OFFSHORE STANDARD
DNV-OS-C401

FABRICATION AND TESTING OF OFF-SHORE STRUCTURES

JANUARY 2001

DET NORSKE VERITAS

FOREWORD

DET NORSKE VERITAS (DNV) is an autonomous and independent foundation with the objectives of safeguarding life, property and the environment, at sea and onshore. DNV undertakes classification, certification, and other verification and consultancy services relating to quality of ships, offshore units and installations, and onshore industries worldwide, and carries out research in relation to these functions.

DNV Offshore Codes consist of a three level hierarchy of documents:

— *Offshore Service Specifications.* Provide principles and procedures of DNV classification, certification, verification and consultancy services.
— *Offshore Standards.* Provide technical provisions and acceptance criteria for general use by the offshore industry as well as the technical basis for DNV offshore services.
— *Recommended Practices.* Provide proven technology and sound engineering practice as well as guidance for the higher level Offshore Service Specifications and Offshore Standards.

DNV Offshore Codes are offered within the following areas:

A) Qualification, Quality and Safety Methodology

B) Materials Technology

C) Structures

D) Systems

E) Special Facilities

F) Pipelines and Risers

G) Asset Operation

Amendments October 2002 and April 2002

This Code has been amended, but not reprinted in October 2002 and April 2002. The changes are incorporated in the Web, CD and printable (pdf) versions. The amendments are shown in red colour in the Web and CD versions.

All changes affecting DNV Offshore Codes that have not been reprinted, are published separately in the current *Amendments and Corrections*, issued as a printable (pdf) file.

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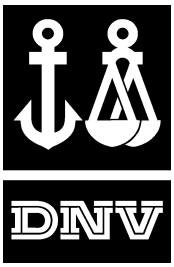
CONTENTS



OFFSHORE STANDARD
DNV-OS-C401

FABRICATION AND TESTING OF OFFSHORE STRUCTURES

CHAPTER 1

INTRODUCTION

CONTENTS PAGE

DET NORSKE VERITAS

Veritasveien 1, N-1322 Høvik, Norway Tel.: +47 67 57 99 00 Fax: +47 67 57 99 11

SECTION 1
INTRODUCTION

A. General

A 100 Introduction

101 This standard contains requirements for fabrication and testing of offshore structures.

A 200 Objective

201 The objectives of this standard are to:

— provide an internationally acceptable standard to ensure the quality of all welding operations used in offshore fabrication, through identifying appropriate welding procedures, welder qualifications and test methods
— serve as a technical reference document in contractual matters between purchaser and contractor
— serve as guideline for designer, purchaser and contractor
— specify minimum requirements for welding operations subject to DNV certification and classification.

A 300 Organisation of contents

301 Ch.2 Sec.1 to Ch.2 Sec.6 give common requirements that are considered applicable to all types of offshore units and installations.

B. Normative References

B 100 General

101 The references given in Table B1, Table B2 and Table B3 include provisions, which through reference in this text constitute provisions for this standard.

B 200 Offshore service specifications and rules

201 The offshore service specifications and rules given in Table B1 are referred to in this standard.

Table B1 DNV Offshore Service Specifications and rules	
Reference	*Title*
DNV-OSS-101	Rules for Classification of Offshore Drilling and Support Units
DNV-OSS-102	Rules for Classification of Floating Production and Storage Units
	Rules for Classification of Ships

B 300 Offshore Standards

301 The offshore standards given in Table B2 are referred to in this standard.

Table B2 DNV Offshore Standards	
Reference	*Title*
DNV-OS-B101	Metallic Materials
DNV-OS-C101	Design of Offshore Steel Structures, General (LRFD method)
DNV-OS-C201	Structural Design of Offshore Units (WSD method)

B 400 Other references

401 The other references given in Table B3 are referred to in this standard.

Table B3 Other references	
Reference	*Title*
ANSI/AWS D1.1	Structural Welding Code - Steel
ASME	Section IX, Welding and Brazing Qualifications Non-Interfiled (Boiler and Pressure Vessel Codes)
ASTM G48	Standard Test Methods for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution
ASTM E562	Standard Test Method for Determining Volume Fraction by Systematic Manual Point Count
BS 7448-2	Fracture mechanics toughness tests. Method for determination of KIc, critical CTOD and critical J values of welds in metallic materials
EN 287	Approval testing of welders - Fusion welding
EN 1418	Welding personnel – Approval testing of welding operators for fusion welding and resistance weld setters for fully mechanized and automatic welding of metallic materials
IACS	Shipbuilding and Repair Quality Standard, Part A - Shipbuilding and repair Quality Standard for New Construction and Part B - Repair Quality Standard for Existing Ships
ISO 148	Steel - Charpy impact test (V-notch)
ISO 898	Mechanical properties of fasteners made of carbon and alloy steel
ISO 6507-1	Metallic materials - Vickers hardness test - Part 1: Test method
ISO 8501-1	Preparation of steel substrates before application of paints and related products -- Visual assessment of surface cleanliness - Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings
ISO 9001:2000	Quality management systems - Requirements
ISO 9606	Approval testing of welders - Fusion welding
ISO 10042	Arc-welded joints in aluminium and its weldable alloys - Guidance on quality levels for imperfections
NACE MR0175	Sulphide Stress Cracking Resistant Metallic Materials for Oilfield Equipment - Item No. 21302

C. Informative References

C 100 General

101 The documents listed in Table C1 include acceptable methods for fulfilling the requirements in the standard and may be used as a source of supplementary information. Other recognised documents as listed below may be used provided it is shown that they meet or exceed the level of safety of the actual standards.

Table C1 DNV Recommended Practices and Classification Notes	
Reference	*Title*
DNV-RP-C203	Fatigue Strength Analysis of Offshore Steel Structures
Classification Note 30.1	Buckling Strength Analysis

D. Definitions

D 100 Verbal forms

101 *Shall:* Indicates a mandatory requirement to be followed for fulfilment or compliance with the present standard. Deviations are not permitted unless formally and rigorously justified, and accepted by all relevant contracting parties.

102 *Should:* Indicates a recommendation that a certain course of action is preferred or particularly suitable. Alternative courses of action are allowable under the standard where agreed between contracting parties but shall be justified and documented.

103 *May:* Indicates a permission, or an option, which is permitted as part of conformance with the standard.

104 *Can:* Can-requirements are conditional and indicate a possibility to the user of the standard.

105 *Agreement,* or *by agreement*: Unless otherwise indicated, agreed in writing between contractor and purchaser.

D 200 Terms

201 *Purchaser:* The owner or another party acting on his behalf, who is responsible for procuring materials, components or services intended for the design, construction or modification of a structure.

202 *Contractor:* A party contractually appointed by the purchaser to fulfil all, or any of, the activities associated with fabrication and testing.

203 *Welding procedure:* A specified course of action to be followed in making a weld, including reference to materials, welding consumables, preparation, preheating (if necessary), method and control of welding and post-weld heat treatment (if relevant), and necessary equipment to be used.

204 *Welding procedure specification:* A document providing in detail the required variables of the welding procedure to ensure repeatability.

205 *Preliminary welding procedure specification (pWPS):* A tentative welding procedure specification, which is assumed to be adequate by the manufacturer or contractor, but which has not been qualified.

206 *Welding procedure test:* The making and testing of a standardised test piece, as indicated in the pWPS, in order to qualify a welding procedure specification.

207 *Welding procedure qualification record (WPQR):* A record comprising all necessary data needed for qualification of a pWPS.

208 *Qualified welding procedure specification (WPS):* A welding procedure specification, which has been qualified by conforming to one or more, qualified WPQRs.

209 *Non-destructive testing (NDT):* Visual inspection, radiographic testing, ultrasonic testing, magnetic particle testing, penetrant testing and other non-destructive methods for revealing defects and irregularities.

D 300 Abbreviations

301 The abbreviations given in Table D1 are used in this standard.

Table D1 Abbreviations

Abbreviation	*In full*
AC	Alternating current
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing of Materials
AWS	American Welding Society
BM	Base material
BS	British Standard (issued by British Standard Institution)
CE	Carbon equivalent
C-Mn	Carbon manganese
CTOD	Crack tip opening displacement
DAC	Distance amplitude curve
DC	Direct current
DNV	Det Norske Veritas
ECA	Engineering critical assessment
EN	European de Normalisation
FM	Fracture mechanics
HAZ	Heat affected zone
IACS	International Association of Classification Societies
ISO	International Organisation for Standardisation
MAG	Metal active gas (welding)
MIG	Metal inert gas (welding)
NACE	National Association of Corrosion Engineers
NDT	Non-destructive testing
PWHT	Post weld heat treatment
pWPS	Preliminary welding procedure specification
RP	Recommended practice
SMAW	Shielded metal arc welding
SMYS	Specified minimum yield stress
TIG	Tungsten inert gas (welding)
WM	Weld metal or Deposit
WPQR	Welding procedure qualification record
WPS	Welding procedure specification
WPT	Welding production test

D 400 Latin symbols

401 The following Latin symbols are used:

a	=	size of test specimen
b	=	size of test specimen
d	=	diameter of round tensile test specimen
d_f	=	distance from the plane of the fatigue pre-crack to the fusion line
e	=	plastic deformation
h_T	=	test pressure height
h_{op1}	=	vertical distance from the load point to the position of maximum filling height
h_{s3}	=	vertical distance from the load point to the top of the tank
h_{p0}	=	height corresponding to valve opening pressure when exceeding the general value
h_{op2}	=	vertical distance from the load point to the position of maximum filling height. For tanks adjacent to the sea that are situated below the extreme operational draught (T_E), h_{op2} is not normally to be taken as being less than T_E
h_{D2}	=	pressure head due to flow through pipes
l_e	=	equivalent parameter for conical shells
l_{min}	=	breadth of test assembly plates
l_r	=	length of template or rod
r	=	nominal radius of the shell
r_a	=	actual distance from the centre of the sphere to the shell wall
r_e	=	equivalent parameter for conical shells

r_a = actual distance from the cylinder axis to the shell wall
s = distance between stiffeners or girders
t = thickness
t1 = wall thickness of the greater tube (can)
t2 = wall thickness of the smaller tube (brace)
A = diameter used in wrap around bending test
C = diameter of roller in bend test
D = outside diameter
D_1 = outside diameter of the greater tube (can)
D_2 = outside diameter of the smaller tube (brace)
KV = impact energy requirement
L_o = length of test area in test specimens
L_{min} = length of test assembly plates
N = number of
R = radius
R_c = forming radius
T = thickness of plate in bend test
W = width of weld

D 500 Greek symbols

501 The following Greek symbols are used:

α = tubular joint angle
δ = measure of deformation compared to theoretical geometry
λ_i = length of area with acceptable location of the fatigue pre-crack
ν = Poisson's ratio
σ_1 = largest compressive principal membrane stress
σ_2 = principal membrane stress normal to σ_1
ψ = ratio between principal stresses.

CHAPTER 2

TECHNICAL PROVISIONS

CONTENTS PAGE

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SECTION 1
WELDING PROCEDURES AND QUALIFICATION OF WELDERS

A. General

A 100 Scope

101 This section specifies requirements for welding procedures and welding procedure tests for C-Mn steel and low alloy steel, aluminium, austenitic stainless steels and ferritic-austenitic (duplex) stainless steels as well as qualification of welders.

A 200 Welding processes

201 Welding may be performed with the following processes unless otherwise specified:

— manual metal arc welding (metal arc welding with covered electrode)
— self-shielded tubular-cored arc welding
— submerged arc welding with one wire electrode
— submerged arc welding with strip electrode
— metal inert gas welding, (MIG) welding
— metal active gas welding, (MAG) welding
— tubular-cored metal arc welding with active gas shield
— tubular-cored metal arc welding with inert gas shield
— tungsten inert gas arc welding, (TIG) welding
— plasma arc welding.

B. Welding Procedures

B 100 General

101 A welding procedure specification shall as a minimum contain the following information as relevant for the welding operation:

— material: standard, grade and modification
— nominal thickness or diameter range (dimensions)
— welding process
— joint or groove design with tolerances
— welding position(s) and direction of progression
— welding consumables: trade name, electrode or wire diameter, shielding gas, flux and recognised classification
— welding sequence: number and order of passes or layers
— electrical parameters: voltage range, current range, polarity
— travel speed- and heat input ranges
— preheat and interpass temperatures
— post weld heat treatment parameters
— details on cleaning processes employed and restrictions if any.

B 200 Preliminary welding procedure specification, pWPS

201 A pWPS shall be prepared for each new welding procedure test. The pWPS shall specify the ranges for all relevant parameters.

202 The pWPS shall be submitted for review and acceptance by the purchaser prior to commencing the welding procedure test.

B 300 Welding procedure qualification record, WPQR

301 The WPQR shall be a record of the parameters used during the welding procedure test and subsequent non-destructive, destructive and corrosion test results. The WPQR shall be submitted for review and acceptance prior to start of production.

B 400 Welding procedure specification, WPS

401 A WPS is a specification based on a WPQR and shall be accepted by purchaser in accordance with those requirements. The WPS shall be the pWPS revised to reflect the welding variables qualified by the welding procedure test.

B 500 Welding procedure tests

501 When a welding procedure specification is required to be qualified by welding procedure tests, the welding shall be performed based upon the accepted pWPS and by applying the type of welding equipment to be used during production welding. The conditions shall be representative of the actual working environment for the work shop or site where the production welding will be performed.

C. Welding Procedure Tests, C-Mn Steel and Low Alloy Steel

C 100 Butt welds on plates

101 The test assembly may consist of two plates welded together. As far as possible the plates shall have a size that can simulate the heat transfer during the production welding. For manual or semiautomatic welding, a test assembly according to Fig.1 shall be carried out with:

l_{min} = 300 mm
L_{min} = 350 mm

For automatic welding, the dimensions shall be:

l_{min} = 400 mm
L_{min} = 1000 mm

Edge preparation and fit-up shall be as detailed in the pWPS.

The plates shall be joined and held by tack welds to provide the correct gap for the edge preparation used. 50 mm of each end of the test piece shall be discarded.

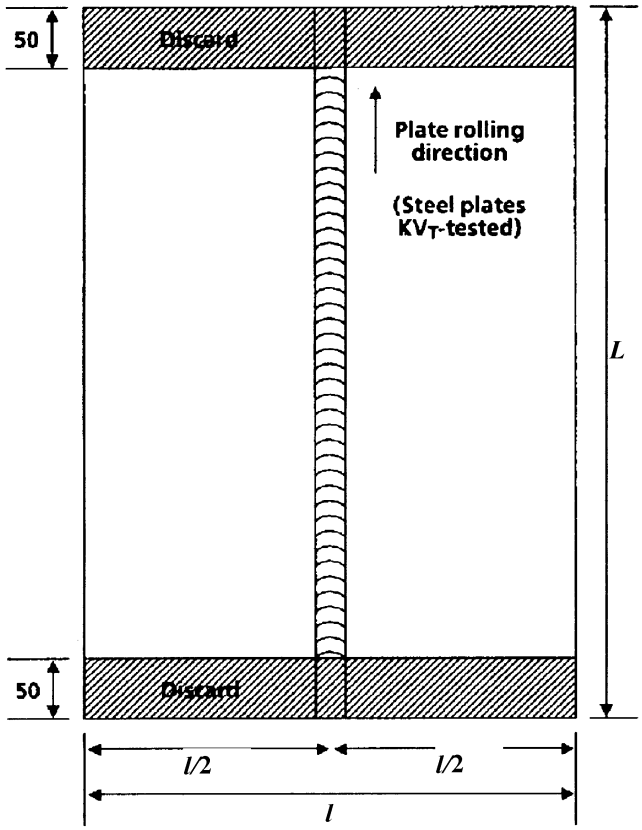


Figure 1
Test assembly for butt welds on plates

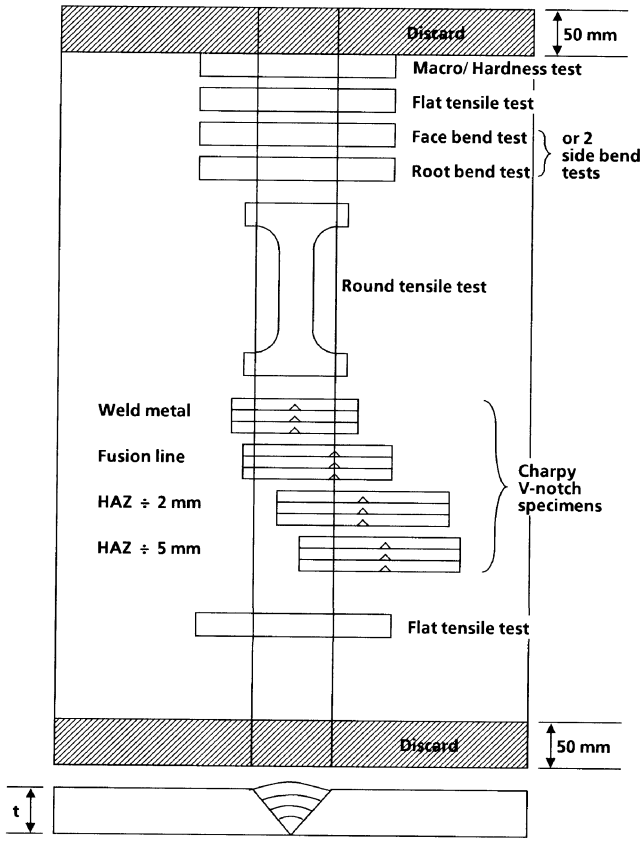


Figure 2
Sampling of test specimens on plates

102 NDT shall be carried out in accordance with the specification given for the production welding in question. The extent of the testing shall be as follows:

— 100% visual inspection
— 100% radiographic or ultrasonic testing
— 100% surface crack detection (dye penetrant or magnetic particle testing).

The soundness of the weld shall comply with requirements given in Sec.3 C.

103 The following mechanical tests are required from each assembly (see Fig.2):

— 2 tensile tests (flat specimen transverse to the weld)
— 1 root and 1 face bend tests when t ≤ 20 mm and 2 side bend tests when t > 20 mm
— 4 (6) sets of Charpy V-notch tests with the notch location as given in 107
— 1 macrosection test (metallographic examination + hardness measurements).

104 Specimens for transverse tensile testing shall be in accordance with G, type B.

The tensile strength shall not be below the specified minimum tensile strength for the steel grade in question.

105 Transverse side bend, root bend and face bend specimens shall be machined to the dimensions shown in G300.

For a mixed or heterogeneous butt joint longitudinal bend test specimens may replace transverse bend test specimens.

The test specimens shall be bent on a mandrel with diameter 4 t, where t is the thickness of the specimen, except for extra high strength steel grades NV 550, NV 620 and NV 690 where the diameter shall be 5 t.

The bending angle shall be at least 120°. After bending, the test specimens shall not reveal any open defects in any direction greater than 3 mm. Defects appearing at the corners of a test specimen during testing may be ignored in the evaluation, if not associated with obvious defects.

106 The macrosection shall include about 10 mm of unaffected base material and shall be prepared and etched on one side to clearly reveal the fusion line and the HAZ. Cracks and lack of fusion are not accepted.

The welded joints shall have a regular profile with smooth transitions to the base materials and without significant or excessive reinforcement.

107 The Charpy V-notch specimens shall be machined in accordance with the requirements given in DNV-OS-B101. Four sets of three specimens each shall be sampled 2 mm below the surface of the parent material and transverse to the weld. 12 Charpy V-notch specimens shall be localised in the welded joint as follows:

— 3 specimens with the notch along the weld metal centreline
— 3 specimens with the notch in the fusion line

— 3 specimens with the notch in the HAZ, 2 mm from the fusion line
— 3 specimens with the notch in the HAZ, 5 mm from the fusion line.

The V-notch shall be perpendicular to the plate surface.

For plate thickness t > 50 mm two additional sets of specimens shall be taken from the root area: one with the notch in centre of weld and one with the notch in the fusion line.

For dissimilar metal joints and/or joints between cast or forged and rolled materials, impact tests shall be carried out on test specimens with notch in fusion line, 2 mm from fusion line and 5 mm from fusion line in each parent material.

The Charpy V-notch test temperature and the average value for absorbed energy (KV) in weld metal, fusion line and HAZ shall be the same as required for the base material in transverse direction (see DNV-OS-B101).

For grades of improved weldability (see DNV-OS-B101), the Charpy V-notch test temperature and the average value for absorbed energy in weld metal, fusion line and HAZ shall be the same as required for the base material of the comparable normal weldability grade in transverse direction.

For ship-shaped units, the requirements given by the Rules for Classification of Ships Pt.2 Ch.3 Sec.2 B308 may be applied as an alternative.

108 In the case of reduced Charpy V-notch test specimens (10 mm x 7.5 mm and 10 mm x 5 mm), the impact energy values to be obtained shall satisfy the requirements in Table C1.

Table C1 Impact energy requirement for sub-size specimens

Dimensions of Charpy V-notch test specimen	*Impact energy*
10 x 10 mm	KV
10 x 7.5 mm	5/6 KV
10 x 5 mm	2/3 KV

109 The average impact requirements shall be satisfied for each notch location, but one single value of three values from specimens from the same notch location may be below the average requirements, but not below 70% of minimum average.

110 Where the results from a set of three impact test specimens do not comply with the requirements, an additional set of three impact test specimens may be taken.

The results obtained shall be combined with the original results to form a new average, which, for acceptance, shall be not less than the required value. Additionally, for these combined results not more than two individual values shall be less than the required average value, and of these, not more than one shall be less than 70% of the average value.

When the result of any test, other than impact test, fails to meet the requirements, two further tests may be made from the same welded joint. If both these additional tests are satisfactory, the test is acceptable.

111 The hardness testing shall be in accordance with ISO 6507-1 or equivalent. The Vickers method (HV10) shall be used.

Indentations shall be made along traverses in the weld, HAZ and the parent metal approximately 1 mm below the surface. For each traverse a minimum of 3 indentations shall be made in the weld, HAZ (both sides) and parent metal (both sides). For HAZ the first indentation shall be placed as close to the fusion line as possible. For double sided welds, for fillet and T-butt welds one additional row of indentations shall be made through the root area.

For material grades up to and including NV 460, a maximum hardness limit of 350 HV10 shall be met for welds in submerged structures exposed to cathodic protection. Hardness limits for higher grades shall be subject to agreement.

Guidance note:

For NV 500, NV 550, NV 620 and NV 690 grades a maximum hardness limit of 420 HV10 is recommended for welds in submerged structures exposed to cathodic protection.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

112 When a butt weld is made between two different material grades, the test temperature and achieved impact energy shall comply with the minimum specified requirements for the lower steel grade.

In the same way, the tensile strength to be obtained on the welded assembly shall be in agreement with the requirements relating to the plate steel having the lower strength.

As an example the test temperature, impact energy and tensile strength for the butt welded joints given in Fig.3 are those required for the plate of grade D in the left assembly and for the plate of grade E in the right assembly.

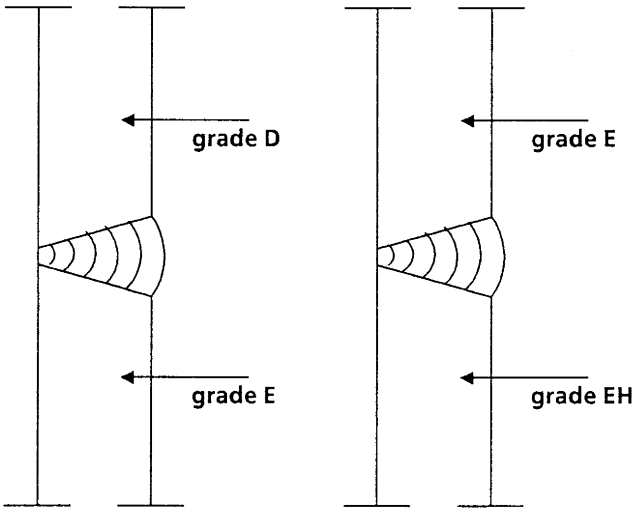
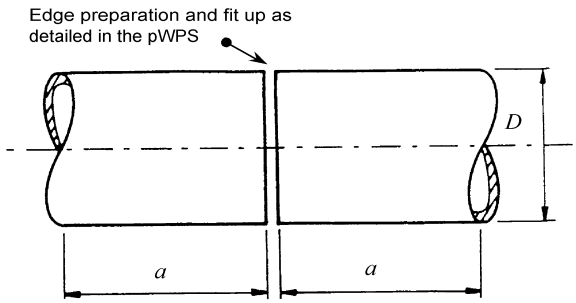


Figure 3
Butt welded plate joints of different grades

C 200 Butt welds on tubes

201 The test assembly shall be in accordance with Fig.4.



a = minimum value 150 mm
D = outside diameter

Figure 4
Test assembly for butt welds on tubes

202 NDT shall be carried out in accordance with the specification given for the production welding in question. The extent of the testing shall be as follows:

— 100% visual inspection

— 100% radiographic or ultrasonic testing
— 100% surface crack detection (dye penetrant or magnetic particle testing).

The soundness of the weld shall comply with requirements given in Sec.3 C.

203 The following mechanical tests are required from each assembly (see Fig.5):

— 2 tensile tests (flat specimen transverse to the weld)
— 1 root and 1 face bend tests when t ≤ 20 mm and 2 side bend tests when t > 20 mm
— 4 (6) sets of Charpy V-notch tests with the notch location as given in 107
— macrosection test (metallographic examination + hardness measurements).

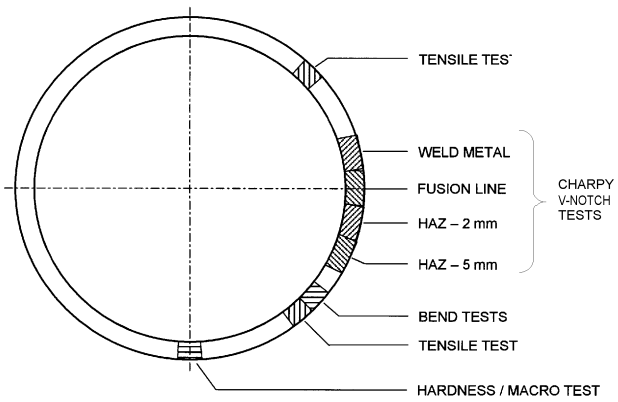


Figure 5
Sampling of test specimens on tubes

204 The results of mechanical testing shall comply with the relevant requirements given in C100.

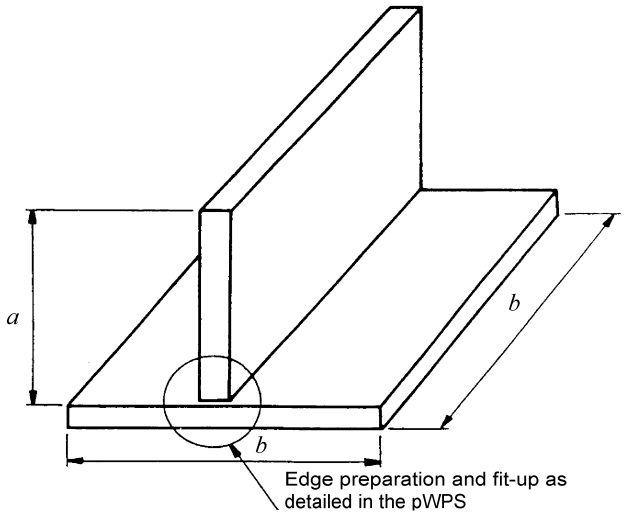
C 300 Full penetration T-, Y-, and K- joints

301 WPQT's for full penetration groove welds between plates at right angles or inclined, i.e. T- or Y- and K- configurations, shall cover a weld length of minimum 350 mm (see Fig.6).

302 NDT shall be carried out in accordance with the specification given for the production welding in question. The extent of the testing shall be as follows:

— 100% visual inspection
— 100% ultrasonic testing
— 100% surface crack detection (dye penetrant or magnetic particle testing).

The soundness of the weld shall comply with requirements given in Sec.3 C.



a = 3 t, minimum value 150 mm
b = 6 t, minimum value 350 mm

Figure 6
Test assembly for full penetration T-joints

303 The following mechanical tests are required from each assembly (see Fig.7):

— 4 (6) sets of Charpy V-notch tests with the notch location as given in 107
— macrosection test (metallographic examination + hardness measurements).

The results of mechanical testing shall comply with the relevant requirements given in C100.

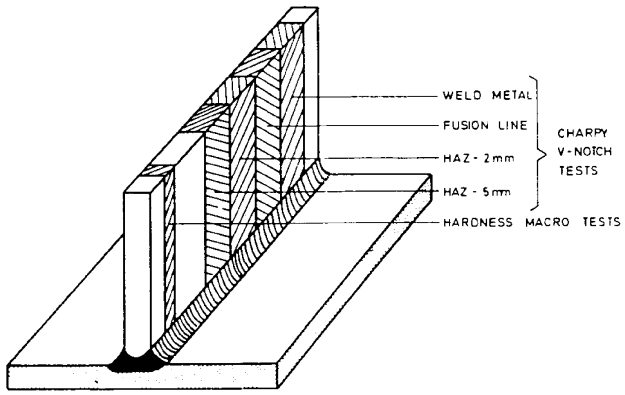


Figure 7
Sampling of test specimens on full penetration T-joints

C 400 Tubular joints

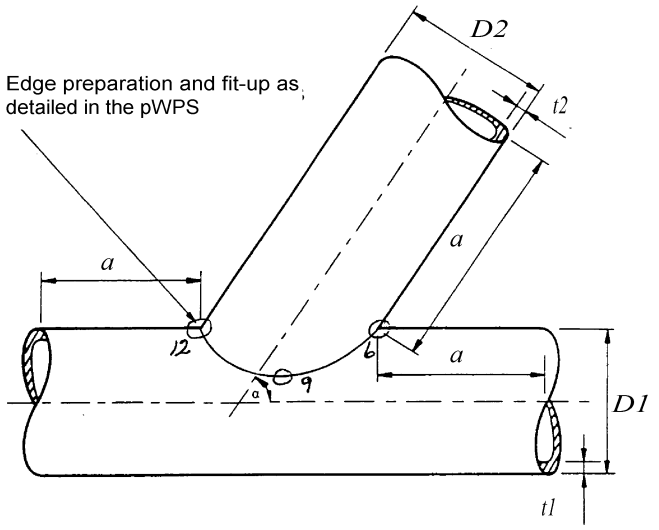
401 The test assembly shall be in accordance with Fig.8.

402 NDT shall be carried out in accordance with the specification given for the production welding in question. The extent of the testing shall be as follows:

— 100% visual inspection
— 100% ultrasonic testing
— 100% surface crack detection (dye penetrant or magnetic particle testing).

The soundness of the weld shall comply with requirements

given in Sec.3 C.



a	=	minimum value 150 mm
D1	=	outside diameter of the greater tubular (can)
t1	=	wall thickness of the can
D2	=	outside diameter of the smaller tube (brace)
t2	=	wall thickness of the brace

Figure 8
Test assembly for tubular joints

403 The following mechanical tests are required from each assembly (see Fig.9):

— Charpy V-notch tests sampled at 9 o'clock and with the notch location as given in 107
— two macrosection tests (metallographic examination + hardness measurements) at 12 and 6 o'clock.

404 The results of mechanical testing shall comply with the relevant requirements given in C100.

405 Restrictions and testing for joint configuration involving acute angles (less than 15°) should be specified. AWS D1.1 is a good reference for structural welds.

C 500 Fillet welds

501 The two plates are assembled and positioned edgewise so as to constitute a tee-assembly with no clearance. As far as possible the plates shall be of a sufficient size to ensure a reasonable heat distribution.

For fillet welds the test assembly shall be as defined in Fig.9.

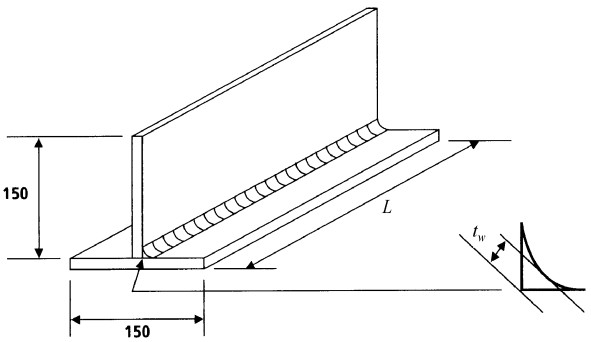


Figure 9
Test assembly for fillet welds

For manual and semi-automatic welding the length of the test piece shall be:

L_{min} = 350 mm

For automatic welding the length shall be:

L_{min} = 1000 mm

Weld and fit-up shall be as detailed in the pWPS.

The test assembly shall be welded on one side only. For manual and semi-automatic welding, the stop and restart position shall be included in the test length and shall be clearly marked for subsequent examination.

The ends of the specimen are exempted from examination over a length of 50 mm.

502 NDT shall be carried out in accordance with the specification given for the production welding in question. The extent of the testing shall be as follows:

— 100% visual inspection
— 100% surface crack detection (dye penetrant or magnetic particle testing).

The soundness of the weld shall comply with the specified requirements given in Sec.3 C.

If the stop and restart spot is included in the test length, special attention shall be paid to this position with respect to profile, proper fusion and absence of crater defects.

503 The following tests shall be performed:

— two macrosection tests (metallographic examination, hardness measurements).

One of the macrosections shall be taken at the marked position of the stop and restart (for more details see 106).

For hardness testing, see 111.

C 600 Re-testing

601 If the welding procedure test fails to comply with any of the requirements for NDT one extra test shall be welded and subjected to the same testing. If this additional test does not meet the relevant requirements, the actual pWPS shall be considered as not qualified and a re-specification of the pWPS shall be made prior to a new welding procedure test.

C 700 Validity of qualified welding procedures

701 The validity of a qualified welding procedure shall be restricted to the workshop or work site performing the qualification. Workshops, work site or workshop branches under the same technical management and working in accordance with the same QA-program and -procedures are considered as one workshop or work site.

702 Qualification of a welding procedure remains valid provided the parameters are kept within the qualified ranges of essential variable during production welding. The essential variables and qualified ranges are given in 703. When variations outside the qualification ranges of essential variables occur, the welding procedure qualification shall be considered invalid, and the WPS shall therefore be re-specified and re-qualified.

703 A qualified welding procedure shall be used within the ranges of the parameters of essential variables listed below.

Base material

The following changes shall lead to a new qualification:

a) In general, significant change of material properties which will obviously affect the weldability and mechanical properties.

Guidance note:

When qualifying a welding procedure, it is recommended to use specified material with highest carbon equivalent (CE) available in the workshop or work site, especially when the thickness is large.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

b) More specifically, structural steels of both normal and improved weldability are grouped in three strength groups:

i) Normal strength steel, grades A, B, D and E or equivalent structural steels with tensile strength 400 to 520 N/mm^2.

ii) High strength steel, grades A 27, D 27, E 27, A 32, D 32, E 32, F 32, A 36, D 36, E 36, F 36, A 40, D 40, E 40, F 40 or equivalent structural steels with minimum specified yield strength 265 to 390 N/mm^2.

iii) Extra high strength steels, grades A-F 420, A-F 460, A-F 500, A-F 550, A-F 620, A-F 690 or equivalent structural steels with minimum specified yield strength 420 to 690 N/mm^2.

The qualification on steel grades of higher toughness requirements will qualify the grades of lower toughness but not vice versa.

704 Thickness, is defined as follows:

a) For a butt weld:
The base metal thickness, which for welds between dissimilar thickness is that of the thinner material.

b) For a fillet weld:
The base metal thickness, which for welds between dissimilar thickness is that of the thicker material. However, for each thickness range qualified, as given in Table C2 there is an associated range of qualified throat thickness.

c) For a set-on tubular joint:
The thickness of the brace.

d) For a set-in or set-through tubular joint:
The thickness of the can.

e) For a T-butt joint in plate:
The thickness of the prepared plate (abutting member).

The requirements for qualified thickness range for butt welds shall be as given in Table C2.

Table C2 Qualified thickness range

Thickness t in mm of test piece	*Qualification range* [1]	
	for single run or single run from both sides	*for multi-run welding and all fillet welds*
t ≤ 12	0.8 t to 1.1 t	up to 2 t
12 < t ≤ 100	0.8 t to 1.1 t	0.5 t to 2 t (maximum 150)
t > 100	-	0.5 t to 1.5 t

1) The qualification range for vertical downward position is 0.5 t to 1.1 t

The requirements for qualified thickness range for single run fillet welds are in addition to the requirements of Table C2, that the throat thickness, t_w, shall be in the range 0.75 t_w to 1.5 t_w. However, a test with a throat thickness ≥ 10 mm shall give qualification for all throat thicknesses ≥ 10 mm.

Where a fillet weld is qualified by means of a butt weld test, the throat thickness range qualified shall be based on the thickness of the deposited weld metal.

Diameter of tubes and tubular joints

The qualification of a welding procedure test on diameter D shall include qualification for diameters in the following ranges as given in Table C3.

Table C3 Qualified range for tube and tubular joint

Diameter of the test piece D (mm) [1] [2]	*Qualification range*
D < 168.3	0.5 D to 2 D
D ≥ 168	≥ 0.5 D and plates

1) D is the outside diameter of the tube or outside diameter of the brace

2) Qualification given for plates also covers tubes when the outside diameter is greater than 500 mm

Angle of tubular joints

A welding procedure test carried out on a tubular joint with angle α shall qualify all tubular joint angles in the range of α to 90°.

Welding consumables

The following changes shall lead to a new qualification:

— any change in consumable classification
— change of consumable brand when impact testing is required at temperatures below – 20°C
— any significant change of mixture or composition (e.g. change from argon or mixed gas to CO_2 gas), flow rate, filling time and filling volume for shielding and purging gases.

Welding positions

The following changes shall lead to a new qualification.

— Change from one principal welding position (see Fig.10, Fig.11 and Fig.12) to another, unless complying with Table C4.

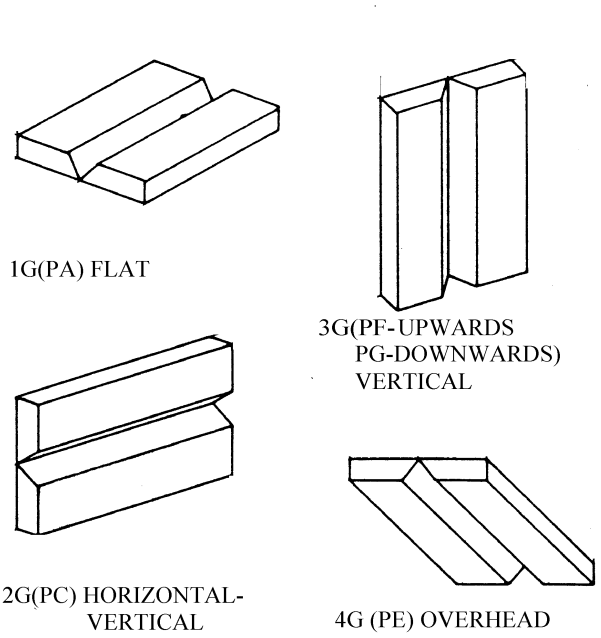


Figure 10
Plate test positions

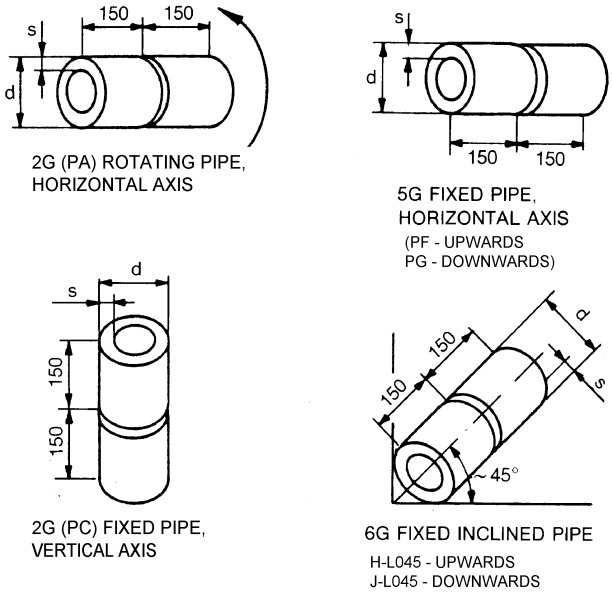


Figure 11
Pipe test positions

Type of joint

The following changes shall lead to a new qualification:

- change from fillet weld to butt weld
- change from two sided welding to one side (but not converse)
- deletion of back gouging
- deletion of backing in cases where the backing material is equivalent to the base material
- addition or deletion of ceramic (temporary) backing
- change from T-, Y- or K-joint to butt joint
- change from butt joint on plate to butt joint on tubular with outside diameter less than 500 mm
- change of specified type of groove, root face and gap, which may significantly affect penetration, fusion and delution of the weld.

Welding condition

The following changes shall lead to a new qualification:

- any change of welding process
- change from weaving to stringer bead technique or converse
- change from multi-run welding to one-run welding
- change of type of welding current from A.C. to D.C. or converse or change of polarity. For SMAW only, the current may be changed from A.C. to D.C. if recommended by the electrode manufacturer
- change in metal powder or wire addition beyond ± 10%
- change from spray arc to short arc or pulsed arc or vice versa
- change beyond ± 25% in heat input
- any decrease in preheating temperature and any increase in interpass temperature beyond 250°C
- change of post weld heat treatment parameters except for holding time, which may be adjusted as a function of thickness.

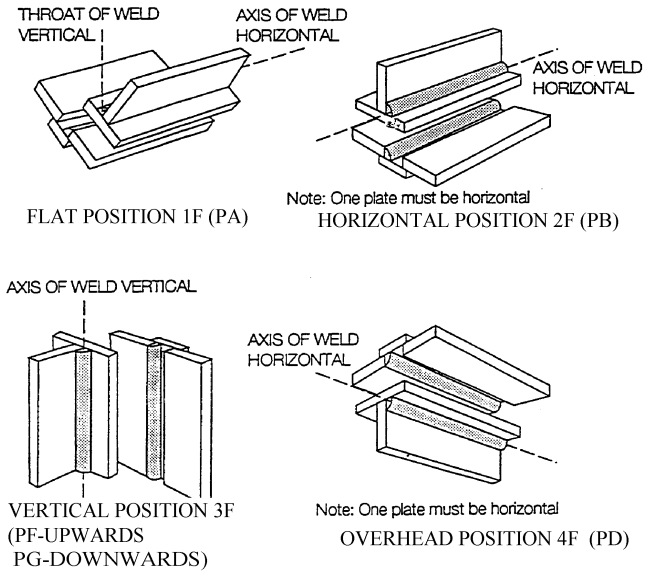


Figure 12
Positions of test plate for fillet welds

Table C4 Qualified principal positions for butt welds and fillet welds, steel

Test weld *Joint configuration* [1][2]	*Principal positions*	*Qualified positions* [3]		
		Butt welds		*Fillet weldsPlates or tubes*
		Plates	*Tubes*	
Butt welds on plates	2G + 3G1G2G3G4G	All1G1G, 2G, 4G3G1G, 4G	All1G1G, 2GNot applicable1G	All1F1F, 2F, 4F3F1F, 4F
Butt welds in tubes	2G + 5G = 6G1G2G5G	All1G1G, 2G, 4GAll	All1G1G, 2G1G, 5G	All1F1F, 2F, 4FAll
Fillet welds	2F + 3F1F2F3F4F5F			All1F1F, 2F, 4F3F1F, 2F, 4FAll

1) Tubes with D > 500 mm are considered equivalent to plates (apply only to the can in tubular joints)
2) Tubular joints shall be qualified separately
3) The vertical downwards position shall be qualified separately

D. Welding Procedure Tests, Aluminium

D 100 General

101 Qualified welding procedures are required for all important structural joints. The procedure tests shall be representative of the following:

- each base material or alloy and temper used in production
- the thickness and diameter range in question (see Table C2 and Table C3)
- each type of consumable and welding process
- welding position (see Table D1)
- joint and groove design
- number of passes
- preheat (if any)
- volt-ampere characteristics

— shielding gas.

Table D1 Qualified principal positions for butt welds and fillet welds, aluminium				
Test weld *Joint configuration*	*Principal positions*	*Qualified positions*[1]		
		Butt welds, plates	*Butt welds, tubes*	*Fillet welds*
Butt welds on plates	1G2G3G4G	1G1G, 2G, 3G1G, 2G, 3GAll	1G	1F1F, 2F, 3F1F, 2F, 3FAll
Butt welds in tubes	1G2G5G	1G1G, 2G, 3GAll	1G2G1G, 5G	1F1F, 2F, 3FAll
Fillet welds	1F2F3F4F5F			1F1F, 2F, 3F1F, 2F, 3FAllAll
1) The vertical downward position shall be qualified separately.				

D 200 Butt welds

201 Each test assembly consists of 2 plates with dimensions 300 x 150 mm. The plates shall be joined with a longitudinal butt weld. For extruded sections and pipes the assembly shall consist of 2 sections each 150 mm long (see Fig.13 and Fig.14).

202 Weld and fit-up shall be as detailed in the pWPS. Welding consumables are those recommended in Table D2.

203 If back-sealing run is specified, this run shall be laid in the same position as for the respective weld.

204 The welds shall be subjected to visual inspection, dye penetrant testing and ultrasonic- or X-ray testing. The requirements for quality level for imperfections shall be as given in ISO 10042 level B.

Table D2 Selection of suitable consumables for combinations of aluminium alloys			
Base metal alloy	*NV-5052, NV-5754 NV-5154,NV-5454 NV-5086*	*NV-5083NV-5383*	*NV-6060, NV-6061 NV-6063, NV-6005A NV-6082*
NV-5052, NV-5754 NV-5154, NV-5454 NV-5086	5356, 5556, 5183	5356, 5556, 5183	5356, 5556, 5183
NV-5083, NV-5383	5356, 5556, 5183	5183 [1]	5356, 5556, 5183
NV-6060, NV-6061 NV-6063, NV-6005A NV-6082	5356, 5556, 5183	5356, 5556, 5183	5356, 5556, 5183
Note: All consumables are covered by the AWS specification. The prefix «ER» is omitted. 1) Other consumables may be used if allowable stresses are reduced.			

205 Side-bend tests shall be carried out for thickness equal to and above 10 mm. Two bend specimens shall be taken from each of the welded assemblies.

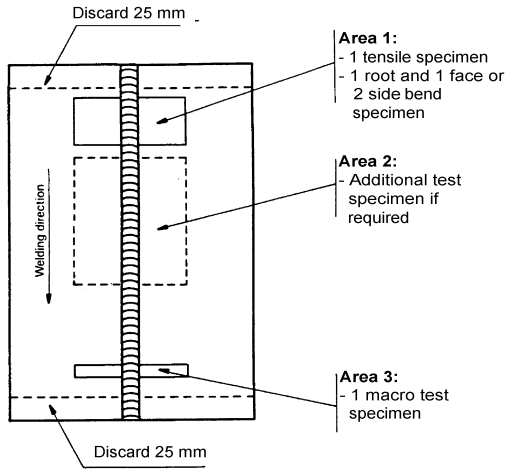


Figure 13
Location of test specimens for a butt weld on plate

206 For thickness below 10 mm one face bend and one root bend test specimens shall be taken. The width shall be 30 mm and the thickness equal to the plate thickness. The diameter of the bending mandrel shall be as given in Table D3.

Table D3 Former diameter for bend tests				
Base metal alloy	*Condition*			
	0, H111	*H116, H32, H321, H34*	*T4*	*T5, T6*
NV-5052, NV-5754 NV-5154, NV-5454	4t	4t	-	-
NV-5086, NV-5083, NV-5383	6t	6t	-	-
NV-6060, NV-6061 NV-6063, NV-6005A NV-6082	-	-	6t	7t

207 *Requirement*

No cracks or open defects exceeding 3 mm measured on the convex surface after bending are accepted. Smaller cracks developing from the edges of the specimens should not be considered as significant, unless there is definite evidence that they result from inclusions or other defects.«Wrap around» bending as shown in Fig.15 is the preferred bending method.

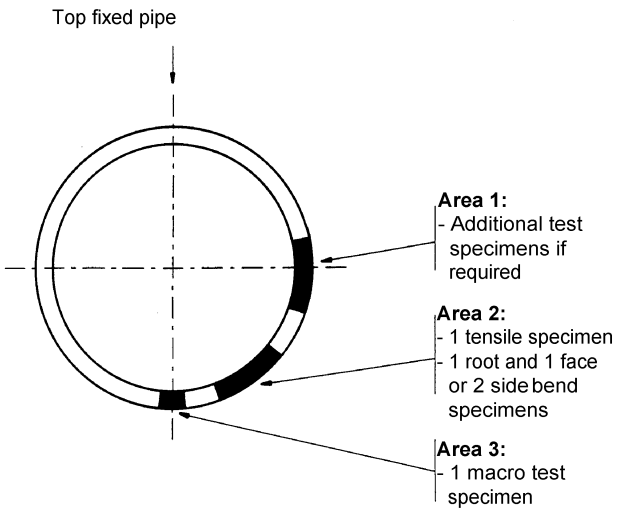


Figure 14
Location of test specimens for a butt weld in pipe

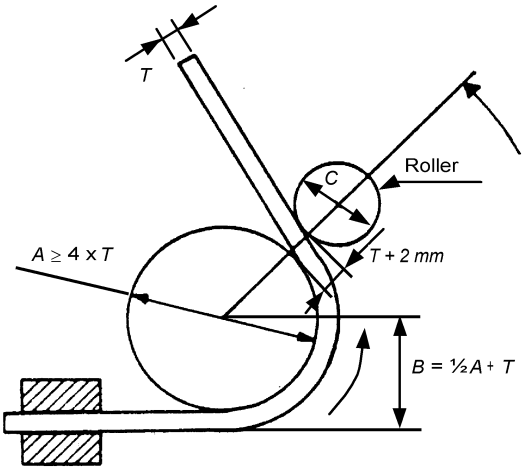


Figure 15
Wrap around bending

208 One tensile specimen shall be taken from each of the welded assemblies. The test specimen, 25 mm wide and with full plate thickness and orientated transverse to the weld, is shown in Fig.16.

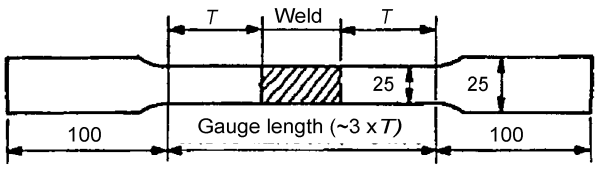


Figure 16
Tensile test specimen

209 The tensile strength of the test specimens shall not be less than specified for the parent alloy in Table D4.

210 One macrosection shall be prepared from the test assembly to reveal the weldment macro structure. The macrosection shall be visually inspected using a magnification of 5 to 10X. The macrosection shall show a regular weld profile with a smooth transition to the base material without significant undercut or excessive reinforcement and show thorough fusion between adjacent layers of weld metal and base metal. There shall be no cracks, lack of fusion and incomplete penetration.

D 300 Fillet welds

301 The two plates are assembled and positioned edgewise so as to constitute a tee-assembly with no clearance. As far as possible the plates shall be of a sufficient size to ensure a reasonable heat distribution.

For fillet welds the test assembly shall be as defined in Fig.9. For manual and semi-automatic welding the length of the test piece shall be:

l_{min} = 300 mm
L_{min} = 350 mm

For automatic welding the length shall be:

l_{min} = 400 mm
L_{min} = 1000 mm

Weld and fit-up shall be as detailed in the pWPS.

The test assembly shall be welded on one side only. For manual and semi-automatic welding, the stop and restart position should be included in the test length and shall be clearly marked for subsequent examination.

The ends of the specimen are exempted from examination over a length of 50 mm.

302 NDT shall be carried out in accordance with the specification given for the production welding in question. The extent of the testing shall be as follows:

— 100% visual inspection
— 100% surface crack detection (dye penetrant).

The soundness of the weld shall comply with ISO 10042 level B.

If the stop and restart spot is included in the test length, special attention shall be paid to this position with respect to profile, proper fusion and absence of crater defects.

303 The following tests shall be performed:

— two macrosection tests (metallographic examination).

One of the macrosections shall be taken at the marked position of the stop and restart (for more details see C106).

D 400 Re-testing

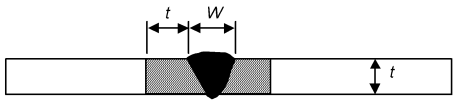
401 If any of the tests do not satisfy the specified requirements, new procedure tests in duplicate may be carried out. The results of both re-tests shall meet the specified requirements, otherwise the test shall be rejected.

Guidance note:

HAZ softening adjacent to welds

The strength of a weldment is a function of the welding process, filler metal and the aluminium alloy in question. For design purposes it is assumed that the strength is reduced in HAZ. The extent of the HAZ is assumed to have the same width as the weldment plus the plate thickness in each direction of the weld as shown in Fig.17.

If the strength shall be measured for information, this shall be carried out on a gauge length 2 t + W of the weld (approximately 3 t).



t = Plate thickness
W With of weld

Figure 17
Extent of HAZ

Table D4 Mechanical properties in the welded condition

Alloy	*Temper*	*Filler*	*Tensile strength R_m, minimum (N/mm^2)*	*Yield stress in HAZ, $R_p0,2$ minimum (N/mm^2)*
NV-50520	F, H111H32, H34	5356	170	65
NV-5754	0, F, H111, H24	5356-5183	190	80
NV-5154A	0, H111	5356-5183	215	85
NV-5454	0, F, H111, H34	5356-5183	215	85
NV-5086	0, F, H111,H116, H32, H34	5356-5183	240	100
NV-5083	0, F t < 6 mm0, F t > 6 mmH116, H321H116, H321	51835356-518353565183	270270270270	125115115125
NV-5383	0, H111, H116,H321	5183	290	140
NV-6060	T5	5356-5183	95	65
NV-6061	T4T5 or T6	5356-5183	165165	115115
NV-6063	T5T6	5356-5183	100100	6565
NV-6005A	T5 or T6	5356-5183	165	115
NV-6082	T4T5 or T6	5356-5183	170170	110115

E. Welding Procedure Tests, Stainless Steel

E 100 General

101 When welding procedure tests are required, the tests shall be performed in accordance with C and the supplementary requirements stated in D200 and D300 (if not otherwise specified herein).

102 The welding procedure tests shall cover all relevant dimensions, positions and material combinations. Details regarding essential variables and validity of the procedure shall be as described in C. Mechanical testing shall be as described in C100, if not otherwise specified in D200 and D300.

E 200 Supplementary requirements for austenitic stainless steel

201 Impact testing is not required for design temperatures above – 105°C. If used at below – 105°C, the test temperature shall be at minimum design temperature.

202 If impact testing is required, the average impact value for the three specimens shall not be less than 34 J.

203 When a butt weld is made between dissimilar material grades, both sides of the weld shall be impact tested.

E 300 Supplementary requirements for ferritic-austenitic stainless steel

301 Impact testing shall be carried out at design temperature or – 20°C, whichever is the lower. The average impact value for the three specimens shall not be less than 27 J.

302 When a butt weld is made between dissimilar material grades, both sides of the weld shall be impact tested.

303 Butt welds and fillet welds shall be corrosion tested according to ASTM G48, Method A. The test specimen shall be in the as welded state after normal weld cleaning operation. The test specimens shall be exposed to the solution at a constant temperature of 20°C for 24 hours.

The following test requirements shall be fulfilled:

— no pitting attack shall be visible on the test face(s)
— general weight loss shall not be less than 4 g/m^2.

Guidance note:

Welds between ferritic-austenitic stainless steels and C- and C-Mn steels need not be subjected to corrosion test.

304 A microstructural examination comprising the weld metal, heat affected zone and base metal is required for each welded assembly. The microstructure shall be suitably etched and examined at 400X magnification and shall be free from grain boundary carbides and precipitates. The ferrite content in the weld metal root and not re-heated weld cap shall be determined in accordance with ASTM E562 and shall be in the range of 25 to 70%.

F. Qualification of Welders

F 100 General

101 The welding processes for which qualifications are re-

quired include those which are designated as manual or partly mechanised welding. Welders shall pass a qualification test in accordance with 200. Contractors are required to keep records of the welders' qualifications and, when required, furnish copies of valid welders' certificates.

F 200 Standards for qualification testing

201 Welders shall be tested according to a recognised standard, e.g. EN 287, ISO 9606, ASME Section IX or ANSI/AWS D1.1.

202 Welding operators using fully mechanised or fully automatic processes need generally not pass a qualification test. However, operators shall receive adequate training in setting or programming and operating the equipment. Appropriate records of training shall be maintained. Contractors may be required to furnish valid qualification test certificates. EN 1418 may be used as a reference.

G. Testing

G 100 General

101 Testing of welds shall be carried out as specified in 200 to 300.

G 200 Tensile testing at ambient temperature

201 For tensile testing of all-weld-metal and butt welds two different types of test specimens may be used, round test specimens or flat test specimens (see Fig.18) as described below:

A - Deposited metal tensile test

Normally, round test specimens with the following dimensions shall be used:

d	=	10 mm
L_o	=	50 mm
L_c	=	60 mm
R	≥	5 mm

B - Butt weld tensile test for testing of the weld as a whole

Flat test specimens with the weld machined flush with the surface of the plate, shall be used. The dimensions shall be as follows:

a	=	thickness of plate, t
b	=	25 mm
L_0	=	L_C = 3 t or 2 t + width of weld, whichever is the greatest
R	=	25 mm

C - Butt weld tensile test

Flat test specimens with the weld machined flush with the surface of the plate, shall be used. The dimensions shall be as follows:

a	=	thickness of plate, t
b	=	30 mm
L_o	=	6 mm + width of weld + 6 mm
R	=	50 mm

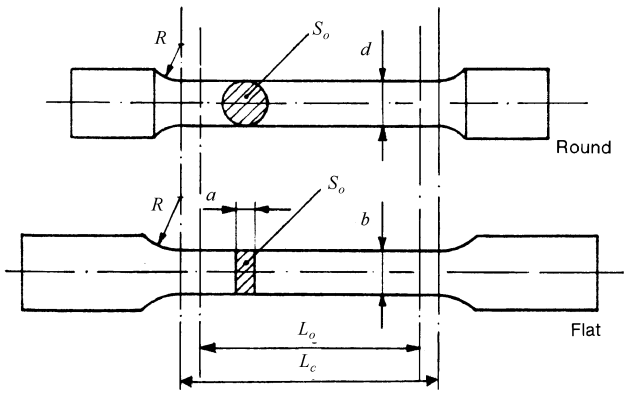


Figure 18
Tensile test specimen

G 300 Bend testing

301 Flat bend test specimens, as given in Fig.19 shall be used. Edges on tension side shall be rounded to a radius of 1 to 2 mm.

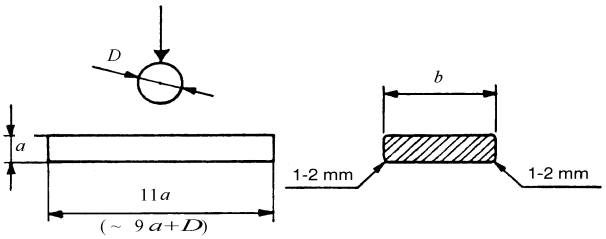


Figure 19
Bend test specimen

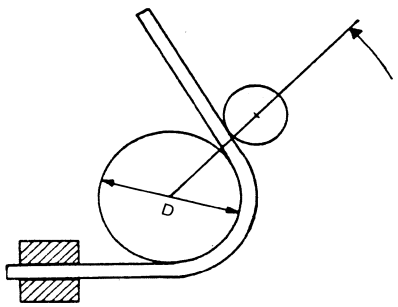


Figure 20
Wrap around bend test

302 When the wrap around bend test, exemplified Fig.20 is used, e.g. for the side bend test of a weld, the length of the test specimen shall be greater than the length 11a shown in Fig.19.

303 For butt weld bend test specimens, the weld shall be machined flush with the surface of the plate.

304 For transverse face-bend and root-bend test specimens for butt weld test the dimensions shall be as follows:

a	=	as rolled thickness t of the plate
b	=	30 mm

If the as rolled thickness t is greater than 25 mm, it may be reduced to 25 mm by machining on the compression side of the test specimen.

305 For transverse side-bend test specimens for butt weld test the dimensions shall be as follows:

a = 10 mm

b = as rolled thickness t of the plate

If $t \geq 40$ mm, the side-bend test specimen may be subdivided, each part being at least 20 mm wide.

306 When a longitudinal face-bend or root-bend weld test is required, a test specimen according to an appropriate standard will be accepted.

SECTION 2
FABRICATION AND TOLERANCES

A. General

A 100 Objective and scope

101 This section gives requirements for fabrication and tolerances of offshore structures.

B. Fabrication Planning

B 100 General

101 As a prerequisite for fabrication, procedures, inspection and test plans and work instructions for execution and control of fabrication activities shall be established. The purpose of the procedures and work instruction shall be:

— to provide instructions and information regarding the requirements for and the principles of the work execution
— to identify and document the responsibilities and plans for the work execution in accordance with the project requirements
— to provide information to the purchaser on how the work is executed and controlled
— to identify applicable procedures, test plans, work instructions, acceptance criteria, hold points and documents to be generated
— to serve as basis for quality audits.

102 Relevant procedures, including information of pre-assembled items and the sequence of fabricating the parts into structure, shall be prepared.

B 200 Quality system and workmanship

201 Fabrication of structural members shall have a documented and implemented quality system according to ISO 9001 or equivalent. The extent of the quality management system shall be dependent on the size and type of the organisation, complexity and interaction of the processes and competence of personnel.

202 Workmanship shall be in accordance with E following written procedures agreed upon.

203 All work shall be skilfully and carefully executed with adequate control by the contractor. All faults and deficiencies shall be corrected before the material is coated with paints, cement or similar. Repair work of significant extent shall be demonstrated as acceptable to the purchaser.

204 Prior to commencement of the work the contractor shall submit a plan for NDT, NDT procedures and documents for NDT inspectors' certification for acceptance by the purchaser. The programme shall contain information and documents for planning, controlling, reporting etc. Acceptance criteria for NDT shall be accepted by the purchaser if they are not specified in relevant documents.

C. Inspection

C 100 General

101 Inspection shall be carried out in accordance with accepted inspection and test plans to confirm that work is carried out in accordance with established project procedures and plans such that all project requirements are complied with to the satisfaction of the purchaser.

The inspection shall cover items such as:

— correct identification and documentation and use of materials
— qualification and acceptance of fabrication procedures and personnel
— inspection of preparatory work (assembly, fit-up form work, reinforcement etc.)
— welding inspection
— inspection of fabrication work for compliance with specifications and procedures
— witnessing NDT, control and testing
— inspection of repairs
— inspection of corrosion protection systems
— ensure functionality of examination or testing equipment and of recording and/or measuring devices vital for correct functioning of equipment and machinery used in fabrication.

102 Due consideration shall be given to the access and the time required for adequate inspection during fabrication.

103 High non-conformance rates in execution of the work or in the product itself shall call for special considerations. Such special considerations may include, but not be limited to, increased inspection, re-qualification of personnel or other agreed remedial actions.

104 Inspectors shall be qualified according to a recognised scheme and shall be able to provide documentation of proficiency.

D. Material Identification, Cutting and Forming

D 100 Material identification

101 A traceability system that ensures correct installation and documentation of the material grades or strength classes shall be established by the contractor throughout the prefabrication and installation process.

Proper care shall be exercised during handling and storage to preserve identification of such material.

D 200 Cutting and forming

201 The effect of work hardening shall be considered if shearing is used for cutting of material. Special attention shall be paid to the risk of cracked edges.

202 Attention shall be paid to excessive local hardening and carbon contaminations by thermal cutting. This may be reduced by suitable heat treatment or removed by mechanical means.

203 Forming and straightening of materials shall be performed according to procedures outlining the successive and controlled steps. Such procedures shall be controlled by inspection.

204 The degree of cold deformation of special and primary structural elements shall be less than 5%. If the deformation exceeds 5%, either heat treatment or strain ageing tests shall be carried out according to an agreed procedure.

Guidance note:

The plastic deformation e may be calculated by the following, simplified formulae:

Single-curvature deformation

Cold rolling or pressing of plates to cylindrical forms:

$$e = \frac{t}{D} 100\%$$

Cold bending of straight pipes to bends:

$$e = \frac{D}{2R_c}100\%$$

Double curvature deformation

Forming of plates to spheres:

$$e = \frac{t(l+v)}{2R_c}100\%$$

t = material thickness
D = outside diameter of pipe or vessel
Rc = forming radius
ν = Poisson's ratio (0.5 for plastic condition).

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

E. Tolerances

E 100 Misalignments

101 Allowable misalignment depends on extent of misalignment, stress level and type of loading as well as type and importance of the joint. See also DNV-RP-C203 Sec. 2.5.

102 The maximum misalignments shall not exceed the values given as standard values in IACS Shipbuilding and Repair Quality Standard, Part A Sec 7 without special consideration. Primary and Special is regarded as "strength" members and Secondary is regarded as "other" in the IACS Shipbuilding and Repair Quality Standard. Separate requirement to misalignment of non-continuos plates in special areas are given in 103.

103 Misalignment of the non-continuous plates in cruciform joints is not to exceed the values given in Fig.1 and Table E1.

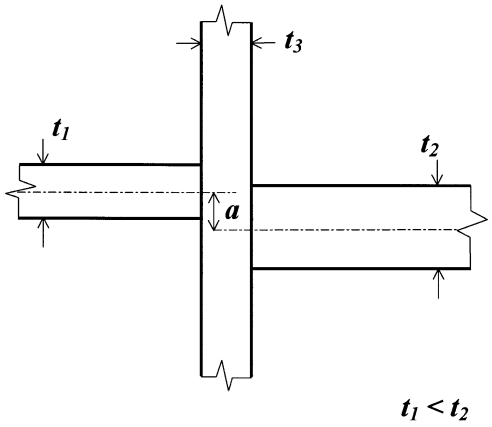


Figure 1
Alignment of cruciform joint

Table E1 Misalignment *a*	
Structural category	Maximum misalignment
Special	0.15 t_1
Primary	0.33 t_1
Secondary	0.5 t_1
t_1 is the smaller thickness of t_1, t_2 and t_3	

E 200 Fairness and straightness

201 The tolerances shall not exceed the requirements given as the standard values in IACS Shipbuilding and Repair Quality Standard, Part A Sec.6 without special consideration.

202 For compression members, the straightness of members shall be in accordance with the buckling code applied in code check.

203 Tolerances for compression members which are based on calculations according to DNV Classification Note 30.1 or DNV RP-C202 shall not exceed the values given in Table E2. The buckling strength of a fabricated structure with larger imperfections may be determined by use of the actually measured imperfection.

For ship shaped units complying with DNV-OS-C102, acceptable tolerances are given in IACS Shipbuilding and Repair Quality Standard.

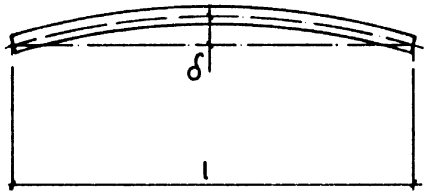
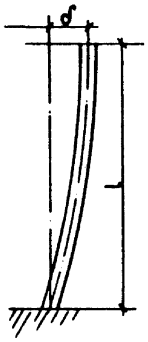
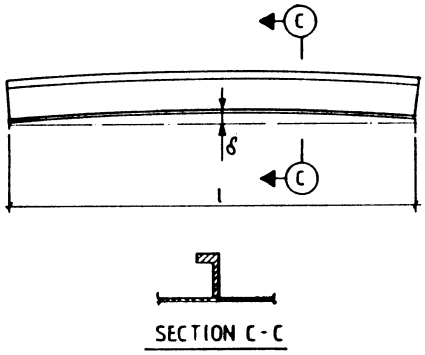
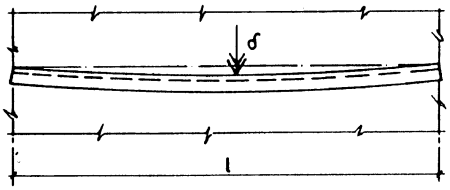
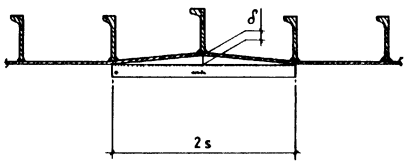
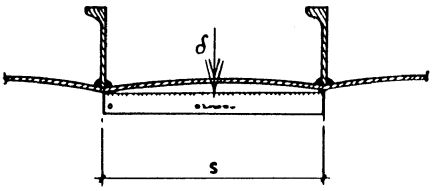
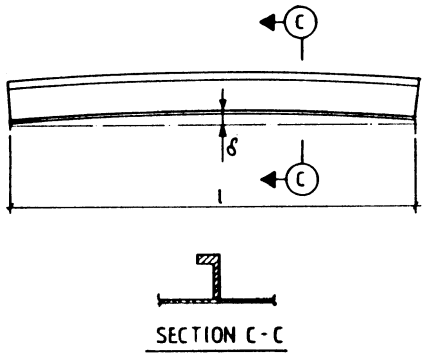
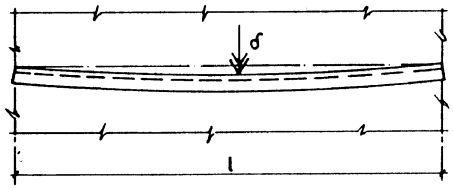
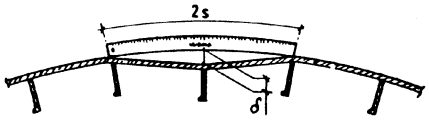
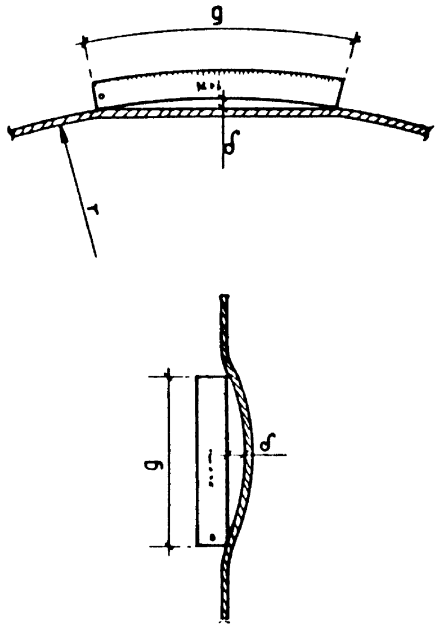
Table E2 Tolerances for compression members			
Detail	*Tolerance*	*Fig.*	*Comments*
Bars and frames	Max. out of straightness $\delta = 0.0015\ l$		l = unsupported length
Pillars, vertical columns	Max. inclination $\delta = 0.001\ l$		l = unsupported length
Stiffened plane plates. Stiffener or girder webs relative to the plate plane.	Max. out of straightness $\delta = 0.0015\ l$		l = Unsupported length of the stiffener or girder
Stiffened plane plates. Stiffener or girder flanges relative to the web plate	Max. out of straightness $\delta = 0.0015\ l$		l = Unsupported length of the flange
Stiffened plane plates. Parallel stiffeners or girders	Max. misalignment $\delta = 0.02$ s		s = distance between parallel stiffeners or girders
Stiffened plane plates. Plates between stiffeners or girders.	Max. out of plane displacement $\delta = 0.005$ s		s = unsupported width of the plate panel

Table E2 Tolerances for compression members (Continued)			
Detail *Circular cylindrical shells.*	*Tolerance* Max. deviation from the nominal radius measured at ringstiffener or bulkhead $\delta = (r_a - r) = 0.005\ r$	*Fig.*	*Comments* r_a = actual distance from the cylinder axis to the shell wall.r = nominal radius of the shell
*Circular cylindrical shells.*Longitudinal stiffeners or girders.	Max out of straightness $\delta = 0.0015\ l$		*l* = Unsupported length of the stiffener or girder.
*Circular cylindrical shells.*Flanges of longitudinal stiffeners or girder webs.	Max. out of straightness $\delta = 0.0015\ l$		*l* = Unsupported length of the flange
*Circular cylindrical shells.*Longitudinal stiffeners.	Max. misalignment $\delta = 0.02\ s$		s = stiffener spacing
*Circular cylindrical shells.*Local out of roundness.Local out of straightness.	Max. imperfection $\delta = \frac{0.01g}{1 + g/r}$		A circular template or straight rod held anywhere on the shell.g = length of template or rod.The length of the circular template shall be the smallest of:s, $1.15\sqrt{l}\sqrt{rt}$ and $\pi\frac{l}{2}$ s = stiffener spacing (of longitudinal stiffeners)l = distance between rings or bulkheadThe length of the straight rod shall be taken equal to the smallest of:*l* and $4\sqrt{rt}$.
Conical shells			The tolerance requirements given for cylindrical shells are applicable also for conical shells.

F. Assembly, Welding, Heat Treatment and Repairs

F 100 Assembly and welding

101 A fabrication sequence shall be established to ensure that the structure can be assembled in a manner that allows for continuous inspection and control during all stages of the work.

102 The welding sequence shall be such that the amount of shrinkage, distortions and residual stresses are minimised.

103 For butt welded joints of plates subjected to dynamic loading with thickness difference exceeding 4 mm, the thicker plate is normally to be tapered. The taper is generally not to exceed 1:4. See Fig.2.

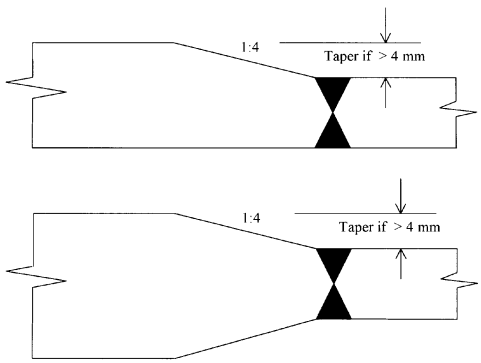


Figure 2
Tapering of butt joints

104 All butt- and full penetration joints should be welded from both sides. Before welding is carried out from the second side, unsound weld metal shall be removed at the root by a suitable method.

105 Tubular members framing into joints shall be carefully contoured to obtain accurate alignment. The bevel shall be formed providing a continuous transition from maximum to minimum bevel angle around the circumference. Generally, the fabrication shall be planned in such a manner that back welding can be performed to the largest extent possible.

106 Members to be welded shall be brought into correct alignment and held in position by clamps, other suitable devices or by tack welds until welding has been completed or progressed to a stage where the holding devices or tack welds can be removed without danger of distortion, shrinkage or cracking. Suitable allowances shall be made for distortion and shrinkage where appropriate.

107 The use of permanent steel backing strips may be permitted after thorough corrosion evaluation and when properly accounted for in the design analysis.

108 Corners of cut-outs shall be given appropriate radii minimising local stress concentrations. Where temporary cut-outs are made, such cut-outs shall be made of sufficient size to allow sound replacement.

109 The fit-up shall be checked for dimensional accuracy before welding. Surfaces to be welded shall be free from mill scale, slag, rust, grease, paint etc. Edges are to have a smooth and uniform surface. No welding shall be performed when the surfaces are damp. Suitable protection shall be arranged when welding is performed during inclement weather conditions. The groove shall be dry at the time of welding and at a temperature of at least + 5°C.

110 Preheating shall preferably be performed with electric heating elements. Gas burners may be used under controlled conditions. Cutting torches should not be used.

111 A WPS shall be established for welds in special areas, primary structural elements and butt welds in secondary structural elements.

112 Welding procedures are qualified for fabrication if satisfactory compliance with requirements is established by one of the following methods:

— performing of welding procedure tests and subsequent review of the welding procedure qualification records
— review of previously qualified welding procedure tests
— review of WPS
— review and verification of documentation showing successful application of welding procedures over a prolonged period of time.

113 Qualified welding procedures (see 112) are required for all production welding of:

— special areas
— primary structural elements.

114 Tack welding incorporated in the production welding shall be qualified. Independent of structural importance welding procedures shall be qualified for:

— new welding methods
— high heat input welding methods (e.g. electrogas, electroslag, triple tandem submerged arc) on steels with impact toughness requirements
— large thicknesses or high structural restraint.

115 All fabrication welding shall be performed within the limits of essential variables of the qualified welding procedure. This also includes tack welding, seal welding, welding of lifting lugs and attachment welds as well as repair welding.

116 When resuming welding on partially filled joints in special areas, preheating shall be performed and the temperature within the specified tolerances, shall if not otherwise agreed, be equal to the interpass temperature for the welding pass in question.

117 Grooves produced by gouging shall be in accordance with the groove profile dimensions given in the welding procedure specification.

118 Welding consumables shall be classified with respect to strength, application area and hydrogen level according to recognised classification schemes. Except for solid wires, such consumables shall for welding in special areas and on primary structural elements be extra low hydrogen i.e. a maximum diffusible hydrogen content of 5 ml/100 g weld metal. For self shielded flux cored wire 8 ml/100 g weld metal may be accepted subject to agreement.

Hydrogen testing shall be according to ISO 3690 or equivalent.

119 Consumables that have been contaminated by moisture, rust, oil, grease, dirt or other deleterious matter, shall be discarded unless properly reconditioned.

Storage and handling of welding consumables shall be in accordance with the manufacturer's recommendations, and in accordance with procedures giving details regarding conditions in storage rooms, temperature in storage ovens and quivers, length of exposure and conditions, as applicable.

Recycling of fluxes for submerged-arc welding shall be performed in a manner that ensures a mixture of new and used flux with continually homogenous properties.

120 Welds shall be terminated in a manner that will ensure sound welds without end-craters. Extension bars and run-off plates shall be removed upon completion and cooling of the weld. The end of the weld shall be made smooth and flush with the edges of abutting parts.

121 Grinding of welds with the intention of increasing the fatigue life and/or reducing the probability of brittle fracture

shall be carried out according to agreed specifications.

122 Welding production tests shall be made during fabrication of welds in special areas and in primary structural elements to verify that the produced welds are of acceptable quality. Minimum one test coupon is required from each applied welding process.

The welding parameters for the WPT shall be as for the actual weld and the environmental conditions shall be kept as realistic as possible. The requirements for a WPT are in general the same as for the relevant welding procedure test.

123 If one or more production tests fail to give satisfactory results, two more shall be made, both of which shall give acceptable results.

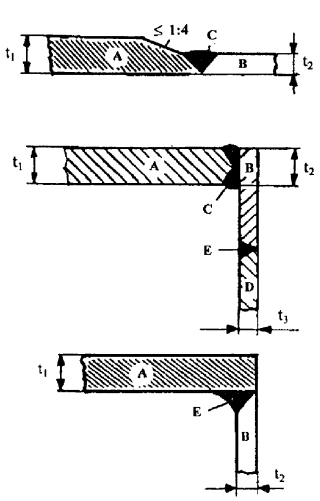
Should one or both of the additional tests fail, the total production welding performed with the welding procedure in question shall be evaluated based on testing of welds and base material cut-out from the actual structure fabricated.

124 In all cases the failure of a production test shall lead to a review of the welding performed to establish the reason for the failure, and appropriate corrective action shall be carried out.

125 Shop primers applied over areas, which will subsequently be welded, shall be of a suitable quality demonstrated to have acceptably low detrimental effect on the finished weld.

F 200 Post weld heat treatment (PWHT)

201 For units that shall stay at one location longer than 5 years, PWHT shall be applied for joints in C-Mn steels in special areas when the material thickness at the welds exceeds 50 mm (see Fig.3 for guidance on material thickness). If, however, satisfactory performance in the as-welded condition can be documented by a fitness-for-purpose assessment applying, for example, fracture mechanics testing and analysis, PWHT may be omitted.



Base material	Weld/HAZ	PWHT
A: t_1 B: t_2	C: t_2	C: t_2

Base material	Weld/HAZ	PWHT
A: t_1 B: t_2 D: t_3	C: t_1 E: t_3	C: t_1 E: t_3

Base material	Weld/HAZ	PWHT
A: t_1 B: t_2	E: t_2	E: t_2

Figure 3
Guidance on material thickness for PWHT

202 Heat treatment shall be performed in accordance with a procedure specification including:

- heating and cooling rates
- temperature gradients
- soaking temperature range and minimum holding time
- heating facilities
- insulation
- control devices
- recording equipment
- configuration of structure to be post-weld heat treated or details if local PWHT shall be carried out.

Heat treatment records shall be kept throughout the heat treatment process.

203 Heat treatment shall be performed at a soaking temperature in the range 580 to 620°C, for a time of at least 2 minutes per mm thickness. Soaking temperature and time shall be selected considering recommendations for the welding consumables and steel grade in question. Soaking temperature for quenched and tempered steels shall be decided in each case.

204 The temperature difference between the outside and the inside surface during soaking shall not exceed 30°C within the heated area. Double-sided heating shall be applied as far as possible.

205 Heating, soaking and cooling shall be carried out in a controlled manner that prevents cracking or distortions outside the dimensional tolerances. The temperature difference along lines or planes of symmetry shall normally not exceed 30°C when the material temperature is above 300°C.

206 The heat-treatment cycle and the actual metal temperature shall be recorded using thermocouples equally spaced externally, and whenever possible internally, throughout the heated region.

207 Heat treatment, wherever possible, shall be carried out in an enclosing furnace according to written procedures agreed upon. The temperature distribution throughout heating furnaces shall be controlled within ± 15°C.

Where it is impractical to heat-treat the whole item in a closed furnace, local heat treatment may be adopted.

208 Only welding consumables recommended for PWHT by the manufacturer shall be used for joints to be post weld heat treated.

F 300 Repairs

301 Repairs shall be carried out in accordance with qualified repair procedures subject to agreement.

302 Guidance to repair work may be found in IACS Shipbuilding and repair Quality Standard, Part A Sec.9 and Part B.

303 Members distorted by welding may be straightened by mechanical means or by carefully supervised application of a limited amount of localised heat. The application of heat or mechanical force shall be in accordance with a written procedure.

304 Defects in welds may be rectified by grinding, machining or welding. Welds of insufficient strength, ductility or notch toughness shall be completely removed prior to repair. The mechanical properties of repair weld shall satisfy the minimum specified properties of the steel in question.

305 Repair welding in the same area may be carried out twice. Further repairs shall be evaluated in each individual case.

306 The use of arc-air gouging shall be followed by grinding, removing the affected material.

307 Whenever a defect is removed, the gouged and ground area shall be examined by magnetic particle testing or other suitable methods to verify complete removal.

308 Repair welding shall be performed using extra low hydrogen welding consumables, applying an appropriate preheating and working or interpass temperature. The preheating and working temperature when making shallow and local repairs in special areas and primary structural elements shall be raised 50°C above the level used for production welding and be at least 100°C unless otherwise agreed. The working temperature shall be maintained until the repair has been completed. To ensure sound repair welds, the single repair length shall not be shorter than approximately 50 mm.

309 Repair of welded joints shall be carried out by removing the unacceptable portion of the weld without substantial re-

moval of base material. For planar defects the repair length on either side of the defect shall be 50 mm longer than the size of the defect as confirmed by NDT. Long defects may be required repaired in several steps to avoid overloading or cracking. Each repair step shall be controlled so as not to cause plastic deformation of the remaining material when removing the defect.

310 Repair welding of post-weld heat-treated joints shall unless otherwise agreed initiate a new heat treatment.

311 Minor discontinuities may be removed by grinding or machining, making a smooth transition into the surrounding material. The thickness shall not be reduced to less than 93% of the nominal thickness but in no case by more than 3 mm. The extent of such repair shall be agreed upon.

312 All repairs shall be re-inspected with the same NDT methods to the same or increased extent as necessary.

SECTION 3
TESTING OF WELDS

A. General

A 100 Scope

101 This section gives requirements for fracture mechanics tests and non-destructive testing.

B. Destructive Testing

B 100 Fracture mechanics (FM) testing

101 For units that shall stay at one location longer than 5 years, FM testing shall be included in the qualification of welding procedures for joints for which all of the following apply:

— the design temperature is lower than + 10°C
— the joint is located in a special area
— where at least one of the adjoining members is fabricated from steel with a SMYS larger than or equal to 350 MPa. (Testing on steel with SMYS lower than 350 MPa is not required.)

102 The test weld shall be made and tested for the actual combination of steel grade, manufacturer, welding process and welding consumable (brand) used. FM testing is, however, not required for consumables used for root passes only in two-sided welds.

103 The FM tests shall be carried out on a full penetration butt-weld with K- or single V-preparation. The back of the K and one of the legs of the single V (on which the FM test shall be carried out) shall be perpendicular to the plane of the plate. Tests on either of these weld bevel preparations qualify for all types of bevel preparations.

104 The test weld shall be welded with a heat input representing the maximum heat input used in the fabrication. The test weld shall be made on a plate with a thickness not smaller than 90% of the maximum plate or wall thickness for which the welding procedure shall apply. The test weld also qualifies for plate thicknesses down to 50% of the test weld plate thickness.

105 On each test weld at least three FM test specimens shall be tested in each of the weld deposit and the heat affected zone (HAZ). (Details regarding the required number of test specimens and the location of fatigue pre-cracks are given further below.)

106 Testing of the HAZ or the weld deposit can be omitted if tests with satisfactory results according to the requirements in this standard have been carried out previously by either the steel manufacturer or the welding consumable manufacturer.

107 The FM tests shall be carried out according to BS 7448 Part 2 (with detailed requirements as given below) using 3-point bend specimens. The CTOD-technique with B x 2B specimens shall be used. For nominal plate thicknesses of the test weld equal to or exceeding 80 mm, B x B specimens may be used.

All specimens shall be tested with the fatigue pre-crack placed in the through-thickness direction. For tests of the weld deposit the fatigue pre-crack shall sample the central part of the deposit. For tests in the HAZ the required location of the fatigue crack depth is given in 108.

An evaluation of the relevant test temperature shall be made for all joints in question. Unless there is a high probability that the extreme loads on the joints will concur with lower temperatures the test temperature shall be:

For joints submerged at lowest waterline:	≤ 0°C
Other joints:	≤ design temperature.

108 Subsequent to the CTOD-test the specimens in the HAZ shall be sectioned and examined as described below.

A metallographic section according to BS 7448 Part 2 Section 11.2 shall be prepared from each HAZ specimen. The metallographic section shall include weld metal and base metal. If necessary, in order to determine the exact location of the fatigue pre-crack, sections from both sides of the pre-crack shall be prepared. The faces of the metallographic sections shall not be taken deeper than the deepest point of the fatigue pre-crack and not more than 3 mm from the deepest point of the fatigue pre-crack.

A figure of a cross-section through the weld (of an un-fractured specimen) is shown in Fig.1.

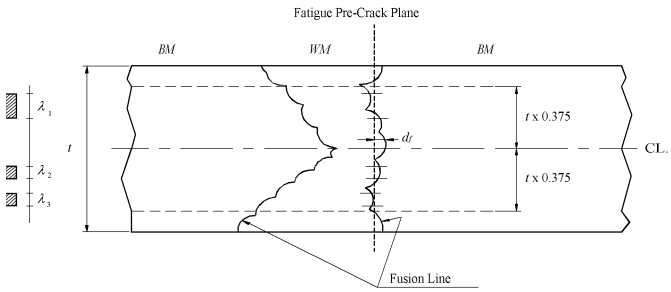


Figure 1
Cross-section through the weld

BM	=	base material
WM	=	weld metal or deposit
d_f	=	distance from the plane of the fatigue pre-crack to the fusion line (varies along the fatigue pre-crack)
λ_i	=	length (in mm) of area with acceptable location of the fatigue pre-crack (see below)
t	=	plate thickness

Measurements of the distance, d_f, between the plane of the fatigue pre-crack and the fusion line shall be taken. Within the central 75% of the plate thickness the areas where $d_f \leq 0.5$ mm shall be identified. The length, λ_i, of each of these areas shall be determined. The location of the fatigue pre-crack shall satisfy the following criteria:

$\Sigma_N \lambda_i$	=	≤ 3 mm	for t ≤ 20 mm
	=	0.15 t	for 20 < t ≤ 80 mm
	=	≥ 12 mm	for t > 80 mm
N	=	number of areas with $d_f \leq 0.5$ mm	

109 Results from HAZ specimens on which the location of the fatigue pre-crack does not satisfy the requirement above, are not valid. In addition to these requirements given for HAZ specimens, all the requirements specified in BS 7448 Part 2 apply for both HAZ and weld deposit specimens.

Three valid tests for each of weld deposit and HAZ shall be carried out. The critical CTOD for all of the specimens shall be equal to or larger than 0.15 mm.

If (for HAZ or weld deposit) one or more of the three specimens has a critical CTOD lower than 0.15 mm additional tests may be carried out. In such a case the characteristic value, as defined in Table B1, shall be equal to or larger than 0.15 mm.

Table B1 Characteristic value of CTOD

Number of valid tests [1]	*Characteristic value*
3 to 5	Lowest result
6 to 10	Second lowest result
11 to 15	Third lowest result

1) All valid tests that have been carried out shall be included in the evaluation. It is not permissible to discard any valid test result.

110 If the characteristic value as specified in Table B1 is larger than 0.15 mm an ECA (Engineering critical assessment) may be carried out with the purpose of demonstrating that extra capacity may be available in the structure.

C. Non-Destructive Testing (NDT)

C 100 General

101 The inspection category shall be defined by the designer in accordance with DNV-OS-C101 Sec.4 or DNV-OS-C201 Sec.4, and shall be specified on the design drawings.

102 Welds shall be subject to visual inspection and NDT as the fabrication and construction proceeds. NDT shall be performed in accordance with accepted procedures and if required, qualified for the work.

103 Methods of NDT shall be chosen with due regard to the conditions including the sensitivity of the method and the method's ability to detect defects likely to occur as a consequence of the chosen welding process.

104 Final inspection and NDT of structural steel welds shall not be carried out before 48 hours after completion, except where PWHT is required.

The time delay may upon agreement be reduced for NV 36 grades or lower and for NV 420 grades or lower for plate thicknesses less than 40 mm, if consistent low failure rate of delayed cracking has been documented for the materials and welding consumables in question.

105 When heat treatment is performed, the final NDT shall be carried out when all heat treatments have been completed.

106 All welds shall be 100% visually inspected prior to carrying out NDT.

107 All NDT shall be properly documented in such a way that the performed examination can be duplicated. The reports shall identify the defects present in the weld area and state if the weld satisfies the acceptance criteria or not.

C 200 NDT procedures

201 NDT shall be performed in accordance with agreed written procedures that, as a minimum, give detailed information on the following aspects:

— applicable code or standard
— materials and dimensions
— welding process
— joint configuration and dimensions
— technique
— equipment, main and auxiliary
— sensitivity
— calibration techniques and calibration references
— testing parameters and variables
— assessment of imperfections
— reporting and documentation of results
— reference to applicable welding procedure(s)
— personnel qualification
— acceptance criteria.

C 300 Personnel qualification

301 Personnel performing NDT and interpretation of examination results shall be certified according to a recognised certification scheme subject to agreement and shall provide a valid certificate of proficiency. The certificate shall state the qualifications as to which examination method and within which category the operator is qualified.

C 400 Extent of NDT

401 The extent of NDT shall be based on type and level of design stresses and on the importance of the connection in question. The welds shall be assigned inspection categories equal to the highest structural category of the two components. The inspection categories shall be applied to the drawings.

Aspects that shall be considered in determining the extent of NDT are:

— stress level and stress direction
— cyclic loading
— material toughness
— redundancy of the member
— overall integrity of the structure
— accessibility for examination in-service.

Guidance note:

150 m water depth should be assumed inaccessible for in-service inspection.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

402 Unless otherwise agreed, NDT shall normally be carried out to an extent not less than required in Table C1. For welds that are examined for only a given percentage, the importance to the integrity of the structure shall be considered when selecting the welds to be examined. However, a representative sampling of the welds shall be performed.

403 Ultrasonic examination may be replaced by radiography and vice versa, when considered suitable.

404 Frequent repairs shall result in increased extent of NDT. The extent of NDT shall be increased in a manner that ensures that all potentially damaging defects are discovered in the significant areas of the structure and that representative sampling is carried out on all welds. If the weld quality level is satisfactory, the extent of examination may be reduced.

405 If severe defects (i.e. cracks and other planar defects or excessive slag lines) occur repeatedly, all welds made with the same welding procedure during the period in question, shall be examined full length.

Frequent occurrence of excessive porosity can be indicative of inadequate handling of welding consumables. If inadequate handling is confirmed, the welds made during the period in question shall be investigated by adequate methods for hydrogen induced cracking.

406 NDT shall cover start and stop points of automatically welded seams.

407 Ultrasonic examination of welds shall include examination of the area adjacent to the weld for laminations and scanning for transverse defects in the weld and base material.

408 Plates which are subjected to significant tensile stresses in the thickness direction in way of cross joints, etc. shall be ultrasonically tested after welding into the structure, to make sure that lamellar tearing has not taken place.

If steel with improved through thickness properties has been adopted, this test may be reduced to spot-checks only.

Table C1 Minimum extent (in %) of non-destructive testing for structural welds					
Inspection category	*Type of connection*	*Test method*			
		Visual	*Magnetic* [1]	*Radiography* [2]	*Ultrasonic* [3]
I	Butt weldCross- and T-joints, full penetration welds-Cross- and T-joints, partly penetration and fillet welds	100%100%100 %	100%100%100 %	100%--	100%-
II	Butt weldCross- and T-joints, full penetration welds-Cross- and T-joints, partly penetration and fillet welds	100%100%100 %	20% [4]20%20%	10% [5]--	20%-
III	Butt weldCross- and T-joints, full penetration welds-Cross- and T-joints, partly penetration and fillet welds	100%100%100 %	Spot [6]Spot [6]Spot [6]	Spot [6]--	Spot [6]-

1) Liquid penetrant testing to be adopted for non ferro-magnetic materials

2) May be partly or wholly replaced by ultrasonic testing upon agreement

3) Ultrasonic examination shall be carried out for plate thicknesses of 10 mm and above

4) For weld connections on hull shell not subjected to high residual stress, spot check will be accepted as sufficient.

5) Additionally, all manual welds in bracings in the main bearing structures such as for conventional stabilised units 100%.

409 *Radiographic testing*

Radiographic testing shall be performed by x-ray according to approved procedures. Use of g-ray is subjected to acceptance in each case. The procedures shall be established according to recognised standards.

410 Suspect planar indications discovered by radiographic testing shall be type determined, located and sized by ultrasonic testing.

411 Processing and storage shall be such that the films maintain their quality throughout the agreed time of storage.

412 *Ultrasonic testing*

Ultrasonic testing shall be performed according to approved procedures. The procedures shall be established according to recognised standards.

413 Ultrasonic examination equipment is to:

- be applicable for the pulse echo technique and for the double-probe technique
- cover as a minimum the frequency range from 2 to 6 MHz
- have a calibrated gain regulator with minimum 2 dB per step over a range of at least 60 dB
- have a flat screen accessible from the front for direct plotting of reference curves or equipped with automatic calibration or DAC (Distance Amplitude Curve)-display presentation
- echoes with amplitudes of 5% of full screen height shall be clearly detectable under test conditions
- include straight beam transducers and angle beam transducers of 45°, 60° and 70°.

414 Calibration of the ultrasonic equipment shall be carried out whenever it has been out of function for any reason including on and off and whenever there is any doubt concerning proper functioning of the equipment.

415 The IIW or ISO calibration block shall be used for calibration of range and for angle determination.

416 For evaluation of flaw indications a reference curve shall be established. The curve shall be plotted on the instrument screen. Imperfections, which produce a response greater than 20% of the reference level shall be investigated to the extent that the operator can determine the shape, identity and location of all such imperfections and evaluate them in terms of the acceptance criteria. All defects exceeding the acceptance criteria shall be reported unless more stringent requirements are agreed.

417 Reference blocks shall be made with thickness and side-drilled holes, as described in Table C2, and shall be used for gain calibration and construction of reference curves. The reference block shall normally be manufactured from the actual material examined and have approved dimensions. When ultrasonic testing is to be performed on steel produced by controlled rolling or thermomechanical treatment, reference blocks shall be produced both perpendicular to, and parallel to, the direction of rolling. The rolling direction shall be clearly identified.

418 Calibration of ultrasonic equipment shall be undertaken in accordance with recognised code or standard.

419 For ultrasonic examination the contact surface shall be clean and smooth, i.e. free from dirt, scale, rust, welding spatter, etc. which may influence the results of the examination.

420 The weld shall normally be examined from both sides and the testing is to include the area adjacent to the weld for laminations and scanning for transverse indications in the weld and base material. Use of multiple angle probes scanning in addition to normal probe scanning is required.

421 For flaw detection the corrected primary gain shall be increased by 6 dB. Defect size evaluation shall not be performed at this increased gain level.

422 The indications shall be investigated by maximising the echoes with different angle probes and by rotating the probes. For dimensional evaluation, either the «20 dB-drop» method or the «half-value-drop» method shall be used.

Table C2 Calibration reference block requirements			
Thickness of material to be examined (mm)	*Thickness of block (mm)*	*Diameter of hole (mm)*	*Distance of hole from one surface (mm)*
10 < t ≤ 50	40 or t	Ø 3 ± 0.2	t/2 and t/4. Additional holes are allowed and recommended
50 < t ≤ 100	75 or t		
100 < t ≤ 150	125 or t	Ø 6 ± 0.2	
150 < t ≤ 200	175 or t		
200 < t ≤ 250	225 or t		
t > 250	275 or t		

423 *Magnetic particle testing*

Magnetic particle testing shall be performed according to procedures subject to agreement. The procedures shall be established according to recognised standards.

424 The equipment shall establish a field strength between 2.4 kA/m and 4.0 kA/m for prods. Prods shall be soft tipped with lead or similar. Use of prods soft tipped with copper is not permitted. Sparks between the prods and the material tested shall be avoided. Electromagnetic A.C. yokes shall develop a minimum lifting force of 5 kg at maximum leg spread. Field strength and lifting force shall be checked at regular intervals.

425 Use of permanent magnets is not permitted.

426 The surface to be tested shall be clean and dry, free from dirt i.e. paint, grease, oil, lint, scale, welding flux etc. which may interfere with the testing.

427 To ensure detection of discontinuities having axes in any

direction, the testing of each area shall be performed with magnetic field shifted in at least two directions approximately perpendicular to each other, and with sufficient overlap to cover the area to be tested.

428 Non-fluorescent wet or dry particles shall provide adequate contrast with the background or the surface being tested.

429 De-magnetisation should be considered in areas where residual magnetism could be detrimental.

C 500 Acceptance criteria for NDT

501 Acceptance criteria for welds in steel are given in Table C3, Table C4 and Table C5. As the test methods differ in their limitations and/or sensitivities special acceptance criteria are given for each method where necessary. Alternative evaluation ensuring an equivalent level of quality may be considered in special cases.

502 Acceptance of defects exceeding the given limits may be granted based on fracture mechanics testing and appropriate calculations. If this approach is considered, the inherent inaccuracy of the NDT methods shall be considered when the critical defect size is determined.

503 The soundness of welds shall comply with the acceptance criteria for each of the NDT methods used. Defects exceeding the limits shall be repaired and after repair welding has been performed, the complete weld, (i.e. the repaired area plus at least 100 mm on each side) shall be subjected to at least to the same NDT method(s) as specified for the original weld.

Table C3 Visual and magnetic particle testing acceptance criteria for structural steel welds

Type of defect	*Structural category*		
	Special	*Primary*	*Secondary*
Cracks	Not acceptable		
Incomplete penetration or lack of fusion	Not acceptable		On the root side of welds for which back welding is not required: Length < t/2, maximum 10 mm and not closer than t
Surface porosity	Not acceptable	Not acceptable in areas with tensile stresses. In other areas the accumulated pore diameters in any area of 10 x 150 mm are not to exceed 15 mm. Maximum size of single pore; t/4 or 4 mm (whichever is the smaller)	
Undercut, maximum depth, mm	Not acceptable	Not acceptable when transverse to tensile stresses. Maximum depth allowed in other areas 0.75 mm	

t is the nominal plate thickness.

General requirements:

Welds shall be of correct shape, size and geometry. Welds shall have a regular finish and merge smoothly into the base material. Groove welds shall have slight or minimum reinforcement or root penetration not exceeding 3 mm in height. The face of fillet welds shall be slightly convex or concave or flat and leg lengths shall be equal.

Table C4 Radiographic testing, acceptance criteria			
Type of defect	*Structural category*		
	Special	*Primary*	*Secondary*
Porosity [1) 2)]			
— Isolated: Maximum pore diameter, mm	t/5, maximum 4	t/4, maximum 5	t/3, maximum 6
— Cluster: Largest pore diameter, mm	2	3	4
— Piping porosity: Maximum length along the weld of projected pore area, mm	20	25	30
— Scattered: Maximum accumulated pore diameters in any 10 x 150 mm area of weld	15	20	25
Slag inclusion [1) 3) 4)]			
— Maximum width, mm	t/5, maximum 4	t/4, maximum 6	t/3, maximum 6
— Maximum length, mm	t	2 t	4 t
Incomplete penetration length [5) 6)] mm	Not accepted in connections where full penetration is required	≤ t, maximum 25	≤ 2t, maximum 50
Lack of fusion length [5) 6)] mm	Not accepted		≤ 2t, maximum 50
Cracks	Not accepted		

1) If the distance between the similar defects (pore or slag) is less than the largest extent of one of the defects, they shall be considered as one continuous defect. If the amount of pores or slag may mask other defects, the testing shall be supplemented with radiographic or ultrasonic testing.

2) If the distance between pores is less than 3 times the diameter, the pores are said to form a line or a cluster. Pores on a line must not be located in the weld surface.

3) Defects of lengths in the direction of the weld exceeding 3 times their widths form a line. If the distance between slag lines is less than 3 times the largest extent of the cross section of the defect, the lines are considered as one defect.

4) If parallel slag lines are found the examination shall be supplemented with ultrasonic tests.

5) Defects on a line where the distance between the defects is shorter than the longest defect shall be regarded as one continuous defect.

6) Not surface open. For incomplete penetration or lack of fusion on root side of welds for which back welding is not required, see Table C3.

Table C5 Ultrasonic testing			
Indication [1)2)3)]	*Structural category*		
	Special	*Primary*	*Secondary*
Echo height above	50% of reference level	100% of reference level	100% of reference level
Maximum length [4)], mm	t/3 or maximum 10	t/2 or maximum 10	t or maximum 20

Cracks are not acceptable regardless of size or amplitude.

1) Indications which the operator based on experience, knowledge of the welding method and joint geometry deems likely to be cracks, lack of fusion or lack of penetration may be unacceptable regardless of echo amplitude and length. In such cases an independent examination by another operator shall be performed.

2) If only one side of the weld is accessible for examination, all indications with a length > t /4 and exceeding 20% of the reference curve for the special category and 50% otherwise, may be regarded as cracks, lack of fusion or lack of penetration unless otherwise proven. In such cases an independent examination by another operator or by different methods shall be performed.

3) For longitudinal defects where the indications intermittently are above and below the acceptance level, the type of defect shall be determined when the areas exceeding the acceptance level are repaired. If the defect is found to be crack, lack of fusion, lack of penetration or slagline(s) the whole defect length is unacceptable regardless of echo amplitude.

4) Length is defined as distance between points where the echo amplitude reach or pass the stated percentages of reference level.

SECTION 4
OTHER TESTS

A. General

A 100 Scope

101 This section covers requirements for testing of watertightness and structural tests.

B. Testing of Watertightness

B 100 General

101 All tanks shall be tested for watertightness by a method subject to agreement. The test may be performed as a hydraulic test using water. Alternatively compressed air and soap-water may be used.

102 If water is applied, the pressure shall not be less than 25 kN/m^2 at the top of the tank. The outside of the tank must be dry and clean.

103 If compressed air and soap solution are used, the air pressure shall not exceed 20 kN/m^2, and shall be reduced to a smaller value, but not less than 15 kN/m^2 before inspection. The soap solution shall give clear indications even of small leaks.

Guidance note:

Care should be taken so that the pressure in the tank does not exceed 20 kN/m^2 above atmospheric pressure because of unexpected increase in ambient temperature, falling atmospheric pressure or otherwise. The pressure shall be measured by an accurate method such as a U-shaped tube with water. Means should be provided to release the pressure in an emergency case.

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104 Bulkheads between tanks arranged to carry different liquid contents shall be hydraulically tested from at least one side.

105 If water is used, the test may be combined with the structural test described in C.

C. Structural Tests

C 100 General

101 At least one of several identical tanks shall undergo a structural test. The test shall by agreement be carried out by applying water.

102 The test pressure height h_T shall be taken as the design pressure height for load case a). This implies that the following test pressure heights will normally apply:

For tanks with a maximum filling height to the top of the air pipe:

$$h_T = h_{op1} \quad \text{or}$$
$$h_T = (h_{s3} + h_{p0})$$

whichever is greater.

For tanks with a maximum filling height less than to the top of the air pipe:

$$h_T = (h_{op2} + h_{D2}) \quad \text{or}$$
$$h_T = (h_{s3} + h_{p0})$$

whichever is greater.

h_{op1} = vertical distance (m) from the load point to the position of maximum filling height (i.e. the top of the air pipe)

h_{s3} = vertical distance (m) from the load point to the top of the tank

h_{p0} = 2.5 m in general

= height corresponding to valve opening pressure when exceeding the general value

h_{op2} = vertical distance (m) from the load point to the position of maximum filling height. For tanks adjacent to the sea that are situated below the extreme operational draught (T_E), h_{op2} is not normally to be taken as being less than T_E

h_{D2} = pressure head due to flow through pipes.

The pressure shall be maintained for at least 20 minutes. The filling rate shall be restricted to avoid excessive dynamic design pressure.

103 The structural test is considered successful if no significant deformations or other damages have developed during the test.

104 Closing appliances for access openings etc. in decks, bulkheads etc. which shall be watertight, shall be separately tested before installation. Structural testing of other parts outside tanks may be required.

105 If structural tests reveal weaknesses in the structure, further testing should be assessed.

SECTION 5
CORROSION PROTECTION SYSTEMS

A. General

A 100 Scope

101 This section lists requirements for application of coating and requirements for fabrication and installation of sacrificial anodes and impressed current systems.

A 200 General

201 Installation or application of corrosion protection systems shall be carried out in conformance with recognised standards of workmanship and specifications agreed upon.

A 300 Application of coating

301 The area to be coated shall be defined and if necessary limited by masking. Components and areas, which may be damaged by the pre-treatment and/or by the coating, such as anodes, shall be shielded.

302 The surfaces to be coated shall be clean and dry. Oil, grease or dirt shall be removed by washing with a suitable detergent. Salts shall be removed by washing with fresh water.

303 Sharp edges shall be rounded and surfaces blast-cleaned to the profile and degree of cleanliness as required in the coating specification and in accordance with the coating manufacturer's recommendations. Normally, the minimum requirements for steel surface quality for primer coating application is ISO 8501-1 Sa 2 1/2 or equivalent for external surfaces and internal zones exposed to sea-water or otherwise intended for coating.

304 Final blast-cleaning and coating application shall when possible be carried out only when the steel temperature is > 3°C above the dew point and the relative humidity < 85% in order to prevent condensation of moisture on the surface.

305 Coating systems shall be applied in the number of coats and within the thickness ranges as stated in the specification agreed upon and in accordance with the manufacturer's recommendations.

306 Inspection, repair and touch-up shall be performed according to specifications agreed upon.

307 Primer-coated surfaces shall be inspected and, if necessary, be adequately cleaned and prepared before applying the next coating layer.

308 Adequate curing times in relation to temperature and humidity conditions, overcoating intervals, dry-film thickness of individual coats and total dry-film thickness, shall be within tolerances stated in the coating specification.

A 400 Fabrication and installation of sacrificial anodes

401 Fabrication and installation of anodes shall be carried out according to drawings and specifications.

402 Anode shapes and their fastening devices (studs, clamps etc.) shall be subject to agreement and may be given as a type approval. For anodes fastened by other means than welding, attention should be paid to the establishing of good electrical contact. Resistance measurements may be required.

Welding of connections shall be carried out by qualified welders.

Welding consumables agreed upon for the steel grade in question shall be used.

Fillet welds shall as far as practicable be continuous (all around the studs).

Anodes shall if not otherwise agreed, be connected to the structure in way of local stiffening.

Any doubling plates to which anodes are welded, shall have a thickness normally not less than 10 mm, well rounded corners (r > 20 mm), and shall be continuously welded. Material grades of the doubling plates and anode studs or pads welded directly to main plating, shall be in accordance with the requirements given in DNV-OS-C101 Sec.4 or DNV-OS-C201 Sec. 4. The doubling plates shall be of the material strength group as the main plate.

403 For anodes connected to bulkhead plating, girder web plates etc. having a thickness equal to or less than 15 mm, at least one of the studs shall be welded on or close to a local stiffener. Anodes connected to shell plating of trusses etc., where no internal stiffening is provided, shall be fastened to doubling plates permanently welded to the shell.

404 Submerged zone: anodes located in way of internal stiffening, except on columns close to truss connections, may be welded directly to the shell plating without doubling plates. Below light water line, such direct welding will be accepted only for anode studs or pads not intended to be removed by renewal of anodes. In any case, anodes located on slim trusses without internal stiffening and on columns close to truss connections shall be fastened to doubling plates permanently welded to the shell.

A 500 Fabrication and installation of impressed current systems

501 The anodes, the cables and the signal receivers shall be furnished with relevant material certificates and be properly marked for identification.

502 The installation of the system shall be carried out according to an agreed specification.

503 All equipment, cables etc. shall be accepted for use in the respective hazardous zones, if applicable.

504 Testing of the proper functioning of the systems shall be carried out. The test method and results shall be reported.

505 Final testing and acceptance of the system shall be performed after installation.

SECTION 6
MISCELLANEOUS

A. Use General

A 100 Scope

101 This section covers requirements for bolts and mechanical fastening.

B. Bolts

B 100 Bolts and nuts

101 Bolts and nuts considered as essential for structural and operational safety shall conform to a recognised standard, e.g. ISO 898.

102 Major pressure retaining or structural bolts and nuts with specified min. yield stress above 490 N/mm^2 shall be made of alloy steel, i.e. (% Cr + % Mo + % Ni) ≥ 0.50 and supplied in the quenched and tempered condition.

103 For general service, the specified tensile properties shall not exceed ISO 898 property Class 10.9 when the installation is in atmospheric environment. For equipment submerged in seawater, the tensile properties shall not exceed property class 8,8 or equivalent.

Guidance note:

For bolted joints to be part of equipment designed for sulphide stress cracking service, lower tensile properties than for 8,8 class may be necessary in order to comply with NACE MR0175.

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C. Mechanical Fastening

C 100 Contact surfaces in slip resistant connections

101 If required, contact surfaces in preloaded joints shall be prepared to produce the class of friction surface as required.

102 Details of surface treatments, which may be assumed to provide the stated classes of friction surface, are given in DNV-OS-C101 Sec.5.

103 The class of friction surface produced by other treatment may be determined according to other international recognised standards.

104 Contact surfaces shall be cleaned and roughened by blasting with an appropriate material to produce a surface confirming the required quality. In case of coated surfaces, this treatment shall be followed immediately by the application of the appropriate coating.

105 At the time of assembly, the contact surfaces shall be free from all contaminants, such as oil, dirt or paint, except for a slip resistant coating. Burr that would prevent solid seating of the connecting parts shall be removed.

106 Oil shall be removed from the surface by using chemical cleaners, not by flame-cleaning.

107 If un-coated surfaces cannot be assembled directly after preparation of the contact surfaces, they should be freed from all thin films of rust and other loose material by brushing with a steel brush. Care should be taken not to damage or smooth the roughened surface.

CHAPTER 3

CERTIFICATION AND CLASSIFICATION

CONTENTS PAGE

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SECTION 1
GENERAL

A. Introduction

A 100 Scope

101 This section lists fabrication and testing related certification- and classification requirements including requirements for documentation to be submitted for review.

B. Specific Certification and Classification Requirements

B 100 General

101 The following requirements shall be applied in conjunction with the technical requirements in the main body of this standard when used for certification or classification purposes.

B 200 Basic requirements

201 Welding of special, primary and secondary structures for hull, welding of superstructure, piping systems and equipment shall be carried out by approved welders, with approved welding consumables and at welding shops and -contractors recognised by DNV.

B 300 Welding shops and -contractors

301 Welding shops and -contractors will have to prove their qualifications for the welding operations in question.

302 It is assumed that the welding shops and -contractors make use of the necessary equipment for carrying out inspection of the welding operations in a satisfactory manner.

303 Important welding operations shall be carried out under daily supervision of an inspector, who has the experience and qualifications, which enable him to judge this type of work. The work of each welder shall be regularly examined.

304 The welding shops and -contractors shall keep a card index or register of all approved welders. The register shall give information on training of the welders and date and results of qualification tests. Information about the base metal, type of welding consumable, joint design and welding positions shall be stated in the event of re-qualification tests. The surveyor shall be allowed to examine the register at any time.

B 400 Welding consumables

401 Consumables for welding of offshore structures intended for classification shall be approved by the Society.

402 Type approval of welding consumables will be considered subject to compliance with the requirements given in the Rules for Classification of Ships Pt.2 Ch.3 Sec.3.

403 All brand names under which a tested and approved welding consumable is marketed, shall be registered by the Society. In order to avoid duplication of tests, the manufacturer shall certify that the welding consumables marketed under alternative brand names are identical with the consumables tested for approval.

B 500 Welding procedures and qualification of welders

501 The welding procedure qualification test shall be witnessed by the surveyor.

502 Welding and testing of weld assemblies for approval of welders shall be performed in the presence of the surveyor. Upon successful completion, the Society will certify that the welder has passed the approval testing.

503 Where certification is performed by other IACS members or independent organisations, e.g. accredited or nationally approved certification bodies, recognition of such certification will be evaluated on a case by case basis. The Society reserves the right, however, to require verification of welders' qualifications when deemed necessary. Such verification may include testing prior to production, extra NDT and/or welding production tests.

B 600 Corrosion protection systems

601 Application of coating, steel surface preparation with respect to application of coating and fabrication and installation of sacrificial anodes and impressed current cathodic protection systems are not included in the Society’s scope of work unless upon special agreement.

C. Records and Documentation

C 100 General

101 Adequate records related to the fabrication of the structure shall be prepared to document that the structure meets the specified requirements. Such records shall be compiled in parallel with the fabrication process. Compiled records shall be systematic and fully traceable. Such records shall reflect all relevant testing, alterations, additions, corrections and revisions made during the fabrication period in order to provide information required during the in- service life of the structure.