$\frac{1}{2} \leq d \leq 4$
High temperature, Stainless steel flanges	A453-660 class B or C	A453-660 class B or C	-29 °C to 538 °C (-20 °F to 1000 °F)	$\frac{1}{2} \leq d \leq 3 \frac{1}{2}$
	A193-B8 class 2	A194-8	-200 °C to 538 °C (-330 °F to 1000 °F)	$\frac{1}{2} \leq d \leq 3 \frac{1}{2}$
Very high temperature, Stainless steel flanges	A193-B8 class 1	A-194-8	538 °C to 815 °C (1000 °F to 1500 °F)	$\frac{1}{2} \leq d \leq 3 \frac{1}{2}$
Low temperature, Stainless steel flanges	A193-B8 class 2	A194-8	-200 °C to 300 °C (-330 °F to 570 °F)	$\frac{1}{2} \leq d \leq 1 \frac{1}{2}$
	A193-B8M2 class 2B	A194-8	-200 °C to 300 °C (-330 °F to 570 °F)	$1 \frac{1}{2} \leq d \leq 3$

4.3 CORROSION ALLOWANCE

- 4.3.1 The minimum corrosion allowance for pressure containing components shall be in accordance with Table 4.2.

Table 4.2 Minimum corrosion allowances

Component and Material	mm	in
Carbon steel and low alloy pressure vessel shell / heads	1.5	1/16
Carbon steel and low alloy nozzles	1.5	1/16
Stainless steel, titanium and nickel alloys	0	0

- 4.3.2 Corrosion allowance shall be in accordance with the material's selection report or selected after consultation with the materials specialist of the Principal.
- 4.3.3 Corrosion allowance shall be listed on the data sheet for each component.
- 4.3.4 The minimum corrosion allowance for internal parts including attachment welds, excluding processing trays, heat exchanger baffles, heat exchanger tubes and other processing parts shall be in accordance with the following:
 - a. 50 % of the value listed on the data sheet for parts which may be removed from the pressure vessel per exposed side.
 - b. Equal to the value listed on the data sheet for parts that are welded to the pressure retaining portion of the pressure vessel per exposed side.
 - c. No corrosion allowance for stainless steel components or components with a corrosion resistant overlay.
- 4.4 VESSELS WITH INTEGRAL CORROSION RESISTANT OVERLAY
 - 4.4.1 For vessels with integral corrosion resistant overlay, the requirements of (Appendix 1) shall be met.
 - 4.4.2 For the requirements for process equipment with internal chemical-resistant brick lining, see DEP 30.48.60.13-Gen. For dense refractory concrete linings see DEP 64.24.32.12-Gen. (for FCCU).

5. DESIGN

5.1 GENERAL

5.1.1 The minimum fabrication thickness of carbon steel and low alloy pressure vessels shall be the greater of the following:

a. 6 mm (1/4 in)

b. $\frac{D}{650} + 1.8$ mm

c. $\frac{D}{650} + 0.071$ (in)

where

D is the inside vessel diameter, expressed in millimetres (inches)

5.1.2 The minimum thickness of all high alloy pressure vessels shall be no less than the greater of 3 mm (1/8 in) or the value as calculated in accordance with (5.1.1 (b) or (c)).

5.1.3 Allowable stresses used in design calculations for non-pressure containing parts welded to the pressure boundary shall be in accordance with the code of construction at the design temperature.

5.1.4 When two sets of allowable stresses are provided for austenitic materials, use of lower value is required for flanges and flanged extension of a tubesheet design.

5.2 DESIGN PRESSURE AND TEMPERATURE

5.2.1 The definition and determination of temperature and pressure levels, including design pressure and design temperature, shall be in accordance with DEP 01.00.01.30-Gen.

5.2.2 The design temperature specified for the pressure vessel shall be 10 °C (18 °F) or more above the maximum operating temperature (MOT). In exceptional cases (e.g., where a higher alloy material would otherwise be required because of oxidation or creep) a design temperature of 5 °C (9 °F) above the MOT may be selected.

5.2.3 The need to specify multiple design temperatures coincident with various operating pressure conditions, such as steaming-out conditions and operational upset, shall be considered.

5.2.4 When a single design temperature is selected, it shall be applied to internal pressure and external pressure conditions.

5.2.5 When multiple design temperatures are selected (see 5.2), the design temperature for external pressure shall be the highest temperature at which full vacuum is applicable.

5.2.6 The lower design temperature (LDT) shall be specified as the minimum metal temperature (MMT) as defined by DEP 01.00.01.30-Gen.

5.2.7 The pressure vessel SHALL [PS] be designed for full vacuum if any of the following conditions apply:

a. If the process is such that vacuum conditions can occur.

b. If the vessel normally operates under vacuum. Vessels that operate at less than full vacuum [i.e., absolute pressure between 0 kPa and 100 kPa (0 psi and 14.7 psi)] shall be evaluated for design at full vacuum.

c. Vessels in steam or steam condensate systems that are not open to the atmosphere.

5.2.8 Jacketed or compartmented vessels that are designed for vacuum in the compartment under consideration shall have the common components designed for an external pressure equal to the sum of internal design pressure of the adjacent compartment plus the vacuum design pressure of the compartment under consideration.

5.3 LOAD CASE

Design loads are classified as follows:

- a. **Dead Load (L1)** is the weight of the vessel including internals, platforms, insulation, fireproofing, refractory, piping, and other permanent attachments.
- b. **Operating Load (L2)** is the weight of the liquid at the maximum operating level or catalyst content. The maximum operating level shall include upset conditions including the liquid full case if this is a credible scenario. When applicable, loadings resulting from topsides acceleration shall be included.
- c. **Pressure Load (L3₁)** is the pressure, internal or external, hot and corroded condition, to which the vessel is certified considering the pressure variations through the vessel, if any. This is typically the stamped MAWP or MAEWP.
- d. **Pressure Load (L3₂)** is the pressure in the new and cold condition. This is considered the maximum allowable pressure, and is designated as MAP. It may be higher than MAWP.
- e. **Thermal Load (L4)** is the load caused by the restraint of thermal expansion / interaction of the vessel and its supports.
- f. **Test Load (L5)** is the load under hydrostatic test conditions including the weight of the test fluid, usually water.
- g. **Wind Load (L6)** see (5.7).
- h. **Seismic Load (L7)** shall be determined in accordance with DEP 34.00.01.10-Gen.
- i. **Piping and Superimposed Equipment Loads (L8)** are loads caused by piping other than Dead Load (L1) and superimposed equipment. Such loads shall be considered as applicable. When applicable, loadings resulting from wave action and/or sloshing shall be considered.

5.4 LOAD COMBINATIONS

5.4.1 General

Vessels and their supports SHALL [PS] be designed to meet the most severe of the load combinations in Table 5.1.

Table 5.1 Load combinations

Load combination	Description
L1 + L6	Erected condition with full wind load
L1 + L2 + L4 + L6 + L8 (Note 2)	Operating condition, no pressure, with full wind load
L1 + L2 + L3 ₁ + L4 + L6 + L8 (Note 2)	Operating condition with full pressure and full wind loads
L1 + L2 + L4 + L7 + L8 (Note 2)	Operating condition, no pressure, with full seismic load
L1 + L2 + L3 ₁ + L4 + L7 + L8 (Note 2)	Operating condition with full pressure and full seismic loads
L1 + (F)L3 ₂ + L5 + (0.25)L6 (Note 1)	Initial hydrostatic test condition when specified by the Principal.
L1 + (F)L3 ₁ + L5 + (0.25)L6 (Note 1)	Future hydrostatic test condition when specified by the Principal.
Lift condition	See (5.16)
NOTE 1: (F) is the hydrostatic test factor from the code of construction. 2: Actual resonant sloshing forces parallel to the longitudinal axis of the vessel. For marine vessels, this shall not be less than 2 times the specified deck accelerations as specified in (5.6).	

5.5 HORIZONTAL VESSELS

In addition to (5.4.1), horizontal vessels shall also be evaluated for buckling, local circumferential bending and shear stresses. The saddle horn tip and shell bending stresses shall be checked for the "filled but no pressure" condition, (L2).

5.6 MARINE VESSELS

All pressure vessels for marine service shall include design data as supplied by the Principal. If specific data is not provided, the following data shall be used:

5.6.1 Wind Loads

Wind loads shall be as follows:

- a. Operating Condition: 479 Pa (10 psf) on projected cylindrical surfaces and 718 Pa (15 psf) on flat surfaces.
- b. Storm Condition: 1437 Pa (30 psf) on projected cylindrical surfaces and 4309 Pa (90 psf) on flat surfaces
- c. Skid/Package Transport Condition wind load shall be the same as that for the Operating Condition.

5.6.2 Dynamic Loads

Dynamic loads shall be as follows:

- a. Operating Condition: Lateral acceleration = +/- 0.10g
Vertical acceleration = +/- 0.10g
- b. Storm Condition: Lateral acceleration = +/- 0.20g
Vertical acceleration = +/- 0.15g

5.7 WIND LOAD

5.7.1 Wind load shall be determined in accordance with DEP 34.00.01.30-Gen. section 3.5 and local requirements. For offshore equipment reference DEP 37.19.00.10-Gen.

If using ASCE 7, the following shall be used:

- a. Classification Category II shall be used unless approval for other category is obtained from the Principal.
- b. Basic wind speed shall be in accordance with ASCE 7, Figure 6.1, or the applicable climate data, for the point of installation of the equipment.
- c. Exposure Category shall be in accordance with ASCE 7 unless otherwise directed by the Principal.
- d. Topographic factor shall be in accordance with ASCE 7.
- e. Force coefficients shall be in accordance with ASCE 7. Vertical vessels provided with spoilers to prevent wind induced vibration shall be considered with a surface type of very rough.

5.7.2 Vessel design shall include analysis for the following:

- a. Tower deflection
- b. Moments and forces at foundation due to wind loads
- c. Vortex shedding effects on the vessel under erection, on standby and in operating conditions.

- 5.7.3 The fabricator SHALL [PS] provide a proposal for mitigation against vortex shedding effects for towers that meet the following conditions:
- H/D ratio of 15 or greater, and
 - Mass damping parameter (MDP) less than 0.8 under operating conditions, or MDP less than 1.1 when the vessel is under erection or on standby.

Where

$$MDP = \frac{m \cdot \beta}{\phi \cdot d^2}$$

m = mass per unit length of the top third of the tower, in the condition considered

β = structural damping ratio, 0.004 for empty, unlined steel vessel

ϕ = density of air

d = mean diameter over the top third of the tower

D = nominal diameter of tower

H = height of tower

NOTE: The term MDP is dimensionless. Consistent units shall be used for the above equation to be valid, and MKS (meter, kilogram, second) units are preferred.

- 5.7.4 Mitigation measures against vortex shedding effects shall include vortex destruction devices such as spoilers, tuned mass dampers or positioning of platforms to reduce vortex formation. Mitigation proposal shall be submitted for review and shall be approved by the Principal.
- 5.7.5 Tower deflection at the top of the equipment shall be no greater than
- H/500 for brick lined equipment
 - H/200 for all other equipment

The calculation of the deflection during operational conditions shall take into account insulation, steel structures and piping that are guided or supported by the equipment. Calculations shall be submitted for review and shall be approved by the Principal when the tower has a natural frequency of less than 1.1 Hz.

5.8 FATIGUE ANALYSIS

The Principal shall specify the required design lifetime and all operating data necessary for the Manufacturer/Supplier to perform a fatigue analysis, if required. If a vessel is intended to be used in a service where more than one set of operating parameters (pressure and temperature) is envisaged (e.g., catalyst regeneration, batch processes, etc.), the data shall include this information and shall state the duration of each envisaged operating mode. Vessels that are subject to cyclic service shall be evaluated in accordance with the code of construction.

5.9 CREEP ANALYSIS

If a vessel is operating above the temperatures given in Table 5.2, where time dependent properties are a consideration, the requirement for a creep analysis shall be investigated. If the code of construction specifies a lower temperature for consideration of creep then that limitation shall be followed.

Table 5.2 Temperatures above which creep analysis is required

Material	Temperature
Carbon steel	380 °C (750 °F)
Nickel steel	400 °C (750 °F)
1 Cr–0.5 Mo	470 °C (875 °F)
1¼ Cr–0.5 Mo	440 °C (825 °F)
2¼ Cr–1 Mo	440 °C (825 °F)
Austenitic stainless steels	500 °C (1000 °F)

If cyclic service is a consideration along with operation in the time dependent temperature range, an analysis for creep/fatigue interaction needs to be considered. Generally accepted methods such as API 579 or BS 7910 can be used for this analysis.

The Principal shall specify the required service lifetime and all operating data, necessary to perform any required creep analysis. If a vessel is intended to be used in a service where more than one set of operating parameters (pressure and temperature) is expected, the data shall include this information and shall state the duration of each anticipated operating mode.

5.10 SHELLS

If shell courses have different thicknesses, the inside diameter shall be constant unless otherwise specified by the Principal.

The minimum distance between two longitudinal seams in one course shall be 200 mm (8 in) or five times the wall thickness, whichever is the larger, as measured between the toe of each weld. The minimum distance between the staggered longitudinal seams of two adjacent courses shall be 200 mm (8 in) or five times the wall thickness, whichever is the greater. However, where this cannot be achieved, the last 300 mm (12 in) of the adjacent longitudinal and the intersected circumferential seams shall be subjected to 100 % examination in accordance with (6.3) or (6.4) as applicable

5.11 FORMED HEADS

5.11.1 Unless otherwise specified by the Principal, heads shall be 2:1 ellipsoidal. For high pressure service hemispherical heads may be specified with the approval of the Principal.

5.11.2 The use of torispherical heads shall be approved by the Principal.

5.12 FLAT HEADS

5.12.1 Unless otherwise specified by the Principal, flat heads shall be attached by full penetration welds, or by bolting.

5.12.2 Flat heads secured by multiple piece retaining rings shall not be used without the approval of the principal

5.13 NOZZLES, CONNECTIONS AND OPENINGS

5.13.1 Unless otherwise specified by the Principal, all connections shall be flanged with through studs, or specified with a butt weld end connection.

5.13.2 For nozzles, Standard Drawing S 10.101 shall apply. Nozzle necks shall be a minimum of DN 40 (NPS 1½) except DN 20 (NPS ¾ in) for Vessel Category 3 in non-toxic, non-flammable, non cyclic and non-vibrating service. Reducers may be installed in accordance with Standard Drawing S 10.101.