

Construction Specification for fixed offshore structures

PUBLICATION 158

Edition 3

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THE ENGINEERING EQUIPMENT AND MATERIALS USERS ASSOCIATION

Construction Specification for fixed offshore structures

PUBLICATION 158

Edition 3

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ENGINEERING EQUIPMENT AND MATERIALS USERS ASSOCIATION

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Comments are considered by the relevant EEMUA Technical Committees and may be incorporated in future editions of this Publication. New editions are publicised on the EEMUA website.

Preface

This Specification was originally developed by the EEMUA Materials for Offshore Service (MOS) technical committee in 1991 and covered the construction of fixed offshore steel structures for installation primarily within the United Kingdom Continental Shelf. Though the original document was created for use in the North Sea, it has been applied successfully in other locations. Therefore changes in this 3rd Edition now reflect the global nature of the offshore oil and gas industry, with the Specification having a much broader applicability. Furthermore, wind turbine installations now constitute a significant proportion of new constructions offshore.

The requirements specified meet the general recommendations contained in the UK Health and Safety Commission document 'Offshore Installations and Wells (Design and Construction etc.) Regulations 1996'. However, because the Regulator's recommendations require that all production welding should be carried out in accordance with accepted standards such as AWS D 1.1M:2010⁽¹⁾, those documents have been used as a regular source in compiling this specification. There is, therefore, no 'ruling code', but reference is made to a number of standards, which apply with only minor amendment. In producing this and all previous editions of the specification, account has been taken from experience gained by the industry and from the latest developments in technology.

EEMUA has published EEMUA Publication 197⁽²⁾ as a companion volume to this Specification. It is recommended that, where appropriate, reference be made to EEMUA 197.

Note: In all instances where a reference is made, the quoted edition is the most recent at the time of publishing. If a newer version becomes available then users should refer to the later edition. In cases where specific clauses within a standard, which are referred to, are amended, users should use discretion to determine if the advice still applies.

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Principal changes in the 3rd Edition

Since the previous editions and amendments to this document were published, the character and location of the fabrication undertaken for the UK Continental Shelf has substantially changed. Additionally, this Specification has been successfully applied to other geographical locations, including the Caspian Sea where it is widely used.

Whilst the use of fixed offshore structures for the oil and gas industry has declined, the use of floating production storage and offloading vessels has increased with a strong emphasis on subsea completions, (EEMUA 194⁽³⁾ is directly relevant in this respect). Nevertheless, fixed offshore installations still have a significant role in the oil and gas industry, both in the North Sea and other areas of operation, and a potentially increasing role in offshore renewable energy.

Workforce skills in the fabrication industry have also changed and there is more emphasis on the application of semi-automatic welding techniques as opposed to the manual process.

Other changes relate to steel plate production, which has largely changed to thermo-mechanically produced lean alloy compositions. This has substantially influenced weldability. Another notable change has been to large tonnage fabrication - which has decreased in the UK, Scandinavia and the rest of Europe - moving largely to South East Asia.

These changes have raised a number of different challenges for the industry and the EEMUA Materials Technical Committee (MTC), largely comprised of metallurgical and welding engineers, have consequently undertaken a critical review of the earlier document and incorporated revisions to account for the industrial changes based on the experience and lessons of recent projects.

Attention is also drawn to ISO 19900:2013⁽⁴⁾, 19901-3:2010⁽⁵⁾ and EN ISO 19902:2007⁽⁶⁾ and EN ISO 13628:2011⁽⁷⁾.

The Certifying Authority's statutory, independent assessment and survey activities are recognised, but are considered to be a matter for agreement between the purchaser and the Authority and are not addressed within this Specification.

1 Introduction and objectives

1.1 Scope

This Specification defines the basic requirements for the fabrication of the primary structures of offshore installations. These will normally include but not be limited to the following:

- Jacket structure including nodes, cones, braces, legs and conductor framing;
- Piles and followers;
- J-tubes and caissons;
- Riser clamps;
- Flotation tanks and buoyancy tubes;
- Module support frame including nodes, cones, braces, padears;
- Module framing including nodes, columns, fabricated beams and padears;
- Flareboom;
- Helideck - when constructed of steel;
- Subsea structures such as manifold and production system support frames;
- Renewable energy structures, both surface and subsea; and
- Other areas designated 'primary' on the Purchaser approved drawings.

The attachment by welding to primary steelwork (but not the fabrication) of items such as doubler plates, riser supports and walkways, also comes within the scope of this Specification.

This Specification may also be used for the fabrication of deck mounted module framing on floating offshore structures.

This Specification may also be used for modifications to existing structures, subject to the limitations imposed by the original materials and fabrication techniques.

All other structural components shall be fabricated to EEMUA 197 or other document approved by the purchaser.

The requirements of this Specification are necessarily of a general nature, and individual projects will normally apply short supplements to reflect any peculiarities of design or duty which affect them.

Pipeline risers are not covered by this Specification.

1.2 Definitions

Throughout this Specification, the following definitions apply:

Purchaser	Refers the client who has placed the contract for construction;
Contractor	Refers to the fabricator to whom the contract has been awarded;

Sub-contractor	Refers to a fabricator to whom the contractor awards any part of the work.
Shall	This term is used to indicate that the contractor/sub-contractor is required to take action.
Should	Used to indicate that the contractor/sub-contractor is advised to take action.
May	This is used to indicate that the contractor/sub-contractor is permitted to do something, or that the purchaser reserves the right to do something, according to context.
Approved/approval	Unless otherwise qualified, means formal, written agreement by the purchaser to a proposal by the contractor/sub-contractor.
Carbon equivalent (CE_{IW})	$CE_{IW} = C + Mn/6 + (Cr+Mo+V)/5 + (Cu+Ni)/15$
Pcm	$Pcm = C + Si/30 + (Mn+Cu+Cr)/20 + Ni/60 + Mo/15 + 5B$
Agreement	A verbal or written response from the purchaser confirming concurrence with a proposal by the contractor/sub-contractor.
Primary structure	Refers to all those components of offshore/subsea installations the failure of which would seriously endanger the safety of the installation; this includes all attachments welded to the primary structure.
Drawings	These are purchaser approved design drawings, or purchaser approved AFC shop drawings.

1.3 Abbreviations

The following abbreviations are used in this Specification. The meaning of each is indicated alongside:

AFC	Approved For Construction
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
AWS	American Welding Society
BINT	British Institute of Non-destructive Testing
BS/BSI	British Standard/s Institution
CE_{IW}	Carbon Equivalent
CSWIP	Certification Scheme for Welding and Inspection Personnel
CTOD	Crack Tip Opening Displacement
DAC	Distance Amplitude Curve

ECA	Engineering Critical Assessment
ECIA	Engineering Construction Industries Association
EEMUA	Engineering Equipment and Materials Users Association
EN	European Standard
EWf	European Welding Federation
FL	Fusion Line
GCHAZ	Grain Coarsened Heat Affected Zone
GMAW	Gas Metal Arc Welding
GSFCAW	Gas Shielded Flux Cored Arc Welding
GTAW	Gas Tungsten Arc Welding
HAZ	Heat Affected Zone
HSC/HSE	Health and Safety Commission/Executive
IIW	International Institute of Welding
ILAC	International Laboratory Accreditation Cooperation
IQI	Image Quality Indicator
ISO	International Organization for Standardization
MCAW	Metal Core Arc Welding
MPI	Magnetic Particle Inspection (or examination)
NDT	Non-Destructive Testing
Pcm	Parameter crack measurement (weldability parameter indicating the equivalent carbon content and composition of steels, from Japan Welding Engineering Society (JWES))
PCN	Personnel Certification in Non-destructive Testing
BSI PD	(BSI) Published Document
PQR	Procedure Qualification Record
PWHT	Post-Weld Heat Treatment (or treated)
pWPS	preliminary Welding Procedure Specification
QA	Quality Assurance
QC	Quality Control
QMS	Quality Management System
QP	Quality Plan
Q&T	Quenched and Tempered
ROL	Run-Out Length
RT	Radiographic Testing
SAW	Submerged Arc Welding
SI	International System of Units

SMAW	Shielded Metal Arc Welding
SMYS	Specified Minimum Yield Stress
SSFCAW	Self Shielded Flux Cored Arc Welding.
SWIS	Site Welding Instruction Sheet(s)
TMCR	Thermo-Mechanical Controlled Rolled
TOFD	Time Of Flight Diffraction.
TS	Tensile Strength
TWI	The Welding Institute
UKAS	United Kingdom Accreditation Service
UT	Ultrasonic Testing
WPQ	Welding Procedure Qualification
WPQT	Weld Procedure Qualification test
WPS	Welding Procedure Specification

1.4 Units

SI units are used throughout this Specification. Consistent units shall be used in all documentation submitted to the purchaser by the contractor/sub-contractor.

All dimensions shown in Figures and Tables are in mm unless otherwise specified.

'Bar' signifies gauge pressure.

1.5 Glossary of technical terms

The following technical terms are used within this Specification with the meanings indicated:

Can	A tube or pipe rolled from plate and longitudinally seam welded.
Node barrel	A main continuous tubular or chord tubular at a node.
Node	An assemblage of structural members meeting at an intersection point.
Tubular	An assemblage of cans or seamless pipes forming a member or part of a member.
Weld pass	A single progression of welding or surfacing along a joint or substrate. The result of a pass is a weld bead, layer or spray deposit.
Weld bead	A weld deposit resulting from a pass.
Single-sided weld	A joint welded from one side only.
Double-sided weld	A joint welded from both sides irrespective of the weld preparation.

Semi-automatic welding	A welding process in which the welding wire is continuously fed to a manually operated welding torch by a mechanised wire feed system.
Flaw	The indication of an imperfection or discontinuity revealed by NDT.
Defect	An unacceptable flaw.

1.6 References

A list of documents referenced in the text of this Specification is given under References in Section 8. The contractor/sub-contractor shall ensure that he has ready access to all current documents. Except where otherwise stated the latest editions of the documents including all published amendments current at the contract date (or at some other date agreed between purchaser and contractor/sub-contractor) shall normally apply. However where reference is made to a particular Section/Clause of a document, the applicable edition of the referenced document (including amendments) shall be that current on 1st February 2014.

2 Quality assurance and safety

2.1 Quality Assurance

The contractor and any sub-contractor shall establish and maintain a Quality Management System (QMS), in accordance with EN ISO/TS 29001:2010⁽⁸⁾, EN ISO 9001:2008⁽⁹⁾ or a purchaser approved equivalent. Further, all welding activities shall comply with ISO 3834:2005⁽¹⁰⁾ Part 2 or a purchaser approved equivalent. Compliance with these Standards will ensure that the goods or services supplied comply in all respects with the requirements of this EEMUA Specification. The contractor shall ensure that the QMS proposed by any sub-contractors meet the above requirements.

Prior to the commencement of any fabrication activity, including material preparation and welding procedure or welder/welding operator testing, the contractor and any sub-contractor shall submit a Quality Plan (QP) for the approval of the purchaser. The QP shall detail the full scope of activities related to the fabrication and erection of the structures.

The personnel responsible for the implementation of the QMS and QP shall be identified and their CVs shall be available for purchaser review and approval.

The purchaser's nominated representative(s) shall have the right to audit the contractor/sub-contractor's QMS at any time during the contract, subject to one day's notice.

The purchaser's nominated representative(s) shall have the right to undertake inspection or testing of the goods or services during any stage of manufacture at which the quality of the finished goods may be affected, and to undertake inspection or testing of raw materials or purchased components.

2.2 Health, safety and environmental issues

The purchaser and contractor/sub-contractor shall at all times maintain awareness of the legislation and regulations concerning safe working practices and environmental issues. It is essential to ensure compliance with these in all fabrication and testing operations concerning constructions for offshore including subsea installations.

All parties shall institute and adopt the use of safe working practices and procedures, and encourage, train and require their workforce and personnel to comply with such practices at all times.

Appropriate personal protective equipment shall be provided to the workforce and attention is drawn to the need for written procedures dealing with aspects such as:

- Working at height (scaffolding/access platforms/fall arrest equipment);
- Working below grade;
- Energy isolation (electrical and pressure);
- Confined space entry; and
- Lifting.

Specific issues related to the safety of welding and its allied activities are detailed in AWS Z49.1:2012⁽¹¹⁾. However, particular attention is drawn to the need to provide adequate ventilation in enclosed fabrication areas in order to control the level of welding fume and the build-up of welding gases.

With regard to Non-Destructive Testing(NDT), particular attention is drawn to the dangers of ionizing radiation and the need to comply with local regulations concerning the use, storage and transport of radioactive isotopes and X-ray machines. For example, in the UK, radiographic operations shall be undertaken in accordance with the Ionising Radiations Regulations 1999⁽¹²⁾ and the Approved Code of Practice L121⁽¹³⁾.

Substances such as those listed below may also present health and environmental issues:

- Liquids employed as UT couplants;
- Magnetic inks; and/or
- Penetrant test cleaning, penetrant and developing liquids;

Consequently, compliance with safety procedures and Health & Safety legislation is required at all times.

EN 14717:2005⁽¹⁴⁾ provides some guidance on environmental issues associated with welding and allied processes.

Attention is also drawn to the ECIA Safety Health and Environmental Manual⁽¹⁵⁾, which is referenced in many contracts, both offshore and onshore.

2.3 Welding personnel

The contractor and any sub-contractor personnel associated with welding operations shall be trained and qualified to recognised industry standards.

2.3.1 Welding engineers

Welding engineers shall be experienced professional engineers holding a degree or equivalent qualification in welding engineering/metallurgy, engineering/metallurgy or materials science. Certification as either, EWF - European Welding Engineer, or, IIW - International Welding Engineer, shall be held. The certified level according to these requirements is a minimum of 5 years active experience, based on evidence or equivalent qualifications.

Certification in accordance with an alternative standard may be approved by the purchaser.

The CV of the contractor's and sub-contractor's welding engineer shall be available for purchaser review and approval.

2.3.2 Welding coordinators

The contractor welding engineer shall be appointed as the principal EN ISO 14731:2006⁽¹⁶⁾ welding coordinator and shall provide technical oversight of the fabrication techniques and production welding. The welding engineer shall also

be responsible for the technical approval of sub-contractors, the sub-contractors' welding coordinator and the sub-contractors' welding and allied procedures.

The contractor may appoint additional welding coordinators meeting the specific knowledge requirements of EN ISO 14731:2006 as required by the scope of the fabrication contract.

Sub-contractors welding coordinators shall comply with the requirements of EN ISO 14731:2006.

The responsibilities of welding coordinators shall be as detailed in EN ISO 14731:2006, Annex B.

The CVs of the sub-contractors' welding coordinators shall be available for purchaser review and approval.

2.3.3 Welding inspectors

The contractor and any sub-contractor shall employ competent and certificated welding inspection personnel in sufficient numbers to ensure that welding related activities are adequately inspected in accordance with the approved QP.

Welding inspectors shall hold, as a minimum, current certification to any of the following Standards:

- AWS QC1⁽¹⁷⁾ (1996 or later edition) – CWI;
- CSWIP⁽¹⁸⁾ (TWI, UK) - Welding Inspector 3.1;
- PCN⁽¹⁹⁾ (BINDT, UK) - Weld Inspection level 2;
- IIW⁽²⁰⁾ Certified Welding Inspector Standard (CWI – S).

Alternative welding inspector certification may be approved by the purchaser.

For major scope of works (e.g. in fabrication yards involving multiple work fronts), a senior welding inspector should be appointed to coordinate and supervise the work of the welding inspectors. Senior welding inspectors shall have:

- At least 10 years of relevant experience and sound knowledge of welding and construction processes and their application;
- Formal engineering training through apprenticeship and technical college education.

Senior welding inspectors shall hold, as a minimum, current certification to any of the following Standards:

- AWS QC1 (1996 or later edition) – SCWS;
- CSWIP (TWI, UK) – SWI 3.2;
- PCN (BINDT, UK) - Weld Inspection level 3;
- IIW Certified Welding Inspector – Comprehensive (CWI – C).

Alternative senior welding inspector certification may be approved by the purchaser.

The CV and current certification of the contractor and any sub-contractor weld

inspection personnel shall be available for purchaser review and approval.

3 Materials

3.1 Weldable structural materials

Steel plate, sections and hollow sections specified on the purchaser approved drawings shall be in accordance with EN 10225:2009⁽²¹⁾.

Alternative, equivalent, impact tested, materials such as seamless and Submerged Arc-Welding Longitudinal (SAWL) tubulars manufactured in accordance with ISO 3183:2012⁽²²⁾, PSL 2 may also be approved by the purchaser.

3.2 Welding consumables

Welding consumables shall be purchased from manufacturers operating a QMS based on ISO 9001, EN 12074:2000⁽²³⁾, or purchaser approved equivalent. The consumables proposed shall enable the lowest possible hydrogen welding practice to be achieved when employed in accordance with the manufacture's recommendations. The trade names and classifications of all welding consumables proposed shall be submitted to the purchaser for approval.

All consumables shall comply with EN, ISO or AWS standards or a purchaser approved alternative.

As a minimum, consumables shall be supplied in accordance with test Schedule 4 (EN ISO 14344:2010⁽²⁴⁾) or Schedule I (AWS A5.01⁽²⁵⁾). Recommended lot classifications are shown below in Table 1.

Table 1 Welding consumables and recommended lot classifications

	AWS	EN ISO	Recommended Lot Classification
GMAW wire	A5.18/A5.18M ⁽²⁶⁾ A5.28/A5.28M ⁽²⁷⁾	14341:2011 ⁽³⁴⁾	S3
GSFCAW wire	A5.36/A5.36M ⁽²⁸⁾	17632:2008 ⁽³⁵⁾	T2
SSFCAW wire	A5.36/A5.36M	17632:2008	T2
MCAW wire	A5.36/A5.36M	17632:2008	T2
SAW wire / flux	A5.17/A5.17M ⁽²⁹⁾ A5.23/A5.23M ⁽³⁰⁾	14171:2010 ⁽³⁶⁾ /26304:2011 ⁽³⁷⁾	Wire S3 / Flux F2
GTAW wire	A5.18/A5.18M A5.28/A5.28M	636:2008 ⁽³⁸⁾	S3
SMAW electrodes	A5.1/A5.1M ⁽³¹⁾ A5.5/A5.5M ⁽³²⁾	2560:2009 ⁽³⁹⁾ /18275:2012 ⁽⁴⁰⁾	C4 or C5
Shielding gas	A5.32 ⁽³³⁾	14175:2008 ⁽⁴¹⁾	-

Submerged arc wires shall be used in combination with the manufactures recommended flux.

If the consumables are proposed for welding procedures which require Crack Tip Opening Displacement (CTOD) testing, the contractor/sub-contractor shall submit evidence that the deposited weld metal will meet the specified requirements.

The purchaser shall maintain the right to specify the need for any additional testing of consumables.

3.3 Miscellaneous materials

3.3.1 Bolts, nuts and washers

Unless specified otherwise on the purchaser approved drawings, structural bolts and nuts shall comply with EN ISO 898, Parts 1⁽⁴²⁾ and 2⁽⁴³⁾, Grade 8.8. The maximum hardness shall be 34HRC. Washers shall comply with EN ISO 887:2000⁽⁴⁴⁾.

Fasteners to be used in air shall be hot dipped galvanised in accordance with BS 7371 Parts 1⁽⁴⁵⁾ and 6⁽⁴⁶⁾.

Fasteners to be used subsea (fully immersed) shall be provided with a thin (≤ 10 micron) coating. The coating may be applied by hot spun galvanising (BS 7371-7⁽⁴⁷⁾), sherardizing (BS 7371-8⁽⁴⁸⁾) or Zn/Ni electroplating (EN ISO 4042:2000⁽⁴⁹⁾).

Fully immersed fasteners shall be electrically continuous with the structure to ensure effective cathodic protection.

For partially wetted applications where full cathodic protection cannot be applied or guaranteed, e.g. the splash zone, fasteners made from a purchaser approved corrosion resistant material may be used.

3.3.2 Castings and forgings

Structural steel castings shall comply with EEMUA 176⁽⁵⁰⁾ or an alternative purchaser approved specification.

Structural forgings shall be supplied to an appropriate steel specification selected by the purchaser.

3.4 Materials substitution

The materials used for the structure shall be of the grade and size defined on the purchaser approved drawings unless approval is given to alternative proposals made by the contractor/sub-contractor.

3.5 Materials handling

3.5.1 Receipt of materials

The materials and sub-assemblies delivered to the site shall be held in quarantine until the items have been identified against the relevant documentation.

The contractor/sub-contractor shall also verify that the information provided complies with the requirements of the appropriate specification. If any item has

inadequate identification or unsatisfactory documentation, it shall be held in quarantine and the purchaser shall be notified as soon as possible.

3.5.2 Maintenance of identity

The contractor/sub-contractor's QMS shall ensure full traceability of materials during storage and fabrication.

3.5.3 Storage conditions

The materials shall be stored in conditions which will avoid damage and deterioration. Different materials and materials used for separate contracts shall be segregated. Warehouse storage is preferred for all small painted or coated items and for portable sub-assemblies.

4 Qualification of welding procedures and personnel

4.1 General requirements

Welding shall be undertaken in accordance with procedures approved by the purchaser and qualified in accordance with this Specification (Sections 4 and 5) and EN ISO 15614-1 2004+A2:2012⁽⁵¹⁾.

The transfer of qualified welding procedures between contractor and sub-contractors is not acceptable.

4.2 Approval process for welding procedures

4.2.1 Initial submission

The contractor/sub-contractor shall submit the following documents, (Sections 4.2.1.1 – 4.2.1.6) in an electronic format agreed by the purchaser.

4.2.1.1 Welding procedure schedule

A schedule of all proposed welding procedures necessary for completion of the work in accordance with the essential variables. This shall contain the following information:

- Types of weld;
- Consumables;
- Welding position;
- Material types;
- Qualified thickness range; and
- Welding procedure specification number.

The Welding Procedure Specifications (WPS) should be grouped and cross - referenced to the relevant welding procedure qualifications (PQR) and, where appropriate, to the Site Welding Instruction Sheets (SWIS) (see Section 4.2.1.6).

The schedule shall indicate the dates by which each new qualification is intended to be completed.

4.2.1.2 Existing welding procedure qualifications

If the contractor/sub-contractor hold appropriate existing welding procedure qualifications, they should be submitted to the purchaser for consideration, together with a list of any deviations between the testing requirements of this Specification and those of the specification to which they were tested.

Note: Existing procedures qualified to EEMUA 158, Edition 2, shall be acceptable without reference to EN ISO 15614-1:2004+A2:2012.

If the purchaser considers an existing procedure qualification to be immediately acceptable or acceptable after additional testing, the contractor will be notified of the steps necessary to obtain approval for construction (AFC).

Any existing procedure qualification which the contractor/sub-contractor proposes to utilise in satisfying the requirements of this Specification shall have been witnessed and verified by a competent third party, acceptable to the purchaser.

A typical example format for the WPS is shown in Figure 1. However, the contractor/sub-contractor may submit proposals on his own documentation if it contains details of the relevant variables.

4.2.1.3 New welding procedures

New welding procedures required to meet the requirements of this Specification shall be submitted as preliminary Welding Procedure Specification (pWPS) for purchaser approval prior to qualification.

The pWPS shall be based on a table of standard parameters proposed for use for all welding with the process-consumable combination nominated. Standard welding parameters shall be provided for each electrode diameter, welding position and location in the joint (i.e. root, 'hot pass', fill, cap, and any other distinctions normally made by the contractor/sub-contractor). The ranges of parameters shall not exceed the limits in Section 4.5.5, and the values shall be selected to represent the welding parameters currently in use.

4.2.1.4 Standard welding practices

The statement of standard welding practices shall include, as a minimum:

- Weld preparation method;
- Standard weld preparation details;
- Preparation cleaning (if any);
- Use of weldable primers (if any);
- Alignment, fit-up and restraint methods;
- Preheat-temperature for each material grade/thickness/welding process, method and control;
- Maximum interpass temperature and method of control;
- Weld cleaning;
- Gas purging (if relevant);
- Back-gouging method and control; and
- Consumables handling.

4.2.1.5 Repair welding procedure/statement

The repair welding procedure/statement shall include, as a minimum:

- scope of application;
- repair method(s), process(es), relevant welding procedures, method of excavation and final preparation including NDT; and
- preheat temperatures, method and controls.

				FABRICATOR								
				LOCATION		SHOP SITE						WELDING PROCEDURE NO.
Welding Procedure Specification												
QUALIFICATION IN ACCORDANCE WITH EEMUA PUBLICATION 158 AND EN ISO 15614-1:2004+A2:2012												
PARENT METAL			PLATE/PIPE THICKNESS			PIPE DIAMETER						
CARBON EQUIVALENT			PLATE/PIPE NO.			CAST NO.						
QUALIFIED THICKNESS RANGE						QUALIFIED DIAMETER RANGE						
WELD PREPARATION (WITH DIMENSIONS AND TOLERANCES)						WELDING SEQUENCE/PASS LOCATION						
MAXIMUM WELD BEAD WIDTH FOR EACH WIRE/ELECTRODE DIAMETER												
PREHEAT TEMP °C			PREHEAT METHOD		MAX INTERPASS TEMP °C				CHECK/CONTROL METHOD			
PREPARATION METHOD			GOUGING METHOD & PURPOSE				GOUGE CHECK METHOD					
TACK WELD TECHNIQUE TACK LENGTH:						TACK SEPARATION:						
SIDE	RUN NOS	WELDING PROCESS	WELDING POSITION & DIRECTION	ELECTRODE(S)			FLUX OR GAS SHIELD	GAS FLOW RATE	AMPS	VOLTS	WELDING SPEED OR R.O.L.	HEAT INPUT kJ/mm
				SIZE mm	TRADE NAME	POLARITY						
POST WELD HEAT TREATMENT				NOTES								
HEATING RATE												
SOAK TEMP °C												
SOAK TIME												
COOLING RATE												
WITHDRAWAL TEMP. °C												
				Specification completed by		Accepted for testing by		Test witnessed by		Procedure approved by		
COMPANY												
SIGNATURE												
PRINT NAME												
DATE												

Figure 1 Example of a welding procedure specification

4.2.1.6 Site welding instruction sheets

Where the contractor/sub-contractor proposes to use SWIS, these should cover all welding procedures for each combination of process and consumable proposed regardless of preparation, thickness, or heat treatment condition (Depending on the contractor/sub-contractor's selection of process and consumables, it is possible that a single SWIS could be developed for each main fabrication area).

Where the SWIS is intended as the primary shop floor communication, it should include all of the information necessary for consistent application of all of the associated qualified weld procedures. As a minimum it shall contain the following information:

- General requirements:
 - preheat and interpass temperature;
 - tack welds-size and technique;
 - controls related to root beads, including maximum root closure gaps;
 - permitted weld interruptions; and
 - restrictions on back-gouging.
- For SMAW (by welding position where appropriate):
 - electrode brand name and diameter;
 - individual welders electrode storage (Section 5.3.2);
 - ROL and assumed stub length per electrode size;
 - weld bead width;
 - controls on any use of temper bead; and
 - current.
- For Submerged Arc-Welding (SAW):
 - wire and flux brand names;
 - number and orientation of wires;
 - travel speed; and
 - for each wire:-
 - diameter;
 - polarity;
 - voltage;
 - current;
 - stickout;
 - separation; and
 - feeding direction/angle.
- For semi-automatic processes (by welding position and joint geometry):
 - electrode brand name and diameter;
 - nozzle size relative to wire diameter/joint geometry;
 - weld bead width;
 - controls on any use of temper bead;
 - stickout;
 - travel speed;
 - voltage;
 - current/wire feed speed;
 - polarity; and
 - gas composition and flow rate (where applicable).

To avoid the need for a separate submission, the SWIS may also include all the relevant elements of Section 4.2.1.4, if appropriate, and any other information which the fabricator considers necessary for the instruction of the welder.

The parameter ranges in the AFC submission shall be based on those recorded on the associated PQR's, taking into account the allowable tolerances for essential variables identified in Section 4.5.

Specific situations may impose exclusions which shall be noted on the SWIS, e.g. wide-gap single-sided closure welds.

An example of a SWIS is illustrated in Figure 2.

Where the contractor or sub-contractor has an existing system of work instructions for welders then this may, subject to purchaser approval, be used in preference to the above referenced SWIS.

SWIS, WPS or other work instructions shall be available in the welders' first language and English.

In addition to written instructions concerning welding operations, welders should be required to attend regular tool box talks at which the elements of good welding practice related to the fabrication contract are emphasised.

4.2.3 Procedure qualification records

The first part of the PQR shall consist of an 'as-run' sheet which is a pass-by-pass record of the test weld, giving the information and measured values of each of the welding parameters detailed below:

- PQR number;
- Test code and relevant specifications;
- Date of test;
- Parent materials, specification, sizes and heat/cast numbers;
- Consumable (including SAW flux) classification, brand name, batch certificate number;
- Welders identification number(s) and name(s);
- Welding position;
- Weld preparation sketch and dimensions;
- Sketch detailing actual pass locations;
- Shielding and backing gases, trade name, composition and flow rates;
- Preheat temperature and method of application/measurement;
- Inter-pass temperature (pass by pass) and method of measurement;
- Consumable diameter for each pass;
- Tungsten type and size for Gas Tungsten Arc Welding (GTAW);
- Shroud diameter and type for GTAW;
- Nozzle diameter for semi-automatic processes;
- Wire feed speed;
- Wire stick out length;
- Polarity for each pass;
- Current and voltage for each pass;
- Pulse shape and duration for pulsed welding;
- Welding speed/electrode run out length for each pass;
- Time for each pass;

- Calculated heat input for each pass;
- Details of any post weld hydrogen release treatment;
- Post weld heat treatment report number; and
- NDT report numbers.

SITE WELDING INSTRUCTION SHEET NO.					
Process(es):			Consumable(s):		
Approved WPQRs:					
Preparations Covered:					
Materials Qualified: <i>eg. Up to 460 grade structural steels in TMCR and Q&T Conditions, max CEq. 0.40</i>					

GSFCAW Table of Parameters						SMAW Table of Parameters			
		S/P. Fillet	2nd Pass *	Fill	Cap			Root	2nd Pass
ø 1.2mm	Polarity	DC+ve	DC+ve	DC+ve	DC+ve		Polarity	DC+ve	DC+ve
1G	Wire Feed					1G	Diameter		
	Volts						Amps		
	Speed						ROL		
2G/2F	Wire Feed					2G	Diameter		
	Volts						Amps		
	Speed						ROL		
3G/3F	Wire Feed					3G	Diameter		
	Volts						Amps		
	Speed						ROL		
4G/4F	Wire Feed					4G	Diameter		
	Volts						Amps		
	Speed						ROL		

Shield Gas:	litres/min
-------------	------------

Preheat Instructions	
(Combined) Thickness Range	Preheat

Control: *eg. Temperature Crayon*
 Method: *eg. Electrical Mats or Propane for Weld Length <= 300mm*
 Interpass: *eg. 250°C maximum*

Approved Heat Input Ranges	
SMAW Root:	
SMAW 2nd Pass:	
GSFCAW Single Pass Fillets:	
GSFCAW 2nd Pass (* or first pass of backgouged welds):	
GSFCAW Fill:	
GSFCAW Cap:	

Heat inputs shown are: unfactored Arc Energy / factored by efficiency factor, 0.8

Other Variables, Comments etc.
eg. Vertical down welding not permitted
eg. For repairs increase preheat by 50°C up to maximum 150°C
eg. GSFCAW fill parameters also used for multipass fillets.

Rev	Approved	Date

Figure 2 Example of a site welding instruction sheet for semi-automatic and manual welding

During procedure qualification the above parameters shall be monitored by automatic arc monitoring equipment, which shall also record arc time. This equipment shall be subject to approval by the purchaser.

Welding parameters for pulsed current and wave form controlled processes shall be recorded using an instantaneous power meter.

The original field report will be acceptable subject to it being legible and to a purchaser approved format. This completed form shall be submitted to the witness, who will sign it if it is a factual record of the information and if the visual examination of the test weld confirms that it meets the requirements of Section 7.5.2.

The second part of the PQR shall consist of the full set of mechanical test results for the test pieces taken from the weld. These tests shall be undertaken by a test laboratory accredited by an ILAC member organisation, e.g. UKAS. Alternatively, a purchaser approved test house may be used. The completed form shall be submitted to the witness, who will endorse it if it is a factual record of the information. A typical mechanical test result format is shown in Figure 3.

4.2.4 Submission of the qualification package

If the NDT and mechanical testing results meet the requirements specified, the following documents shall be compiled and submitted to the purchaser for each qualified procedure:

- The WPS based on as-run information;
- All parts of the PQR, bearing the signatures of the witnesses;
- Parent material and consumables certificates; and
- NDT and Post Weld Heat Treatment (PWHT) records.

Each qualification package will be reviewed for approval by the purchaser, and the contractor/sub-contractor notified in writing of the results of this review.

Where used, SWIS shall be prepared in accordance with Section 4.2.1.6 once any relevant welding procedure has been approved. All SWIS will be subject to approval by the purchaser prior to issue for production welding. SWIS shall be revised, re-approved and re-issued as necessary when additional associated weld procedures are approved by the purchaser.

4.3 Restrictions on welding practices

For certain welding practices, the purchaser will require extensive background data and assurance of adequate QC. It should be noted that the processes and techniques listed below are not necessarily prohibited but will require additional technical justification before approval.

- SMAW for heat inputs exceeding 3kJ/mm;
- SMAW bead widths exceeding three times the core wire diameter;
- SMAW vertical down;
- GMAW (except for the root pass in double-sided SAW welds);
- Gas shielded welding processes (except where adequate environmental shielding is provided to ensure security of the gas shield);
- Semi-automatic welding without the voltage and wire-feed speed pre-set;
- Semi-automatic welding with weave beads (i.e. not stringer beads);

- Semi-automatic welding vertically up (except for root passes);
- Flux cored weld passes followed by any high dilution process;
- The use of semi-automatic welding for the root of single sided joints;
- Butt welds, where both edges are square, greater than 8mm thick;
- Full penetration T-butt welds without bevels where the incoming member is greater than 8mm thick;
- Included angles of bevelled welds below 45° (except as covered by 4.5.2(g));
- Included angles below 60° for closing welds in tubulars above 40mm thick;
- Welding on the second side of a joint without back-gouging or grinding except for SAW procedures using the punch-through technique;
- Use of SAW punch-through technique for Grade 460 steels
- Use of a 'temper bead' technique;
- Maximum interpass temperature exceeding 250°C;
- Single-pass fillet welds (other than by SAW) with a design leg length greater than 6mm;
- Use of backing strips; and/or
- Use of ceramic inserts.

4.4 Welding procedure qualification tests

4.4.1 General requirements

The contractor or sub-contractor welding engineer shall be present during the qualification of welding procedures.

Since the purpose of the test is to demonstrate that the procedures are suitable for use in construction, the test conditions shall be a realistic simulation of the actual conditions that will be experienced.

Procedures qualified in shops may be used in the open if adequate temporary protection is provided.

Weld test pieces shall be restrained to a similar degree to the corresponding production weldments.

		FABRICATOR		WELDING PROCEDURE NO.							
		LOCATION	SHOP SITE								
Welding Procedure Specification				TEST WELD THICKNESS		mm					
				TEST WELD WIDTH		mm					
				TEST WELD LENGTH/DIA		mm					
TRANSVERSE OR ALL WELD	THICKNESS mm	WIDTH mm	DIA-METER mm	GAUGE LENGTH	YIELD N/mm ²	TS N/mm ²	ELONG %	RED'N OF AREA %	LOCATION OF FRACTURE		
BEND TESTS					STANDARD HAZ HARDNESS SURVEY Hv10						
TYPE	THICKNESS mm	RADIUS mm	RESULT		1	6	11	16			
					2	7	12	17			
					3	8	13	18			
					4	9	14	19			
					5	10	15	20			
WELD METAL C.T.O.D. TESTS TO EN ISO 15653											
NOTCH LOCATION (IT/SURFACE)	T °C	W mm	B mm	L mm	a mm	P N/mm ²	V ₀ mm	c mm	u mm	m mm	COMMENTS
NDT (ACCEPTABILITY & REPORT NO.)											
VISUAL						MAGNETIC PARTICLE					
X-RAY/GAMMA RAY						UNTRASONIC					
CHARPY V-NOTCH IMPACT TESTS (10 x mm at °C)											
WELD CAP	J	WELD ROOT	J					J			
WELD METAL		WELD METAL									
WELD METAL		WELD METAL									
WELD METAL		WELD METAL									
FUSION LINE		FUSION LINE									
FUSION LINE		FUSION LINE									
FUSION LINE		FUSION LINE									
FL-2 mm		FL-2 mm									
FL-2 mm		FL-2 mm									
FL-2 mm		FL-2 mm									
FL-5 mm		FL-5 mm									
FL-5 mm		FL-5 mm									
FL-5 mm		FL-5 mm									
				MACRO (PHOTO ATTACHED)							
				DATE(S) OF TESTS							
		Tested by	Form completed by		Test witnessed by		Results approved by				
COMPANY											
SIGNATURE											
PRINT NAME											
DATE											

Figure 3 Example of a PQR mechanical test report

When PWHT of nodes or other sub-assemblies is required, all relevant procedures and qualifications shall include PWHT over the full range of material thickness.

The purchaser may choose to nominate certain plates, tubulars or sections for use in welding procedure tests and the contractor/sub-contractor shall comply with any such requirement. Test welds in plate shall be made parallel to the rolling direction of the plate with at least 250mm of plate width on each side of

the weld (note that wider plates will be needed for CTOD testing) Test welds in seamless tubulars and sections shall normally be made perpendicular to the rolling direction.

Welding procedures for butt welds shall be qualified in two positions which represent the highest and the lowest heat inputs as agreed with the purchaser.

Plate butt welds qualify T-butt welds provided that the test joint preparation has one square edge, but the test in 4.4.2.3 (b) is still required for stub to barrel welds. Only consumables which have been qualified on butt welds may be used, and testing requirements shall be agreed with the purchaser. T-butt welds may also be qualified separately.

On node joints where 'point-to-point' fabrication techniques are proposed, such that the closure joint will be welded single sided, a full size joint mock up shall be undertaken for NDT and mechanical test purposes as per 4.4.2.3 (b). The brace to be welded to the continuous member shall have a cover, tack welded over the open end, to prevent internal access prior to the weld completion and NDT. This mock up shall also be used for NDT procedure qualification.

Single pass fillet welds shall be qualified on plate of minimum thickness 30mm. Qualification shall be in the 2F and 4F positions at the minimum specified leg length.

Additionally, the consumables employed for fillet welds shall have been tested in a plate butt weld.

When procedures require PWHT, the soak time for the test weld shall not be less than 1 hour per 25mm of section thickness or 4 hours whichever is greater. The PWHT soak time qualified shall be the maximum the contractor/sub-contractor intends to use in practice. This shall allow for one repeat PWHT cycle to cover weld repairs made after the first PWHT.

Post-weld hydrogen release treatments may be used subject to agreement with the purchaser.

If the contractor/sub-contractor becomes aware of an error likely to result in rejection of the test weld, welding shall be stopped immediately, the test weld discarded, and a new one welded. Weld repairs to a test weld shall not be undertaken without the agreement of the purchaser.

For butt welds, all passes in the cap of the qualification weld shall use the same electrode diameter, although the diameter may be increased for production welds within the limits of 4.5.3 (d).

The interpass temperature prior to the deposition of the capping passes of the Weld Procedure Qualification Test (WPQT) shall be limited to the minimum preheat temperature.

4.4.2 Types of test weld

4.4.2.1 Comprehensive tests

Three types of weld require full qualification testing:

- Butt welds in plate;
- Butt welds in tubulars below 600mm diameter; and
- Single pass fillet welds.

4.4.2.2 Optional tests

The following types of weld do not require separate qualification if the conditions specified are observed:

- partial penetration welds made with qualified full penetration butt weld parameters;
- multipass fillet welds made with qualified full penetration butt weld parameters;
- tack welds made with qualified root pass parameters;
- weld metal buttering deposited with qualified full penetration butt weld parameters.

If the contractor/sub-contractor wishes to work outside these conditions, the purchaser shall specify the testing to be undertaken.

4.4.2.3 Single tests and demonstrations

The following types of weld require 'one-off' demonstrations of the suitability of the contractor/sub-contractor's qualified procedures for each type of welding process and consumable to be used. However, additional tests will be specified if the purchaser is not satisfied with the results of the demonstration.

The NDT applied to these tests and demonstrations shall be specified by the purchaser.

4.4.2.3.1 Repair welds using a different procedure from that of the original weld

A fusion line excavation to mid-thickness shall be made in a test weld of the greatest thickness to be qualified. This shall be repaired in the vertical position using the qualified full penetration butt weld parameters for the repair consumable. The Heat Affected Zone (HAZ) mechanical tests required shall be taken from both sides of the repair, i.e. parent material and original weld. The requirements for PWHT or CTOD testing of the repair weld shall be the same as those for the original weld. Separate tests are necessary for as-welded and PWHT procedures.

4.4.2.3.2 T-K-Y joints

A joint between two tubulars shall be assembled as illustrated in Figure 4. With the approval of the purchaser, the tubular dimensions may be varied to sizes appropriate to those on the purchaser approved drawings.

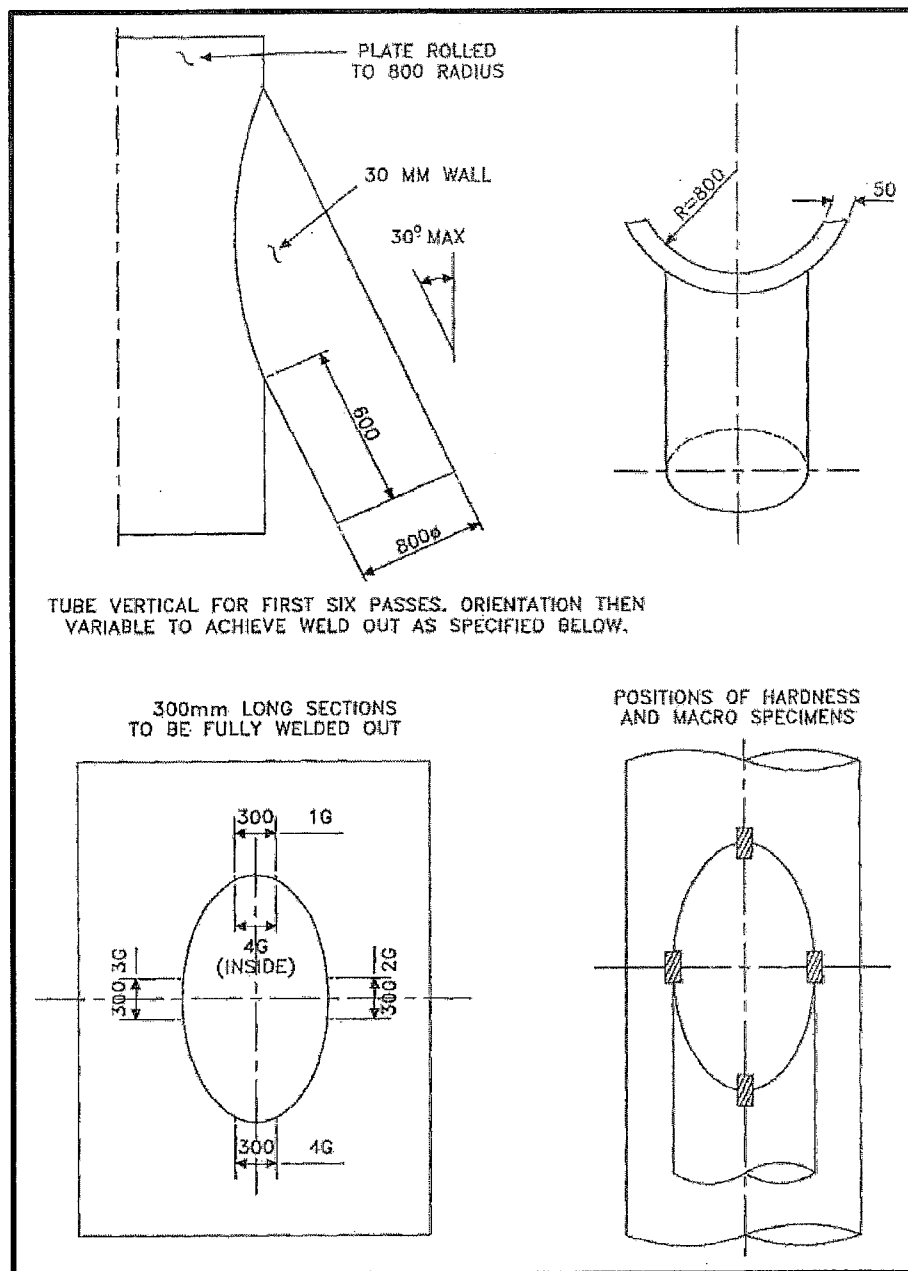
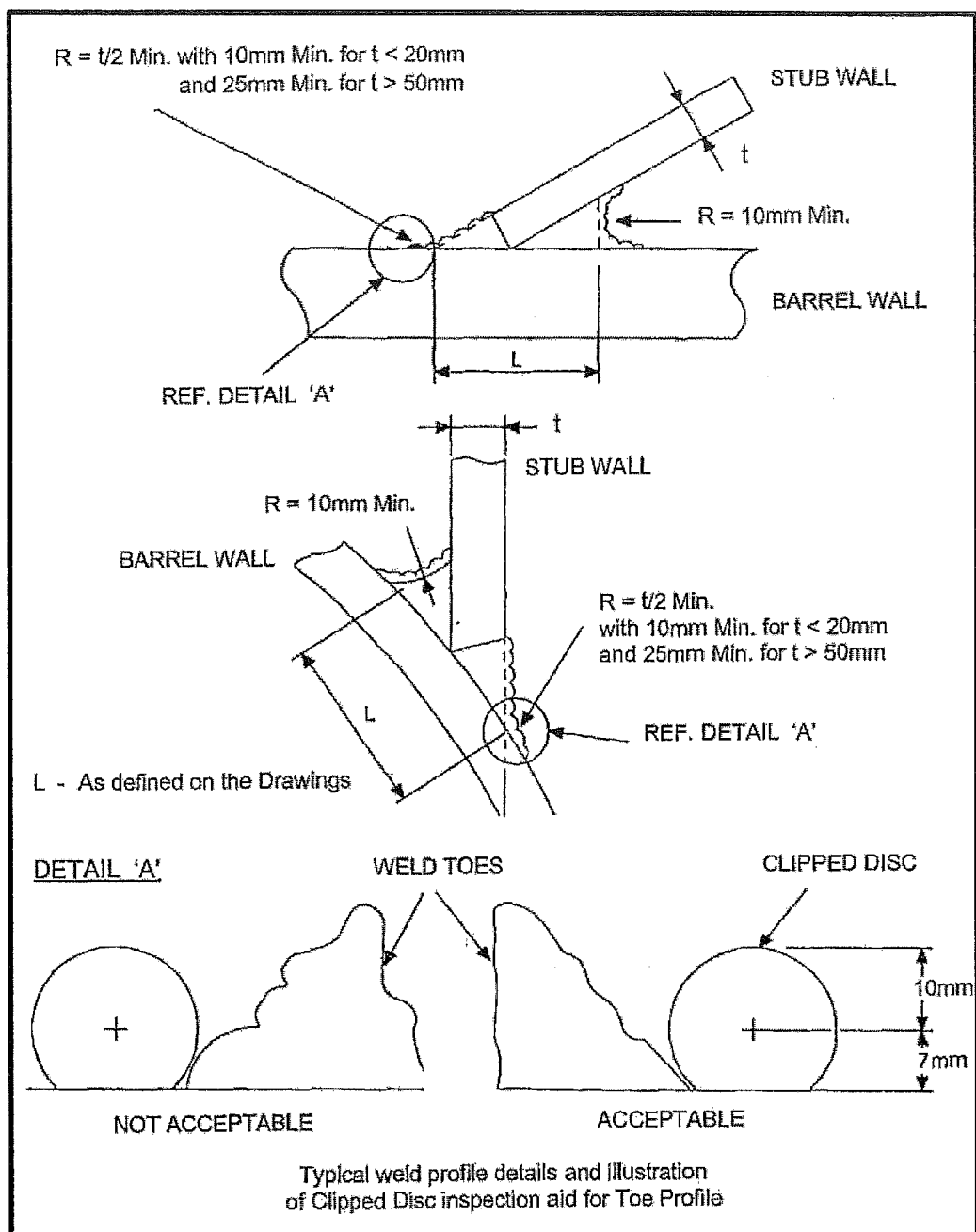


Figure 4 Demonstration piece for T, K and Y joints

Six passes shall be completed externally all around the joint, with the weld being filled and capped along 300mm sections, as illustrated in Figure 4. Where the test is required to demonstrate double-sided welding, an additional pass (or passes) shall be deposited in the 4G position as shown in Figure 4. Weld surface profiles shall be as illustrated in Figure 5. Similar joints in plate structures shall be subject to agreement between the purchaser and the contractor/sub-contractor.



Note: Other locations shall be in accordance with the purchaser approved drawings and Section 7.5.2

Figure 5 Examples of acceptable weld profiles for tubular intersections

4.4.2.3.3 Wide gap tubular closing butts

For tubular closing butts a single-sided joint between two tubulars at least 600mm diameter and at least 40mm thick shall be assembled, with the tubulars in the fixed horizontal position. The root pass shall be deposited using root gap dimensions agreed with the purchaser.

The test joint shall be welded out completely and then tested at the 3, 6 and 12 o'clock positions by macro-examination, hardness and root Charpy tests against the requirements of this Specification.

Testing requirements for plate closing butts shall be agreed between the purchaser and the contractor/sub-contractor.

4.4.2.3.4 Grout beads

Welding procedure qualification for depositing 'grout beads' on piles or pile sleeves shall be undertaken by depositing a full circumferential bead on a can of the material of the diameter and thickness shown on the purchaser approved drawings, using appropriate production welding equipment. Surfaces on to which grout beads are to be deposited shall be identical in qualification tests and production. Visual examination shall show that bead height, bead width and toe profile are as specified on the purchaser approved drawings. 100% Magnetic Particle Inspection (MPI) shall be performed and show freedom from defects. Macro-examination (two sections, 1m apart) shall show freedom from solidification cracking and other defects. Hardness indents shall be made as shown in Figure 6 and shall not exceed 325HV10.

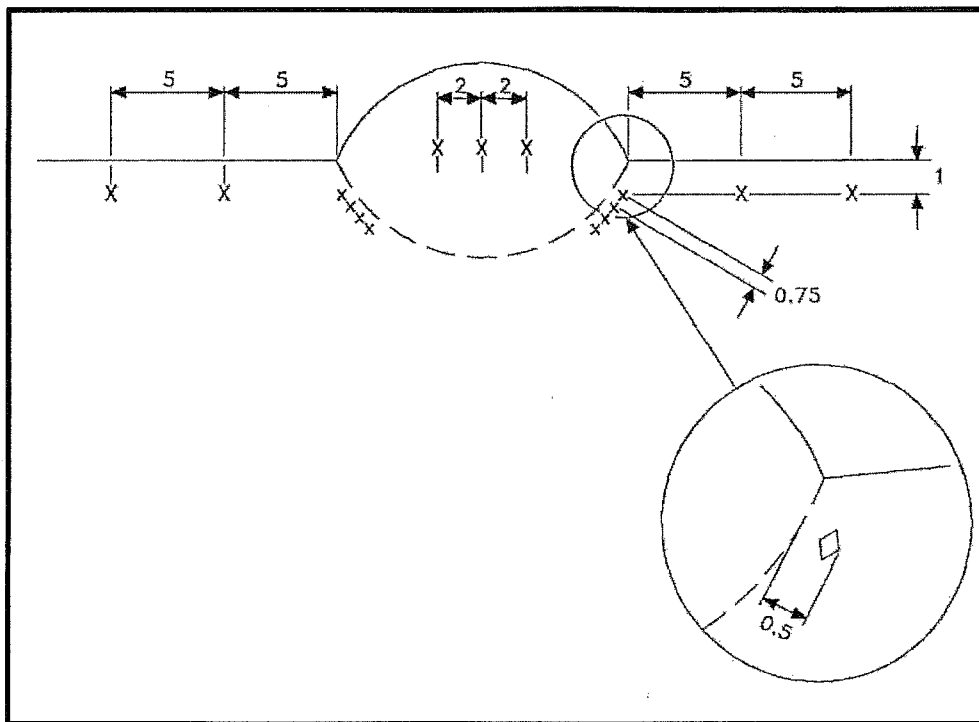


Figure 6 Hardness indentation locations for grout bead procedures

4.4.3 Inspection and NDT requirements and acceptance criteria

4.4.3.1 Visual inspection

Each completed test weld shall be visually inspected and shown to comply with the relevant clauses in Section 7 of this Specification.

If inspection of the root of a single-sided weld reveals an unacceptable profile, the purchaser may require the contractor/sub-contractor to repeat the test using a different technique. This change would apply to all single-sided production welds using the same root pass consumables in the same position as the test welds.

4.4.3.2 Non-destructive testing

Not less than 48 hours following completion of welding, the test weld shall be non-destructively tested in accordance with Section 7 of this Specification, using test procedures which have been approved by the purchaser. Extent and type of NDT shall be in accordance with Table 2 Category I for butt welds and 100% MPI for fillet welds. When a test weld is to receive PWHT, final NDT examination shall take place after PWHT.

Table 2 Requirements for extent and type of inspection and NDT

Inspection/ NDT category	Extent of visual examination	Extent of ultrasonic examination ^(a)	Examination level to EN ISO 17640:2010 ⁽⁵²⁾	Extent of Magnetic Particle Inspection ^(f)
I	100%	100%	Nodes Level B, or, D if specified by purchaser. Others joint details Level C.	100%
II	100%	100%	Level B	100%
III^(e)	100%	100% ^(b)	Level B	100% ^(b)
IV^(e)	100%	10% ^(c)	Level B	10% ^(c)
V	100%	-	-	10% ^(c, d)

Notes:

- (a) For thicknesses where the use of UT is impractical, radiography shall be used.
- (b) This may be reduced to 20% when the contractor/sub-contractor has been able to demonstrate to the satisfaction of the purchaser that a consistently low repair rate has previously been achieved.
- (c) 10% examination is defined as examination of 10% of the length of each weld, unless the length of the weld is less than 1m, in which case 10% of all similar welds shall be inspected (see Section 7.2.1.5),
- (d) Alternative inspection requirements may be specified for pipe grout beads, e.g. creeping waves.
- (e) Fillet welds falling into Categories III and IV shall be subjected to visual examination and MPI only
- (f) MPI shall only be applied to the external surface of weldments unless otherwise specified by the purchaser.

Preliminary NDT may be conducted immediately after welding, but repair welding is not permitted. Flaws exceeding the acceptance criteria of Section 7 may be permitted on condition that they can be categorized as welder induced. In this case the weld shall not be considered as qualifying the welder.

If ultrasonic examination reveals no flaws exceeding the reference level, but more than three reflectors in any metre of weld length exceed 50% of the reference level, then the procedure and consumables shall be considered suspect. If a further test piece using the same consumables and a similar procedure also shows reflectors above 50% of the reference level, the purchaser may reject all procedures using the consumables or joint geometry which the purchaser considers to be responsible.

The locations of all imperfections exceeding 50% of the reference level shall be marked, and the cutting of test pieces shall be arranged to avoid these regions.

4.4.4 Mechanical testing requirements and acceptance criteria

Mechanical testing shall be undertaken as detailed below.

The number and types of tests required for any test weld are specified in Table 3. The purchaser shall be notified of all test failures, even where retests are permitted, before additional testing is undertaken. Where dissimilar material welds will involve a thickness transition to compensate for a difference in strengths, the mechanical test requirements shall comply with those of the stronger material.

4.4.4.1 Transverse tensile tests (EN ISO 4136:2012⁽⁵³⁾)

The tests shall take the form of the 'reduced transverse test' except that the parallel length of the test piece shall not exceed 6mm on each side of the weld. For acceptance, the tensile strength shall not be less than the minimum value specified for the parent material. In the case of welds between materials of different specified minimum tensile strengths, the acceptance level shall be the lower of the two.

If fracture occurs at less than 95% of the specified minimum tensile strength on one or both specimens, the procedure shall be rejected. If fracture occurs at between 95% and 100% of the specified tensile strength then two retests shall be carried out for each failure recorded, all of which shall meet the specified minimum tensile strength.

4.4.4.2 All weld metal tensile tests (EN ISO 5178:2011⁽⁵⁴⁾)

The locations from which the test pieces shall be taken are illustrated in Figure 7. The upper yield or 0.5% proof stress (total extension) and the tensile strength shall not be less than those specified for the parent material, and the elongation shall not be less than 20%. The test house shall state whether the measured value is upper yield or 0.5% proof stress. In the case of welds between materials of different specified minimum strengths, the acceptance level shall be the higher of the two.

If the test fails to meet the specified minimum properties, two retests shall be carried out on pieces taken from the original weld, both of which shall meet the specified requirements.

Table 3 Types and number of mechanical tests required for WPQ

Test Material (t = thickness)	Macro	Hardness	Bend test (o)	Tensile tests		Charpy test sets ^(a)		Weld metal CTOD sets ^(a)
				All weld	Trans- verse	Cap	Root	
Pipe $t \leq 10\text{mm}$	1 ^(d)	1 ^(d)	(p)	0	2	4 ^(b,e)	0	0
Pipe $10 < t \leq 20$	2 ^(d)	2 ^(d)	(q)	0	2	4 ^(e)	0	0
Pipe $20 < t \leq 40$	3 ^(d)	3 ^(d)	(q)	1	2	4 ^(e)	4 ^(e)	0
Plate $t \leq 20\text{mm}$	1	1	(p) (q)	0	2	4	0 ^(e)	0
Plate $20 < t \leq 40$	1	1	(q)	1	2	4	4	0
Plate $40 < t \leq 50$	1	1	(q)	1	2	4	4	1 ^(f,g)
Plate $t > 50$	1	1	(q)	1	2	4	4	1 ^(g,h)
Fillet weld	2	2	0	0	0	0	0	0
Repair welds	1	1	0	1 ⁽ⁱ⁾	2	3 ^(j)	1 ^(k)	1 ^(l)
T, K, Y tests (Fig 4)	4	4	0	0	0	0	0	0
Wide gap test	3 ^(d)	3 ^(d)	0	1	2	0	3 ^(m)	0
Grout bead tests	2	2	0	0	0	0	0	0

Notes

- (a) Charpy tests on sets each comprising 3 specimens are required from the weld, fusion line (FL), FL+2mm, and FL+5mm locations unless otherwise stated (see Figure 9)
 (b) Charpy tests on pipes up to 10mm thick shall use 10mm x 5mm test specimens
 (c) Charpy test specimens on 5G or 6G pipe welds shall be taken from the 3 o'clock or 9 o'clock positions
 (d) Specimens for macro and hardness tests on 5G or 6G pipe welds shall be taken as follows:

$t \leq 10\text{mm}$: 6 o'clock position
 $10 < t \leq 20\text{mm}$: 6 and 12 o'clock positions
 $t > 20$: 3, 6 and 12 o'clock positions

Macro and hardness tests are only required from one location in 2G butts,

- (e) Root Charpy tests are required regardless of thickness if a 'punch-through' technique is used; see Figure 11 for location
 (f) CTOD tests are required for welding procedures qualified in the as-welded condition for use on stub to chord (barrel) or other highly stressed welds, unless otherwise advised by the purchaser
 (g) HAZ CTOD tests are only required when specifically advised by the purchaser (see Appendix A) CTOD tests are required for all welding procedures qualified in the as-welded condition
 (h) CTOD tests are required for all welding procedures qualified in the as-welded condition
 (i) All-weld tensile tests are required on the repair weld only
 (j) Charpy test specimens shall be taken from the repair weld centre and from the fusion line on each side of the repair, see Figure 10
 (k) For Charpy tests required at the root of a repair weld, see Figure 10
 (l) CTOD testing of repairs to welds left in the as-welded condition shall apply to repairs of node welds in material greater than 40mm thickness and to all other welds greater than 50mm thickness
 (m) Charpy tests of wide gap procedure test welds shall be taken at the 3, 6 and 12 o'clock positions in the weld metal only
 (n) A set of CTOD specimens comprises three specimens
 (o) Specimens and testing shall be in accordance with ISO 5173:2010+A1:2011⁽³⁵⁾
 (p) For thicknesses $\leq 10\text{mm}$ two transverse root and two transverse face bend test specimens shall be tested
 (q) For thicknesses $> 10\text{mm}$ four transverse side bend specimens shall be tested instead of root and face bends

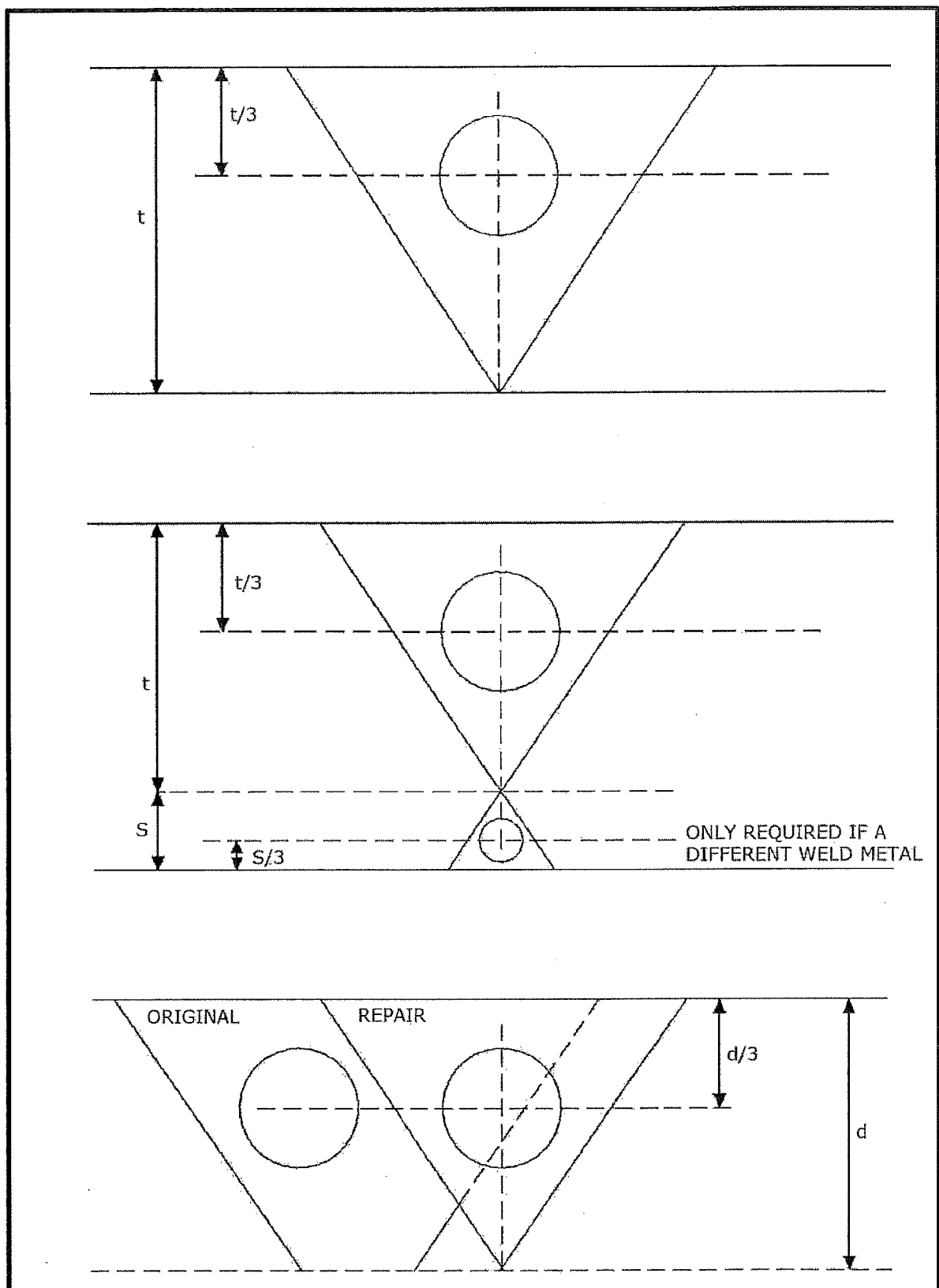


Figure 7 All weld tensile test piece locations

4.4.4.3 Macro-examination (EN ISO 17639:2013⁽⁵⁶⁾)

The macro-examination test piece shall be prepared to a 600 grit finish or better, and then etched to show the fusion boundary clearly.

The test sample shall show full penetration and shall meet the requirements of 7.5.4. If only isolated inclusions are found outside the limits of 7.5.4, two further macro sections shall be taken from the same weld and shall be shown to be free of defects. Fillet weld leg lengths shall be at least equal to the value specified.

If cracks or lack of fusion are found, the test weld shall be rejected. A new one may be made to identical parameters if the cause of the defects can be explained. If this second test weld also shows cracks or lack of fusion, the procedure has failed. The parameters shall be amended appropriately before a further test is undertaken.

4.4.4.4 Hardness survey (EN ISO 9015-1:2011⁽⁵⁷⁾)

Vickers hardness indents shall be made on the macro-section in accordance with Figure 8.

A photo-macrograph shall be produced showing the whole weld at a magnification of 1 to 3 times, illustrating the location of the hardness indents. Individual hardness figures in the weld or HAZ shall not exceed 325HV10. If any individual hardness value exceeds the limit specified, two further sections shall be taken, both of which shall meet the specified requirements.

Hardness traverses carried out to different requirements from those indicated in Figure 8 on prequalified procedures will be considered by the purchaser.

4.4.4.5 Charpy tests (EN ISO 9016:2012⁽⁵⁸⁾)

The locations from which Charpy tests shall be taken are illustrated in Figures 9 to 11. The acceptance criteria are specified in Table 4.

Transverse Charpy specimens shall normally be used for tests across the HAZ in plate, and longitudinal specimens for the HAZ in rolled sections and seamless tubulars. Under certain conditions, and when called for by the purchaser, transverse specimens may be necessary for rolled sections. Where asymmetric V and K preparations are used, HAZ samples shall be taken from the straight edge of the preparation.

If the average value of the three impact tests is less than the minimum average specified in Table 4, or if one individual value is less than 70% of the specified minimum average, three additional test pieces from the same samples shall be tested. The results shall be added to those previously obtained and a new average calculated. The new average value shall be not less than the specified minimum average. Not more than two of the individual values shall be less than the specified minimum average. Not more than one individual value shall be less than 70% of the specified minimum average.

Welding techniques which involve double-sided welding without back-gouging on the second side (punch-through) shall require additional Charpy testing: see Table 4 and Figure 11.

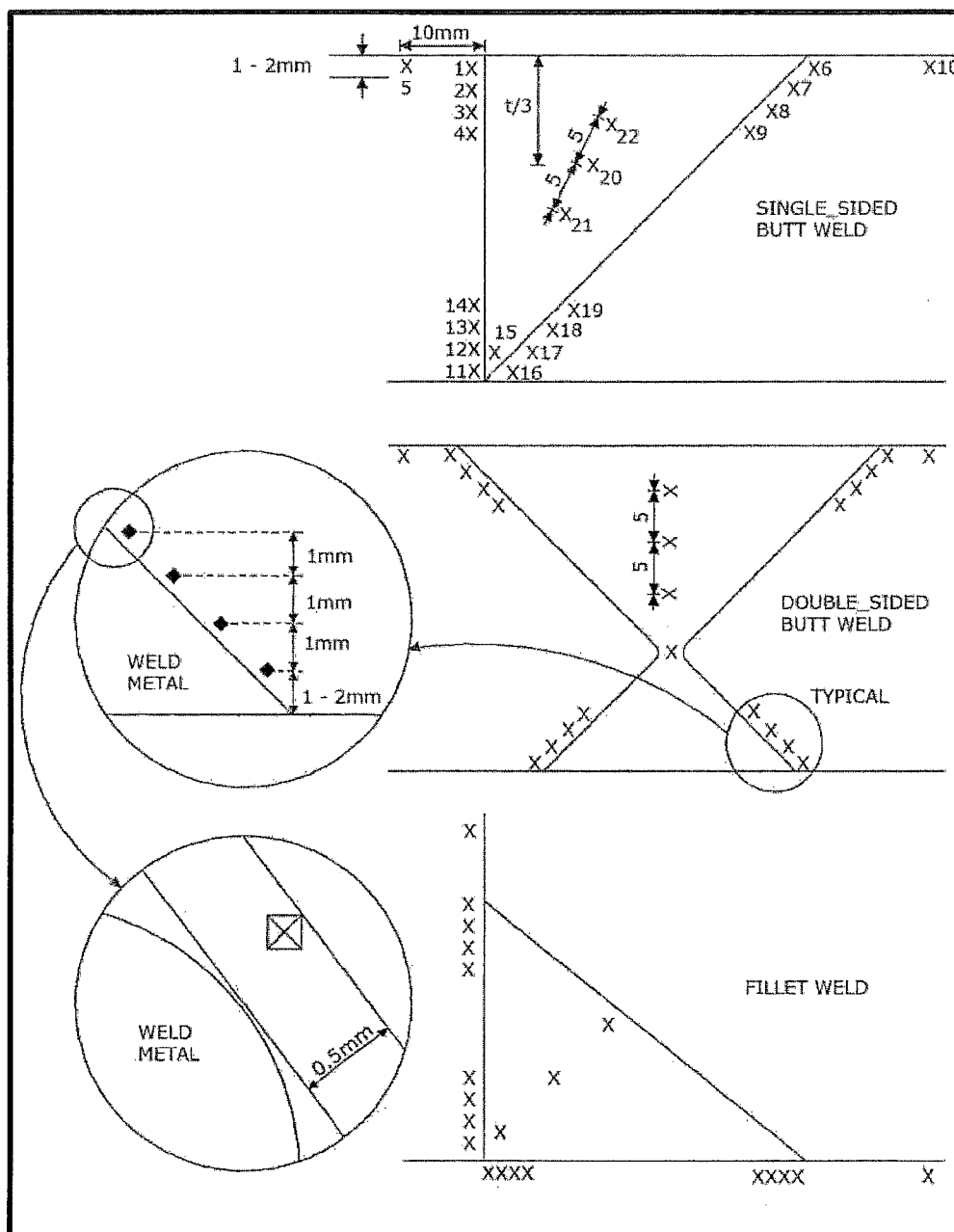


Figure 8 Locations of indents for hardness surveys

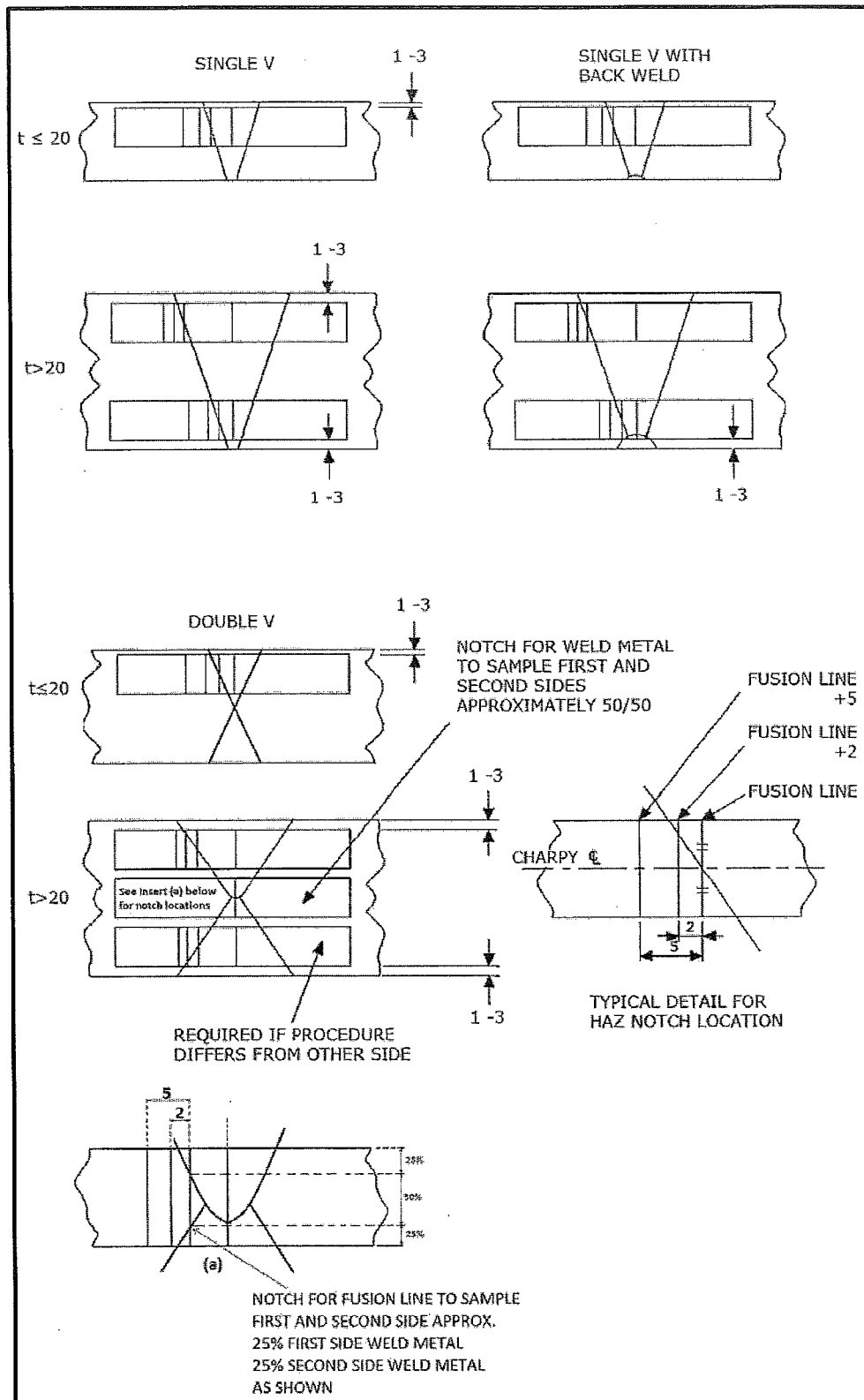


Figure 9 Locations and notch positions for weld metal/HAZ Charpy specimens

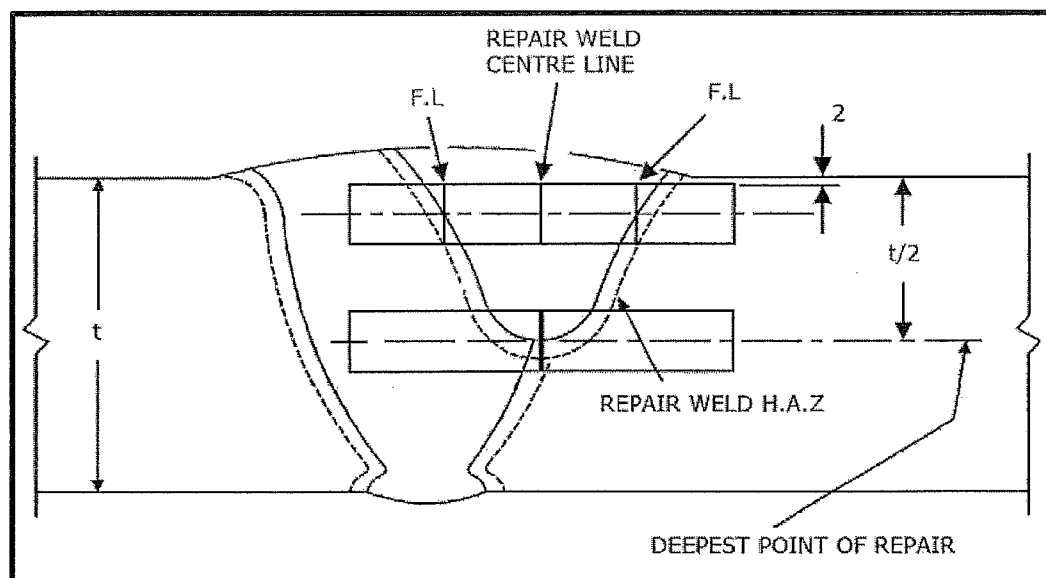


Figure 10 Charpy specimen locations for weld repairs

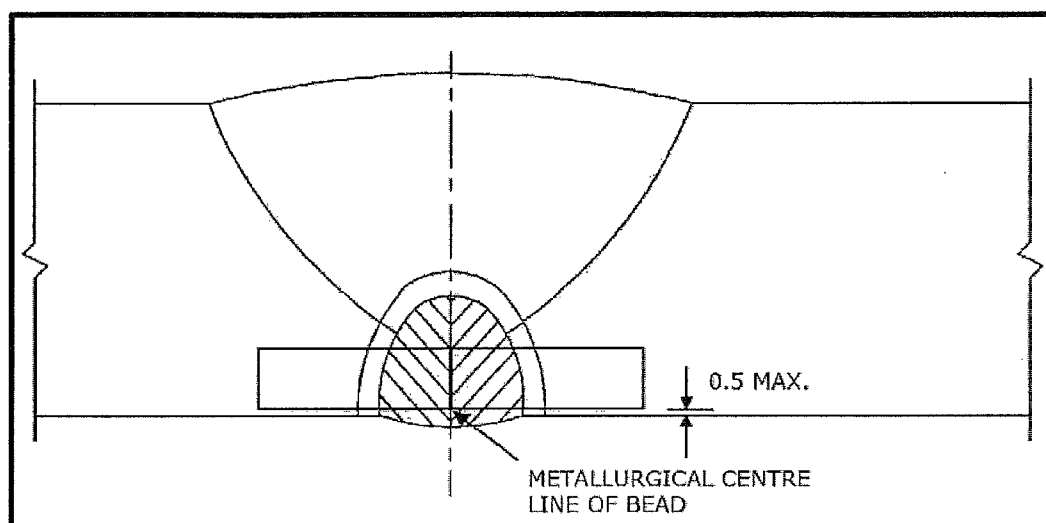


Figure 11 Location of Charpy specimens in punch-through weld

Table 4 Weld metal and HAZ Charpy test requirements

Maximum Thickness (mm)	Specimen Location ^(g)		Test Temperatures (°C) ^(a, b)	
	Weld Metal	HAZ ^(c) (FL, FL+2mm and FL+5mm positions)	As Welded	PWHT
t ≤ 20	Sub surface ^(d)	Sub surface ^(d)	-20	-20
20 < t ≤ 100	Sub surface ^(d) + root ^{(d)(f)}	Sub surface ^{(d)(e)}	-40	-30
t > 100	To be agreed with the purchaser			

Notes

(a) Test temperatures given are based on a minimum design of -10°C. This temperature is appropriate for the UK continental shelf, but may need to be revised (as advised by the purchaser) if structures for other offshore regions are constructed to this Specification

(b) The minimum Charpy energy values to be obtained at the relevant test temperature for the three grades of steel listed in EN 10225:2009 are as follows:

Grade	Average of three	Individual
335	36 Joules	27 Joules
420	42 Joules	32 Joules
460	46 Joules	35 Joules

Where dissimilar strength grades of steel are joined, the weld metal Charpy impact requirements shall meet the minimum values specified for the higher strength steel.

(c) HAZ Charpy specimen locations are shown in Figure 9.

(d) 1 to 3mm from upper or lower surfaces as indicated in Figure 9.

(e) If welds are single-sided, with or without back welding, or the welding procedures for each side of a double-sided weld differ, HAZ Charpy specimens are required from both sub-surface locations (Figure 9).

(f) Additional weld metal specimens shall be taken from the root area if the weld is single sided, or from the inter-fusion zone region if the weld is double sided or back welded from the second side (Figure 9).

(g) Specimens shall be extracted with their upper (or lower) surfaces parallel to the surface of the test piece and shall be notched through the specimen thickness. In the case of butt welds between dissimilar grades, the HAZ of both materials shall be tested.

4.4.4.6 Weld metal CTOD tests¹

Weld metal CTOD tests shall be carried out on test welds made in the as-welded condition, using the parameters from each WPS or SWIS to be approved, in the welding position that requires the smallest number of runs to bring the weld flush with the plate surface. The tests shall be performed on the greatest plate thickness to be welded by the WPS or SWIS to be qualified. If the SWIS concept is not adopted, CTOD tests shall be required from a plate of the greatest

¹ The latest revision of BS 7910:2013⁽⁵⁹⁾ is expected to remove the fracture assessment route using CTOD as the measure of fracture toughness, but will provide a normative method of converting CTOD values to the J-integral measure of toughness. Hence the use of CTOD to measure fracture toughness has been retained in this revision of EEMUA 158.

thickness to be welded without changes to the essential variables of Sections 4.5.3, 4.5.4 and 4.5.5.

Separate tests are required to qualify single- and double-sided weld preparations, except that a double-sided weld may be considered to qualify both, where appropriate to the work.

An all weld metal tensile test specimen shall be removed from the weld used for the weld metal CTOD tests, and tested to provide the yield stress value to be used in calculating CTOD.

Weld metal CTOD testing shall be carried out in accordance with EN ISO 15653:2010⁽⁶⁰⁾ using preferred geometry specimens as for example in Figure 12.

Surface notched subsidiary geometry specimens (Figure 12) shall be used for repair weld tests unless the repair weld consumable has been qualified by CTOD testing of a full penetration butt weld made using the same welding parameters in the same position.

Local compression from both sides of the specimen up to 0.5% is permitted if the test laboratory considers that it will improve the fatigue crack shape. Tests shall be made preferably within 21 days of the completion of welding. The testing machine shall be operated in displacement control mode.

The first critical event on the load/clip gauge trace shall be reported (i.e. either delta-c, delta-u or delta-m). If the temperature deviates by more than 2°C from the nominal value before this occurs, the test shall be abandoned. The value achieved when the temperature exceeded this tolerance shall be reported.

CTOD requirements are a function of design philosophy, and when required both test temperatures and acceptance levels shall be specified by the purchaser. Weld metal CTOD retests shall be allowed if one valid specimen fails to meet the specified value. For acceptance, a minimum of five valid results shall then meet the specified value. All traces, whether 'pass' or 'fail', shall be submitted with the PQR together with photographs of the fracture faces. The actual fracture faces shall also be made available for inspection by the purchaser.

In tests where a 'pop-in' occurs, but is followed by attainment of maximum load, an evaluation shall be made in accordance with EN ISO 15653:2010.

'Pop-ins' giving both force drops and displacement increases of less than 1% may be ignored. All other 'pop-ins' shall be considered significant unless ascertained otherwise by post-test sectioning.

HAZ testing in accordance with Appendix A shall be required when specified by the purchaser.

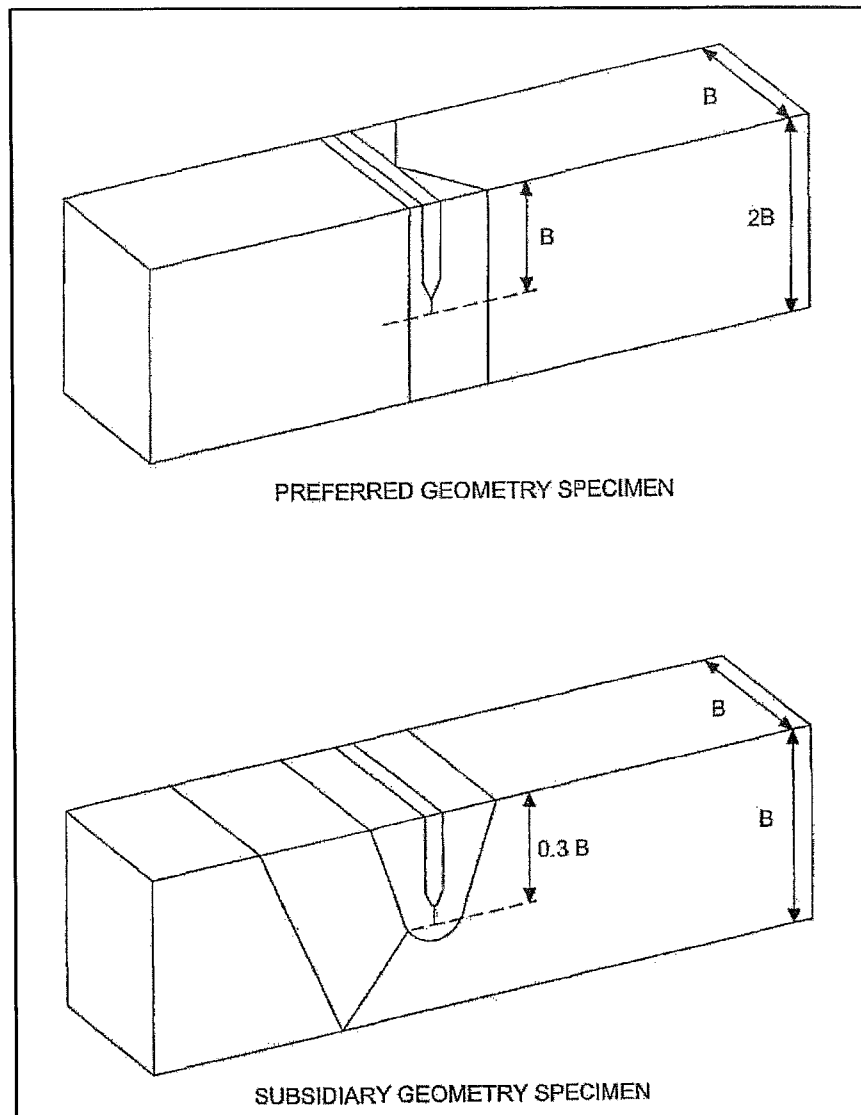


Figure 12 CTOD test piece geometries and notch locations

4.4.5 Failed procedures

If any procedure fails to meet the specified requirements, even after any permitted retests, it shall be rejected. The contractor/sub-contractor shall identify the problem and submit a revised WPS for the specific application. If the cause of the failure is directly associated with the variables specified in the WPS, approval may be withdrawn for other procedures related to the same WPS.

4.5 Essential variables

An approved WPS (or SWIS) is valid for welds that differ from the one tested, if the difference does not infringe the limits and conditions of the 'essential variables', as set out in Sections 4.5.1 to 4.5.5 below. In each of the following cases a new qualification test shall be necessary, and a revised WPS (or SWIS) may be required for approval.

4.5.1 Materials related variables

- If the base material manufacturing/heat treatment process, is changed (e.g. from normalised to Q&T, normalised to Thermo-Mechanical Controlled Rolled (TMCR) or from Q&T to TMCR);

Note: At the option of the purchaser, this may be by verification testing of a selected number of welding procedures.

- If the base material SMYS is increased;
- If the CE_{IIW} of the base material (by product analysis) is more than 0.03% above that of the material qualified;
- If the Pcm of the base material (by product analysis) is more than 0.02% above that of the material qualified;
- If the diameter of the tubular is below 508mm and not within $\pm 50\%$ of the diameter qualified;
- If the diameter of the tubular is 508mm or larger and the diameter qualified was below 324mm;
- If flame-cut weld bevels are not ground to bright metal;
- If a protective finish applied to the weld bevel is changed.
- Welding of non-primary attachments to primary steel is qualified by a primary to primary steel weld provided that all of the essential variables remain unaltered, i.e. items (a), (b) and (e) above do not apply.

4.5.2 Weld geometry related variables

- If the nominal throat thickness of the butt weld is less than half of that qualified;
- If the nominal throat thickness of the butt weld is increased over that qualified where CTOD testing is specified;
- If the nominal throat thickness of the butt weld exceeds 1.5 times that qualified for welds which do not require CTOD testing;
- If the nominal throat thickness of the butt weld would require more stringent mechanical testing (e.g. lower Charpy test temperature) than that already required, or would require either CTOD testing or PWHT;
- If the weld heat input departs from the range qualified by the two positions which represent the highest and lowest heat inputs;
- If the shape of the weld preparation changes, except that: a single bevel qualifies a single V; K qualifies X; and 2:1 and 1:1 preparations qualify each other and all intermediate geometries;

- If the included angle of the groove is less than the value tested and qualified by the WPS. Acute angles in stub to barrel welds, where the included angle is less than 45°, are qualified by the test in 4.4.2.3(b);
- For single-sided welds: if the root face is more than 0.5mm above or 1.5mm below that qualified, or if the root gap is more than 3.0mm above or 0.5mm below that qualified;
- For double-sided welds: if the root face is more than 2mm above or below that qualified or if the root gap exceeds 6mm;
- For fillet welds, any increase in root gap. However, for multipass fillet welds any root gap shall be compensated for by a corresponding increase in fillet leg length up to a maximum of 6mm. For single-pass fillet welds the root gap shall be limited to 3mm maximum, and the weld leg length shall be increased by the same amount;
- If the joint misalignment on tubulars and skid beams exceeds the following:
 - for double-sided joints: the smaller of 6mm or 10% of the joint thickness, except that a 2mm misalignment is permitted regardless of thickness
 - for single-sided joints: the smaller of 3mm or 10% of the joint thickness, except that a 2mm misalignment is permitted regardless of thickness;
- If the joint misalignment on sections other than those in (k) exceeds the smaller of 5mm or 12% of the joint thickness, except that a 2mm misalignment is permitted regardless of thickness; and/or
- If there is any addition or deletion of backing strips.

4.5.3 Consumables and equipment variables

- If the power supply to any electrode (i.e. ac, dc+, dc-) is changed;
- If the number of SAW wires used for any pass is changed;
- If the wire diameter used for SAW or any semi-automatic pass is changed;
- If the core diameter of a SMAW electrode is increased to one which did not make at least 25% of the passes in the qualifying weld;
- If the core diameter of a SMAW electrode used for the capping passes is reduced;
- If the classification or nominal composition of any wire, electrode, flux, or gas is changed;
- If a welding consumable is used for a fillet weld of throat thickness greater than the thickness of the butt weld by which it was qualified; and/or

- If any changes are made to pulsed power welding parameters.

4.5.4 Procedural variables

- If the welding process used for any part of the weld (i.e. root, second pass, fill or cap) is changed;
- If the difference between the preheat of the qualification weld and that required by 5.3.3 is not maintained;
- If grinding between passes is omitted or if back-gouging is omitted;
- If the depth of back-gouging/grinding is reduced;
- If the depth of back-gouging/grinding is increased to more than 10mm;
- If the back welding used in qualification is omitted;
- If the first side to be welded in an unequal double-sided preparation (or one using different consumables on either side) is changed;
- If PWHT is added or omitted;
- If the total PWHT soak time (initial plus any repeat) is increased by more than 25% of that qualified;
- If there is any change in joint restraint from free rotation to restrained or vice versa; and/or
- If temper bead was permitted and is deleted.

4.5.5 Welding parameter variables

The following variations apply to the mean parameters measured during procedure qualification:

- If the travel speed for any SAW or semi-automatic weld pass is changed by more than 10%;
- For SMAW, if mean ROL for any electrode size is changed by more than 10%;
- *Note: Where the ROLs in two positions are different, qualification in both positions qualifies all intermediate ROLs.*
- If the bead width for any SMAW electrode, or semi-automatic wire diameter is increased beyond the maximum specified in the WPS;
- If the mean voltage for any semi-automatic weld pass is changed by more than 5%;
- If the measured current for any SMAW electrode diameter is changed by more than 20%;

- If any change in current, voltage or travel speed/run-out length results in the heat input differing from that of the qualifying welding procedure by more than 10%;

Note: Where the heat inputs in two positions are different, qualification in both positions qualifies all intermediate heat inputs.

- If the wire feed speed or current setting for any SAW or semi-automatic weld pass is changed by more than 5%;
- If the shielding gas flow rate for any gas-shielded process is changed by more than 10%;
- If the contact tip to work piece distance for any SAW pass is changed by more than 5mm;
- If the separation of tandem SAW arcs, transverse or longitudinal, is changed by more than 10%; and/or
- If the feeding direction of a SAW wire is changed by more than 5° transverse or 3° longitudinal to the weld.

4.6 Qualification of welding personnel

4.6.1 General requirements

The following requirements shall apply to the qualification of welders and welding operators:

- Qualification shall be in accordance with an approved code, e.g. EN ISO 9606-1:2013⁽⁶¹⁾ except as modified below;
- The qualification test shall be welded in accordance with the parameters of a welding procedure approved by the purchaser;
- The inability of a welder or welding operator to follow the welding procedure shall be cause for rejection;
- The base material used for qualification shall be carbon steel; and
- Welders and welding operators shall not be qualified on production welds except with the specific approval of the purchaser.

4.6.2 Existing qualifications

The purchaser will accept existing qualifications in accordance with the above, subject to the following:

- The test shall have been performed by the welder/welding operator either while working for the same (present) contractor or sub-contractor or while working for one who participates with the present contractor or sub-contractor in a formal scheme for mutual recognition of qualifications. Any break in employment with that contractor or sub-contractor since qualification shall not have exceeded six months;

- The test certificate shall be an original, endorsed on a 2 yearly basis by an independent 3rd party witness acceptable to the purchaser;
- If the test was welded more than 6 months previously, the certificate shall have been re-endorsed by the contractor/sub-contractor at intervals not exceeding 6 months to indicate that the welder has continuously used the process in production welding with satisfactory results;
- At the request of the purchaser the contractor/sub-contractor or 3rd party shall produce fabrication and NDT records to demonstrate the above continuity to the satisfaction of the purchaser; and
- The test shall have been welded using welding consumables with the same classification and electrical characteristics as will be used in production.

Failure to meet any of the requirements above requires requalification.

4.6.3 Categories of qualification and testing requirements

In addition to the requirements of the applicable code the following shall also apply:

- Testing of GMAW butt welds;

GMAW butt welds shall be subject to both radiography and bend testing;

- Mechanised welding;

Three levels of qualification are possible:

- (i) single wire
- (ii) tandem arc (which includes (i))
- (iii) twin wire (which includes (i)).

Narrow gap joint configurations shall not be qualified by conventional V-configurations;

- Single sided manual and semi-automatic welding.

Welders shall be qualified on a test weld configuration in accordance with Figure 13 for welding under normal shop and site conditions.

With the agreement of the purchaser welders may be qualified for fill and cap passes only.

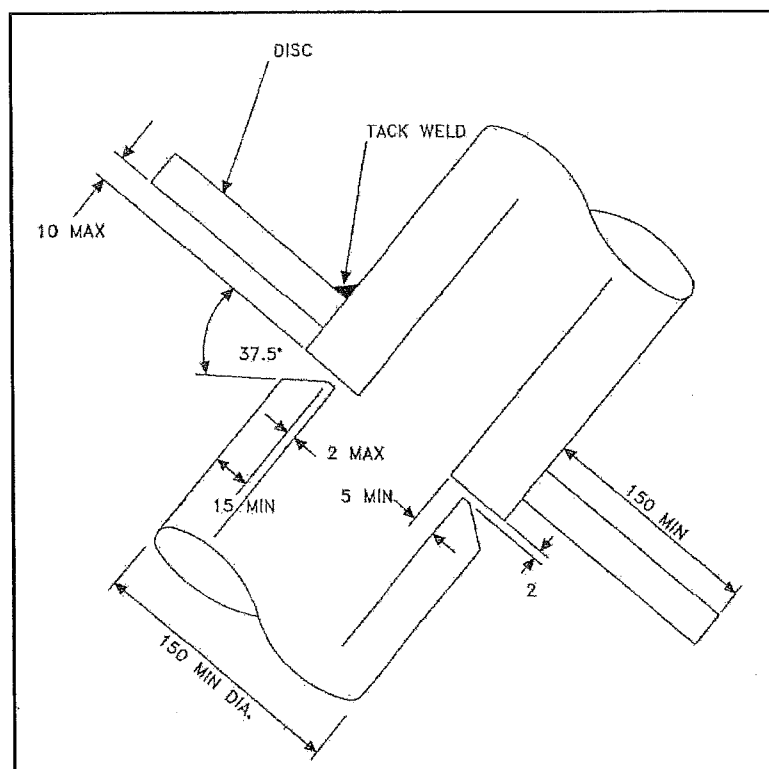


Figure 13 Welder test piece for single sided welds

In addition to the above, at the discretion of the purchaser welders for special applications, such as closure welds, wide gap or in-situ buttering may be required to further demonstrate their ability by means of the test(s) shown in Figure 14.

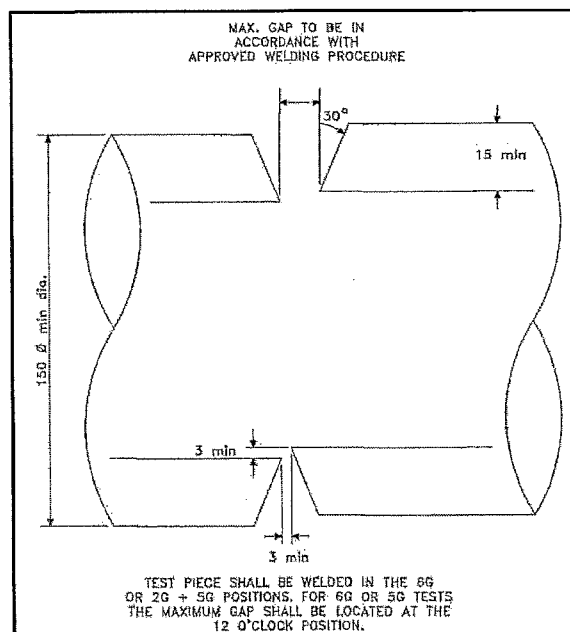


Figure 14 Welder test piece for special applications

These shall be set up in the 2G+5G or 6G positions and shall qualify all positions. Plate tests may be substituted only when approved by the purchaser. The welder shall deposit the root and second pass in each test assembly using the parameters of the relevant welding procedure. Assessment shall be by visual inspection only. This qualification entitles the welder to deposit the root pass and second layer in single sided welds where the root gap does not exceed 10mm. Requalification is necessary if a different welding consumable classification is used.

If a welder fails the special application test, further attempts shall only be allowed after suitable periods of further training and practice;

- Air carbon arc gouging

The requirement and test conditions for personnel to demonstrate their ability to remove metal by gouging in a controlled manner shall be agreed with the purchaser. Assessment shall be by visual inspection only;

- Tack welding

If the purchaser gives approval for the separate qualification of tack welders the criteria for qualification shall be as defined as in the applicable code.

4.6.4 Re-testing

Welders or welding operators who fail the initial test for any welding process, air carbon arc gouging or tack welding may immediately undertake one repeat test.

If the second test also fails further attempts shall only be allowed after a suitable period of additional training and practice.

4.6.5 Requalification

Welders whose period of qualification has lapsed within the provision of Section 4.6.2 shall repeat the original qualification test.

If the purchaser becomes aware of a welder whose welding is unsatisfactory and notifies the contractor/sub-contractor, the welder's qualification shall be withdrawn. The welder shall undertake supervised practice for a sufficient period of time before being allowed to retest.

4.6.6 Qualification test records

The contractor/sub-contractor shall draw up a test certificate for each welder giving details of process consumables and reference to the WPS. This shall be submitted to the independent witness for endorsement and then to the purchaser for approval. The contractor/sub-contractor shall maintain a current list of welders holding purchaser approved qualifications in each Group. The list shall give name and identification number, process, consumables, and qualification expiry date, and shall be available to the purchaser for verification.

The contractor/sub-contractor shall have an acceptable system of identifying a welder.

5 Construction

5.1 General requirements

The construction work shall be undertaken in accordance with established safe practices, utilising equipment which complies with all necessary statutory requirements for testing and certification. All construction staff shall be suitably qualified for the work they are to undertake. Certain construction staff (e.g. welders) shall be qualified in accordance with the requirements of this Specification.

Fabrication, assembly and erection shall be in accordance with purchaser approved drawings and procedures.

Welding and assembly sequences and temporary support arrangements shall be designed to minimise distortion and the level of residual stresses in the structure.

The contractor/sub-contractors supervisory and inspection personnel shall be available on site at all times when fabrication, assembly and erection is taking place.

5.2 Preparation and assembly

5.2.1 Handling procedures

Handling of tubulars and components should be by slings. Soft-faced hooks in contact with tubulars may be accepted for lifting but chains are not acceptable for any item. Where the contractor or sub-contractor wishes to use temporary lifting lugs, calculations shall be submitted to the purchaser for approval in advance.

Items containing incomplete welds shall be supported or suitably slung during lifting (see also Section 5.3.6).

5.2.2 Efficient use of free issue materials

Components shall always be fabricated from the largest plates available, consistent with design requirements, in order to minimise the amount of welding.

To minimise wastage of materials, cutting plans shall be submitted to the purchaser for agreement.

Offcuts exceeding 1m² shall have their material type marking retained and shall be used in the most efficient manner for the preparation of secondary items such as doubler plates and other attachments to the structure.

Scrap materials shall be disposed of in accordance with contract requirements.

5.2.3 Spacing of seams and splices

Splices shall be fabricated using full penetration welds and subject to the following restrictions (dimensions are weld toe to weld toe):

- a) All cans in a tubular shall be at least 1m long;

- b) All cans for piles shall be at least 1m long;
- c) When cans are circumferentially welded together any longitudinal seams shall be offset by a minimum of 90°;
- d) Node barrel cans should be at least 2.5m long to ensure adequate separation between welds. Restrictions on circumferential weld locations are shown in Figure 15;

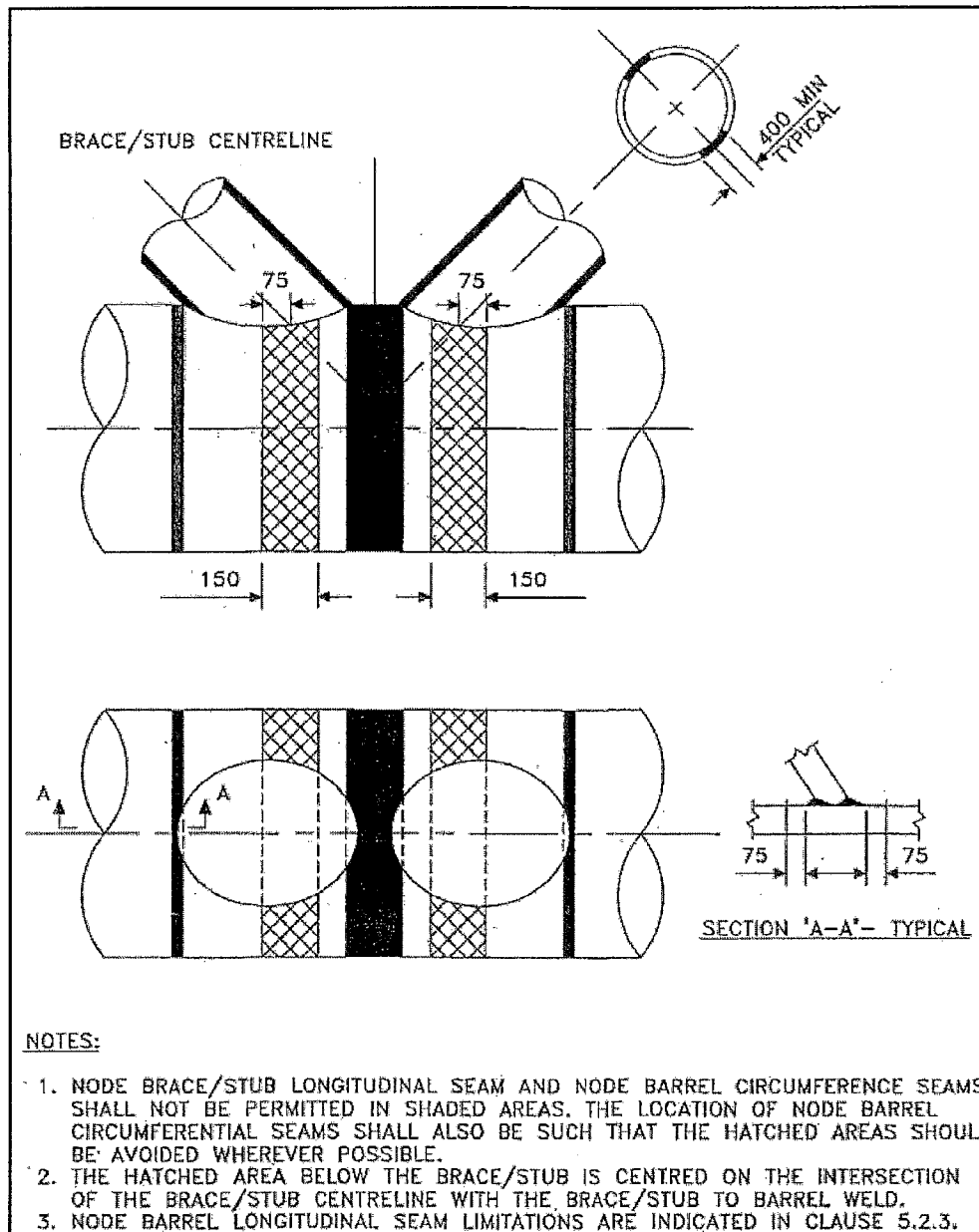


Figure 15 Prohibited areas for node barrel and stub welds

- e) Circumferential welds are not permitted within cones and node stubs, unless approved by the purchaser or specified on the purchaser approved drawings;
- f) Node stubs shall be at least 600mm long and the whole of the brace-stub weld shall be at least 500mm from the node barrel;
- g) Splices in plate girders and sections shall not be less than 1m apart and shall be limited to a maximum of one per 6m length;
- h) Staggered splices shall be used;
- i) All splices, except those in ring stiffeners, shall be made before assembly;
- j) The locations of all splices shall be shown on as-built purchaser approved drawings;
- k) Longitudinal stiffeners shall be at least 150mm from longitudinal seams;
- l) Ring stiffeners shall be at least 100mm from circumferential seams, but where this is not possible the toes of the ring stiffener welds shall not be coincident with either toe of the circumferential seam weld;
- m) Node stubs shall be at least 75mm from longitudinal seams (as shown in Figure 15) except that, where this is not possible, the stub shall overlap the longitudinal seam. In such a case the longitudinal weld shall be ground flush at all points within 100mm of the proposed attachment weld and subjected to MPI and UT;
- n) Temporary attachments and permanent non-structural attachments to the primary structure shall be at least 75mm from any other weld; and
- o) Where splices are used in beams they shall not be within $\frac{L}{8}$ of the supports (where L is the distance between supports) or in the central $\frac{L}{4}$. However the $\frac{L}{4}$ restriction may be ignored provided such joints are treated as required by Table 4 for Category I welded joints. Where the beam is cantilevered, any splice shall be closer to the free end than to the support.

5.2.4 Design of welded connections

Except as noted on the purchaser approved drawings, all butt welds shall be continuous, full penetration and double-sided. Single-sided butt welds will normally be specified only for tubulars of less than 600mm internal diameter. Fillet welds shall not have a leg length less than 6mm. When intermittent welding is specified, a sealing fillet is required in all other areas.

Where point-to-point construction is employed, consideration shall be given to the possible effects of this method of construction on root quality.

Consideration shall also be given to the practicality of performing NDT in the root region of such joints, together with appropriate acceptance criteria.

Where the use of an asymmetric single bevel or K preparation is proposed, consideration shall be given to access for effective ultrasonic testing.

5.2.5 Forming and straightening

All rolling, straightening and other forming processes shall be subject to purchaser approval and shall include details of NDT. In the case of forming to a diameter to thickness ratio less than 20:1, or where local strain exceeds 5%, mechanical tests will be required to demonstrate that the steel retains the properties required by the purchase specification. Post-forming heat treatments, or hot forming, may be necessary to ensure this.

When post-forming heat treatment or hot forming is proposed, full details of heating and cooling rates, soaking temperatures and times, and forming temperature ranges will be required for purchaser approval.

The forming of T-sections into flanged ring stiffeners of any diameter will require mechanical tests (to demonstrate that the properties required by the purchase specification are maintained after trial forming) to justify acceptance, regardless of the proposed diameter.

Acceptance of wedges or other techniques to assist rolling will be subject to the visual acceptability of the product and to acceptable mechanical test results from regions of maximum strain.

Any materials which require straightening before use, in order to achieve the specified tolerances, may be cold straightened if the strain will not exceed 5%.

If hot straightening is proposed, the temperature shall not exceed 500°C unless otherwise approved by the purchaser. These limits also apply to re-rolling of cans after welding to restore shape to within tolerance limits.

5.2.6 Edge preparation

Prior to cutting individual pieces shall be marked with their unique identification (see Section 3.5.2).

Materials shall be prepared by machining, or by flame cutting followed by grinding to bright metal. If the contractor or sub-contractor successfully qualifies all welding procedures using materials which have not been ground after flame cutting, the purchaser may consider relaxing this requirement for edges to be welded.

Surfaces to be welded shall be visually examined to ensure freedom from laminations, cracks, slag inclusions and cutting notches. Any such defects observed shall be dressed out by grinding. If the depth of excavation exceeds 5mm, a weld repair shall be made using a purchaser approved WPS. The surface of the steel within 75mm of the proposed weld shall be dry, clean and free from loose scale or paint (except that the use of a protective primer may be qualified by use in all welding procedure qualification tests).

Flame cut edges, which are not subsequently welded, shall be ground smooth to remove nicks and burrs. The use of flame gouging or 'washing' is not permitted.

5.2.7 Alignment and fit-up of welded joints

For any through member whose thickness exceeds 25mm, the portion which will lie under, or within 50mm of, a T-butt weld (or a fillet weld with leg length exceeding 20mm) shall be examined by UT in accordance with EN 10160:1999⁽⁶²⁾. Acceptance criteria should be agreed between the purchaser and the contractor/sub-contractor. If this examination detects laminations or other reflectors which will interfere with examination of the weld, and the member cannot be repositioned to avoid them, then remedial action shall be agreed with the purchaser. Where low sulphur steels with guaranteed Z-direction properties are used, this examination is not required.

Weld preparation tolerances shall comply with, and misalignment at butt welds shall not exceed, the values given in 4.5.2.

Single-sided closure butt weld root gaps of 12mm maximum up to 150mm in length are permitted even if this exceeds the tolerance on the basic welding procedure.

Components should be trial fitted before welding.

Where root gaps are out of tolerance, the joint shall be dismantled to permit local grinding, or buttering followed by grinding, back to the required profile. The depth of buttering on any member shall not exceed 15mm. Alternatively, the requirements of 4.4.2.3.3 and 4.6.3 (third bullet point) may be applied.

In exceptional circumstances, and with the agreement of the purchaser, in-situ grinding or buttering of the weld preparation may be permitted in order to deal with localised wide gaps.

In this case a joint as depicted in Figure 4 shall be prepared such that an agreed wide gap exists between 6 and 9 o'clock. The remainder of the joint shall exhibit the normal root gap. Working to a purchaser agreed method statement a welder shall satisfactorily close the wide gap and complete six external passes all around the joint. The joint shall be fully welded at 12 and 3 o'clock (300mm min length) and 6-9 o'clock location. The full weld length at each of these locations shall be subject to NDT and further tested by macro examination, hardness and Charpy tests against the requirements of this Specification. For the 6-9 o'clock segment the macro examination, hardness and Charpy tests shall be taken at the 7.30 location.

If this test is successful the purchaser agreed method statement may be applied to wide gaps on a purchaser agreed case by case basis.

Welders working to the agreed method statement shall have successfully completed the wide gap test depicted in Figure 14.

Where butt welds are to be made between members of different thicknesses, a transition using a taper of 1:4 shall be provided. This taper may be wholly or partially within the width of the weld. When necessary, the thicker member shall be tapered.

Fit-up using clamps or other fabrication aids may be used where appropriate. When tack welds are necessary they shall be at least 50mm long and shall consist of at least two passes of sufficient cross sectional area to resist restraint cracking. The preheat shall not be less than for welding the joint. Tack welds which are to form part of the completed joint are permitted for double-sided welds provided they are feathered at both ends. For single-sided welds, mild steel bars temporarily welded to the fusion face of the bevel are preferred so that the root pass can be deposited with minimum interference. When agreed with the purchaser, root tacks which are to remain in the joint may be permitted in single-sided welds if the ends are feathered.

When agreed with the purchaser, tacking may be performed by fitters/platers qualified in accordance with AWS D 1.1M:2010 provided that such tacks in single-sided butt or fillet welds are not incorporated into the finished weld.

5.2.8 Rat-holes, penetrations and cut-outs

Rat-holes penetrations and other cut-outs shall be avoided wherever possible. Where considered essential, and their use is approved by the purchaser the following shall apply:

- Permanent rat-holes shall be cut by automatic processes, and ground smooth with radiused edges unless otherwise agreed by the purchaser. Permanent rat-holes shall have a radius of 50mm or twice the plate thickness whichever is the greater. Where rat-holes of these dimensions would jeopardise structural integrity, the Purchaser may require them to be less than 50mm radius. Fillet welds shall be continued through the rat hole.
- Temporary rat-holes (those approved subject to their being reinstated or sealed) shall have a radius not less than twice the plate thickness and shall be reinstated to a purchaser approved procedure. Filling with weld metal is not permitted; and
- The radius of any approved cut-outs other than rat-holes shall not be less than 100mm. Where necessary, the area shall be checked by UT before cutting to ensure that no cut is made within 300mm of internal stiffeners. The original plate shall be clearly marked and shall be welded back into the cut-out, unless other proposals are approved by the purchaser.

5.3 Control of production welding

5.3.1 Welding environment

Welding shall be performed in conditions which permit satisfactory welding and adequate inspection. Whenever possible, welds should be made in fabrication shops with outdoor welding being restricted to final erection or to sub-assemblies which are too large or heavy to be welded elsewhere. No fabrication shall always be undertaken in fabrication shops. Outdoor welding shall be protected from the effects of adverse weather by the use of temporary shelters. Closure joints shall not be welded if there is water trapped in the members to be joined.

5.3.2 Welding consumables and equipment

Storage and handling procedures for welding consumables shall be in accordance with manufacturer's recommendations. The contractor/sub-contractor's written storage and handling procedures shall specifically deal with the measures required to control consumable moisture levels, e.g. drying and recycling of SAW flux and exposure times for vacuum packed SMAW electrodes.

Only purchaser approved storage and handling procedures shall be used in production.

All welding consumables shall be clearly labelled, on the packet or drum, with the names of manufacturer and product and the batch number.

The brand name of the product shall also appear on each reel of SAW and semi-automatic wire, and the brand name or other unique identification shall be printed on every SMAW electrode. Each GTAW wire shall be similarly identified by stamping or engraving adjacent to each end.

Welding equipment shall be maintained in good working order, and earth connections to the work piece shall make good electrical contact.

Regular calibration checks shall be carried out on all equipment in accordance with a purchaser approved procedure.

5.3.3 Preheat and interpass temperature requirements

The contractor/sub-contractors method of establishing the minimum permissible preheat/interpass temperature for the avoidance of fabrication hydrogen cracking (HAZ and weld metal cracking) shall be agreed by the purchaser.

Guidance on the determination of preheat/interpass temperatures is provided by EN 1011-2:2001⁽⁶³⁾ Annex C.

When EN 1011-2:2001 Annex C, Method A is used the particular diagram employed for reference shall be established by using the maximum permitted CE_{IIW} value for the steel to be welded, together with the maximum weld metal hydrogen level guaranteed by the consumable manufacturer.

Having identified the relevant diagram, the minimum calculated heat input for any pass to be welded will give the minimum permissible preheat and interpass temperature for any given combined thickness of material.

However, it should be noted that modern structural steels readily satisfy the criteria for more stringent preheat requirements detailed in EN 1011-2 paragraph C.2.9, and extreme caution needs to be applied in the use of method A.

When EN 1011-2:2001 Annex C, Method B is used (preferred), the contractor/sub-contractor shall propose the method of application to the range of steels to be welded in production.

When establishing minimum preheat/interpass temperatures due regard shall also be paid to the influence of atmospheric absolute moisture content on weld metal hydrogen levels. For example, under tropical and sub-tropical climate conditions

atmospheric absolute moisture levels vary substantially between winter and summer months with the consequence that weld metal hydrogen levels may double from season to season making it impossible to achieve low hydrogen welding ($< 5\text{ml H}_2/100\text{g}$ of weld metal) in the summer. Therefore, higher preheat/interpass temperatures may need to be qualified.

High strength steels, i.e. S460 and greater (S690 grades may be used in drill rig structures), require careful control of the overall weld thermal cycle and the use of slow cooling under insulation on completion of welding or a specific post weld hydrogen release heat treatment may be necessary to avoid fabrication hydrogen cracking.

Irrespective of the method of establishing preheat/interpass temperatures the following additional restrictions shall apply:

- a minimum preheat of 150°C for SAW with any material above 100mm thick;
- a minimum preheat of 100°C for SAW with any material above 40mm thick.
- a minimum preheat of 100°C for welding any temporary attachment.

For multipass fillet welds in which the root gap exceeds 2mm, the preheat shall be raised 50°C above that qualified. The same requirement applies for all repair welds using the same procedure as the original weld up to a maximum of 150°C .

If the actual preheat used in the procedure test exceeds the figure derived above, the same margin shall be applied to calculated preheats for all other combined thicknesses encountered in fabrication.

The whole length of the joint to be welded, and 75mm on each side, shall be preheated to the required temperature. Preheat shall be applied by electric resistance heating elements held in place by magnets. Fixed gas burners or radiant heating panels shall only be used with the agreement of the purchaser. Hand held oxy-propane torches shall only be used for welds shorter than 300mm. In all cases the contractor/sub-contractor shall demonstrate that the design, placement and control of the proposed preheating method ensure uniform temperature distribution over the weld preparation to be preheated.

The contractor/sub-contractor shall verify that the correct preheat has been attained before a tack weld or the first pass is deposited. Welders shall be issued with appropriate temperature indicating crayons and shall use them to ensure that the weld area lies between minimum and maximum inter-pass temperatures before depositing each pass. The minimum inter-pass temperature shall not be less than the preheat temperature and inter-pass temperature shall be measured either in, or, immediately adjacent to the weld bevel.

Where possible, preheat should be applied and checked on opposite sides of the member. Where this is not possible, a soak time of 2 minutes per 25mm shall be employed. In addition, when hand-held oxy-propane torches are in use, the flame shall be removed from the surface for 60 seconds before the preheat temperature is checked.

5.3.4 Temporary and non-structural attachments, ancillaries and miscellaneous steelwork

This category includes both permanent attachments such as doubler plates, and temporary attachments such as strong-backs and lifting eyes. Temporary attachments are, in general, not shown on the purchaser approved drawings.

Where attachments are required on items which will receive PWHT, they shall be welded on before heat treatment. Doubler plates shall incorporate vent holes irrespective of whether or not PWHT will be carried out.

Temporary attachments made directly to primary structure shall be removed.

Removal may be by flame cutting or gouging at least 3mm from the base metal surface, then grinding flush and inspecting by wet MPI. It is permissible to grind up to 1mm into the base metal surface to remove any undercut associated with the attachment weld. If there is damage to the primary structure as a result of flame cutting or gouging, it shall be rectified by grinding followed by repair welding, and subsequently the flame cutting/gouging position shall be changed to 6mm from the base metal surface.

5.3.5 Weld execution

Welding shall be undertaken by welders who are approved in accordance with this Specification, using a purchaser approved WPS. Each welder shall be issued with, or have ready access to, a copy of the approved SWIS or WPS relating to the joint to be welded, and with temperature-indicating crayons appropriate to the preheat and interpass temperatures.

When the contractor/sub-contractor has verified that fit-up and preheat are within permitted ranges, welding may begin. Any unacceptable tack welds shall be ground out and re-welded. Each pass shall be de-slugged and cleaned up, but peening is not permitted. The arc shall be struck only on existing weld metal or on to the fusion faces of the preparation. Back-gouging followed by grinding shall be done in accordance with a purchaser approved procedure to produce an acceptable profile for further weld deposition.

Welders depositing the root pass in single-sided welds, or the cap passes in any weld, shall paint-mark their number beside the length of weld they have made. Other welders working on each joint shall be recorded by the contractor/sub-contractor for possible future reference. Apart from minor cosmetic grinding, the cap shall not be dressed unless specified by the purchaser.

The contractor/sub-contractor shall make single-sided closure welds available for fit-up inspection by the purchaser. If this and the preheat are satisfactory, welding may begin. The root and first fill passes shall be deposited, leaving two diametrically opposite windows (at positions to be agreed with the purchaser) to permit visual inspection. Preheat shall be maintained during this inspection. If it is agreed that no defects can be seen, the windows shall be welded up and the joint filling continued until the weld throat reaches 15mm.

At this point the purchaser may require radiography on certain critical joints. If the radiograph is satisfactory welding shall continue to completion.

If preheat capability is lost during welding, the joint shall be lagged and allowed to cool slowly.

Any occurrence of cracking, in this or any other circumstance, shall be immediately reported to the purchaser and the use of the WPS shall be suspended. The cause of the cracking shall be investigated to the satisfaction of the purchaser. The WPS shall be revised accordingly and, if necessary, re-qualified, before welding may recommence. The SWIS shall also be revised.

5.3.6 Weld interruptions

Weld metal deposition may only be interrupted (i.e. stopped for a period greater than that necessary to de-slag, grind or change electrode/wire) under one of the following conditions:

- For closing welds: to permit internal visual inspection of the root run as required in 5.3.5. Preheating shall be maintained during this inspection, which should be completed within 2 hours;
- For welds where electrical preheating is maintained: an indefinite interruption will be permitted as soon as the root and first fill pass are complete; or
- For welds where no preheating is required, or where preheating cannot be maintained: an indefinite interruption will be permitted when the throat thickness of the partially completed weld is at least 15mm or $1/3t$ for thicknesses, t , above 45mm. With the approval of the purchaser, this restriction may be waived for assemblies where handling stresses can be shown to induce low ligament stresses. In cases where throat thickness is less than 15mm, an MPI examination shall be conducted, when power is restored, before re-establishing the correct preheat and recommencing welding. This examination may be waived by the purchaser in the case of root passes where the welding procedure involves complete re-melting of the root pass by SAW or removal of the root pass by subsequent back-gouging and/or grinding.

After any weld interruption, the pre-heat shall be re-established in accordance with Section 5.3.3 and the relevant WPS, prior to the restart of weld deposition.

5.3.7 Weld repairs

Repairs shall not normally be undertaken without the prior approval of the purchaser. However, volumetric defects such as slag and porosity may be repaired without approval subject to local agreement between the contractor/sub-contractor and the purchaser.

Defects shall be removed by machining, or by air carbon-arc gouging followed by grinding. For single-sided weld root repairs, the last 5mm shall be removed by grinding. Single pass surface weld repairs shall have a minimum length of 50mm. Other weld repairs shall not be less than 100mm in length. If repair excavations are less than 100mm apart they shall be linked into a single repair. MPI shall be used to confirm complete removal of defects.

Repair welding preheat shall be 50°C above that required by the approved welding procedure for a butt weld of the same thickness up to a maximum of 150°C.

Inspection and NDT requirements for repairs shall be identical to those originally applied to detect the defects, and shall include the weld metal and fusion faces within 100mm of the repair in all directions.

Purchaser agreed records shall be kept by the contractor/sub-contractor which detail the location of all repairs, the defect, the WPS number, the names of the original welders, dates and repair procedures.

5.3.8 Welding restrictions on PWHT items

Welding to PWHT items is prohibited except in the following instances:

- where defects are found in PWHT welds. Following the repair, the complete weld shall be subject to PWHT and the specified NDT;
- welding to existing doubler plates, or for assembly of a node into the main structure;
- attachments to PWHT items where the throat thickness of the attachment weld does not exceed 40mm for nodal joints or 50mm for other joints, and provided the toe of the weld is not less than 75mm from a PWHT weld (see 5.4.1).

5.3.9 Weld profile, surface finish and clean-up

Welds shall be of the specified size and shape unless otherwise agreed by the purchaser, and shall blend smoothly into the parent metal without overlap or unacceptable undercut. The weld profile shall not interfere with the NDT technique specified.

Grinding of the cap (except for minor cosmetic grinding) shall not be undertaken unless specified by the purchaser or required for the purposes of NDT. However, where a weld has to be crossed by another member, the cap shall be ground flush with the plate surface.

Where toe grinding is specified, the technique shall be submitted to the purchaser for approval. A burr grinder with a diameter of at least 10mm shall be used, and final grinding marks shall be transverse to the weld toe. Grinding penetration into the base metal shall not be less than 0.5mm or more than 1.5mm unless otherwise specified on the purchaser approved drawings. Rotary discs shall not be permitted for use on weld toe grinding.

The purchaser may require the contractor/sub-contractor to demonstrate the ability of individual operators to apply the technique satisfactorily.

Arc strikes, burrs and weld spatter shall be ground smooth and checked by MPI in accordance with Section 7. Flame cut ends not incorporated into a welded joint shall be ground smooth with radiused edges.

5.3.10 Production controls

The contractor/sub-contractor shall institute a system of weld checks which shall be subject to approval and audit by the purchaser. These should incorporate a permanent record of the voltage, current, travel speed or run out length, and heat input being used by the welder. The permanent record shall also include welder's or welding operator's identity, WPS number, consumable identity and size, and, the welding position.

The monitoring schedule shall provide for the random monitoring of an agreed percentage of all welders/welding operators at work in each shift where inspection category I or II welds (Table 5) are being made, but shall not be less than 10% at the commencement of the contracted work. Subject to the prior approval of the purchaser the absolute number of welders/welding operators monitored per shift may be reduced once good performance has been established. The schedule shall also ensure that the sample monitors as large as possible selection of welders/welding operators active on the identified welds over the total period of work.

Records shall be made for each monitored welder or welding operator covering a period of continuous welding. The records shall be in a format approved by the purchaser.

For SMAW within the nominal current and voltage ranges, only the ROL and electrode stub length for each pass need be recorded. For other processes, the records may be made on an automatic electronic monitor capable of capturing and printing records of voltage, current, travel speed, wire feed speed and heat input. Alternatively, by agreement with the purchaser, calibrated manual monitoring equipment may be utilised. Monitoring reports shall be submitted to the purchaser within 24 hours.

If such checks, either by the contractor/sub-contractor or the purchaser, detect welders or welding operators working outside their WPS parameter limits, the contractor/sub-contractor shall undertake an additional procedure test(s) in accordance with the actual parameters measured. If this meets the requirements of Section 4, the purchaser may permit an extension of the welding parameter limits. If the procedure test fails to meet the specified properties, any production welds made to the suspect procedure shall be identified and may be required to be removed, unless a satisfactory technical basis for concession can be established.

When the contractor/sub-contractor elect not to institute a monitoring system, production tests shall be performed on all butt welds greater than 20mm thick.

One production test weld shall be carried out for every 25 circumferential and longitudinal seams on tubulars. For items other than tubulars, the production test frequency shall be one test coupon for each 30m of weld.

Production weld test coupons shall be tested as for welding procedure qualification, but excluding CTOD test(s).

5.4 Post Weld Heat Treatment (PWHT)

5.4.1 Welds requiring PWHT

The purchaser approved drawings should specify those welds or fabricated items which are to be heat treated. Where the purchaser approved drawings give no indication, all welds with a design throat thickness exceeding 40mm on nodes and 50mm elsewhere shall be post-weld heat treated. Any dispensation from the above requirements for PWHT will be subject to CTOD testing and a full ECA of the welds under consideration. However, if a CTOD level $\geq 0.25\text{mm}$ is achieved on testing an ECA is not required unless advised otherwise by the purchaser. Welding procedure qualifications for PWHT welds shall take into account the potential need for multiple heat treatment cycles associated with repair welds.

5.4.2 PWHT procedures

The contractor/sub-contractor shall prepare detailed procedures for PWHT and submit these to the purchaser for approval. They shall include a sketch of the item to receive PWHT, illustrating the method of support and the locations of all thermocouples. In calculating the locations of supports, the contractor/sub-contractor shall assume a yield strength at soaking temperature of 35 N/mm^2 for all grades of material.

Nodes shall be heat treated in furnaces, complete with doubler plates and attachments; this method is also preferred for other fabricated items requiring PWHT. The procedures employed shall be in accordance with the relevant sections of established international standards, e.g. PD 5500:2012+A2:2013⁽⁶⁴⁾, and shall be submitted to the purchaser for approval. Unless specified otherwise, the soaking temperatures shall be $580 \pm 20^\circ\text{C}$.

The purchaser may permit local heat treatment of circumferential welds provided, again, the procedures are in accordance with established international standards.

Note 1: For Q & T steels, the purchaser is encouraged to utilise the steelmaker's data to determine the optimum PWHT temperature. As a general rule this should be at least 25°C below the tempering temperature used for the steel.

Note 2: For TMCR steels, the purchaser should be aware that PWHT may reduce the mechanical properties of the steel. The purchaser should seek the advice of the steelmaker before specifying PWHT.

Table 5 Recommended inspection/NDT categories

Inspection/ NDT Category	Application	Typical areas of application (Jackets)	Typical areas of application (Decks)
I	Highly stressed welds where alternative load paths are not available in case of failure, and welds which have relatively low fatigue lives.	All node welds. All lift points. Girth welds in legs and pile sleeves. Brace to leg, and sleeve and brace closure welds. Riser guides and supports. Girth welds in piles. All attachments to the above.	Main columns and main column nodes (except longitudinal and flange weld joints where structural redundancy exists). Lift points. Crane pedestals. Riser supports. Plate girder and flange splices where there is no structural redundancy. All attachments to the above.
II	Less highly stressed welds which have relatively high calculated fatigue lives and where adequate alternative structure load paths exist.	Some circumferential brace welds remote from nodes. Structural installation aids. Girth welds in caissons and J-tubes. Conductor guides. Internal stiffeners to legs.	Nodes (other than those specified in Category I). Some circumferential brace welds remote from nodes. Structural installation aids (excluding lift points). Vent boom flare towers. Runway beams.
III	Low stressed welds, welds in shear and welds with relatively high calculated fatigue lives.	Longitudinal welds in tubular members (including caissons, J-tubes, piles and pile sleeves). All attachments to tubular members (including doubler plates). Sea fastenings.	Longitudinal welds in tubular members and fabricated primary sections. Sea fastenings.
IV	Low stressed welds which are not subject to any significant cyclic loading.	Mudmats. Installation aids other than those in Category II.	Welds in module structures other than those in Categories I, II and III.
V	Other low criticality, very low stressed welds which are not subject to cyclic loading.	Pile grout beads. Non-structural attachments. Temporary attachments. Minor installation aids.	Non-structural attachments. Deck plates. Under-deck stringers. Walkways. Major pipe supports.

5.4.3 Certification

On completion of PWHT, the contractor/sub-contractor shall prepare a heat treatment certificate for each item. This shall give the unique identification of the item, the date, the heating and cooling rates, and soaking temperatures and times. It shall be submitted to the purchaser together with the temperature chart or digital record.

5.5 Bolted connections

5.5.1 General

Bolted connections shall comply with the requirements of 5.5.2. Holes shall not be drilled in structural members other than at locations indicated on the purchaser approved drawings, unless otherwise approved by the purchaser.

5.5.2 Bolting details

The following bulleted list details bolting requirements:

- All holes for bolted connections shall be 2mm larger in diameter than the specified bolts, unless otherwise agreed with the purchaser. Bolt holes shall be drilled to size, or drilled and reamed if necessary. Enlarging by thermal means is not permitted. Holes shall be clean cut without burrs, or torn or ragged edges. All holes shall be finished prior to the application of any protective coating;
- Bolts shall be of sufficient length to protrude by a minimum of two full threads beyond the nut. Fitted bolts shall clear the hole before the thread starts. Bolts and nuts shall rest squarely against the metal. All misalignments shall be reported to the purchaser who may allow the hole to be reamed;
- Bolt heads and nuts shall be drawn tight against the work by a method approved by the purchaser. Bolt heads shall be tapped with a hammer while the nut is being tightened;
- All high strength bolts shall be pre-tensioned to the proper proof load or specified torque;
- All bolts, with the exception of friction grip bolts, shall have a locking washer or other locking device. All bolt locking devices shall be approved by the purchaser;
- Where friction grip bolting is specified it shall be the load-indicating washer type and shall be pre-tensioned to the correct proof load. In the event of a friction grip bolt being loosened after application of proof load, the complete bolt shall be removed;
- Bolts transmitting shear shall have plain shanks and be threaded to such a length that not more than one thread shall lie within the structural members, i.e. that part of the bolt under shear shall not contain more than one thread;
- Washers shall be provided at slotted holes and elsewhere as specified by the purchaser. On galvanised steelwork, washers shall be under both the head and nut. Square taper washers shall be provided for all bolts and nuts bearing on to surfaces with tapers exceeding 3°;
- Where, for the connection of equipment or piping, holes are provided which may affect major structural items, these members shall be reinforced adequately; and

- Bolts and nuts shall not be welded under any circumstances.

5.6 Piles and followers

The surface of piles and followers shall be bare metal, free from mill varnish, oil and paint, except for specified markings. The area of the surface used for markings shall be the minimum required consistent with adequate identification.

6 Fabrication tolerances

6.1 General

The contractor/sub-contractor shall provide qualified personnel, equipment and the instruments necessary to set out, monitor and control dimensions and tolerances.

The dimensional controller shall be either a qualified surveyor or shall have had at least five years' experience of similar work. The qualifications and CV of the dimensional controller shall be available for purchaser review and approval.

The instruments used shall be in accurate adjustment and shall have current valid calibration certificates.

Prior to commencing fabrication, the contractor/sub-contractor shall submit for the purchaser's approval, procedures for control of tolerances during fabrication together with his construction method philosophy. The fabrication procedures proposed by the contractor/sub-contractor and approved by the purchaser shall stipulate the frequency of inspection of all tolerances defined in this Section, in Figures 16 to 40 of this Specification, at all the stages at which such tolerances are to be checked for each sub-assembly, and during the erection sequence.

Tolerances shall be checked at each stage in accordance with the fabrication procedures, and the final survey shall meet the defined tolerances. The final survey shall be on complete sub-assemblies and on the completed structure after PWHT, if applicable, and shall be carried out by the contractor/sub-contractor.

Where the frequency or location of tolerance measurement is not defined in this Specification, the tolerances shall be taken to apply to the whole structure.

The frequency of tolerance checks defined in this Specification may be modified for specific locations subject to conforming to the structural design requirements and agreement between the contractor/sub-contractor and the purchaser.

The contractor/sub-contractor shall work within the tolerances listed in this Specification unless otherwise specified in the purchaser approved drawings. No forcing or constraining of components shall be undertaken to obtain the required tolerance without the prior approval of the purchaser.

Tolerances shall be based on theoretical setting-out points and centre lines of the structure referenced to permanent approved datum points (e.g. co-ordinated survey stations) and corrected to a temperature of +20°C.

Permanent survey stations shall be protected from disturbance, and a means for confirming their accuracy shall be established. The accuracy of all survey measurements shall be demonstrated to the purchaser at the beginning of the contract prior to any setting out of temporary or permanent works. As a guide, setting out points should be accurate to within 1mm on levels and 2mm on position.

All setting out and fit-ups shall be subject to a tolerance measurement. Where local or global tolerances are not detailed in this Specification the item in question

shall not deviate from the nominal design size, shape or position by more than $\pm 15\text{mm}$.

The purchaser shall have the right to employ independent dimensional control sources as a cross-check whenever considered necessary throughout the fabrication programme.

Fabrication and yard assembly supports shall be set to within 5mm of the appropriate position shown on the contractor/sub-contractor purchaser approved setting-out drawings. Where no such drawings exist, fabrication shall be carried out from a level plane to within 5mm.

As soon as field erection of the structure commences, the contractor/sub-contractor shall monitor the position of the supports to ensure that they remain within tolerance. This shall be done on a monthly basis and on any other occasion when weld-out of a member will fix one support relative to another. All findings shall be passed to the purchaser. Where there is settlement of supports outside the tolerance given above, this should be immediately reported to the purchaser and remedial action undertaken. Where required to meet the tolerances of this Specification, e.g. for stab-in nodes (Section 6.3.1), such settlement shall be corrected by shimming and therefore fabrication and yard assembly supports shall be designed to allow such adjustment.

The dimensional tolerance of launch-way centre lines shall be within 20mm of the theoretical position, but shall also be within 6mm of the reference elevation. The variation in elevation between any two points on a launch-way shall not exceed 3mm within any 3m.

Tolerances specified in Section 6.1 and 6.2 of this Specification shall be controlled for structural components and sub-assemblies so that the cumulative effect of such tolerances does not negate the global tolerance requirements of Section 6.3. The required tolerances shall apply at all stages of fabrication and assembly.

The contractor shall ensure that components fabricated by sub-contractors meet, where applicable, all tolerances specified in this Specification.

Allowance shall be made for weld gap tolerances and weld shrinkage in all component, sub-assembly and global tolerance calculations.

Where tolerances have to be derived from a formula (i.e. tolerances expressed in terms of a dimension of the component, e.g. wall thickness) the results shall be taken to the nearest mm. All component dimensions in this Specification shall be assumed to be in mm unless otherwise stated. In Section 6.2.2 (rectangular plated sections) and Section 6.2.3 (stiffened plate panels) the calculated tolerance shall apply where this is less than the specified limiting value, otherwise the maximum tolerance shall apply.

6.2 Local tolerances for structural components and sub-assemblies

6.2.1 Fabricated tubulars and cones

6.2.1.1 Circumference

The external circumference, as shown in Figure 16, shall not differ from the nominal external circumference by more than the following limits:

- In Zone A (at joints or within 610mm from the joint), 30% of the nominal wall thickness or 10mm whichever is the smaller;
- In Zone B (the remaining length of the tubular), the tolerances in (a) may be multiplied by 1.5 (i.e. to 45%);
- Where it can be demonstrated to the satisfaction of the purchaser that particular tubulars will be butt welded together in the completed assembly, then the Zone A tolerance in (a) above may be multiplied by 1.5 provided the individual tolerances are of the same sign (i.e. both positive or both negative). In addition, the misalignment tolerance of 4.5.2 shall be met.

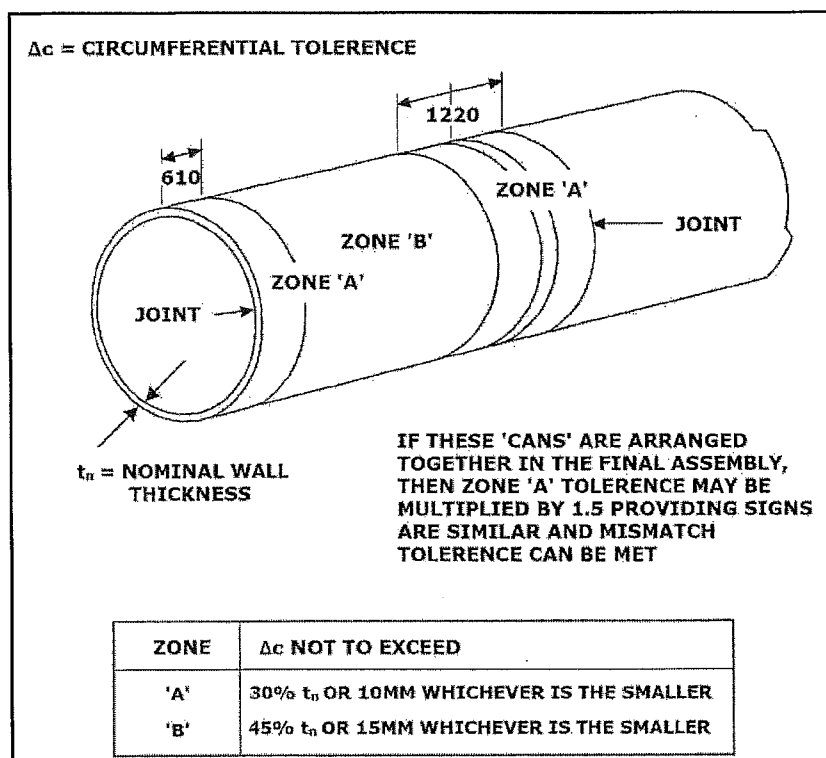


Figure 16 Circumferential tolerance

6.2.1.2 Ovality

Ovality of tubulars is defined as the difference between the measured maximum and minimum external (or internal) diameters, as shown in Figure 17, and shall not be more than as shown in the following Table 6 and Table 7:

Table 6 Allowable ovality

Nom. Dia. (mm)	Allowable ovality
≤ 610	1% of nominal diameter
$>610 \leq 2000$	greater of 6mm or 0.75% of nom. dia.
>2000	greater of 15mm or 0.5% of nom. dia.

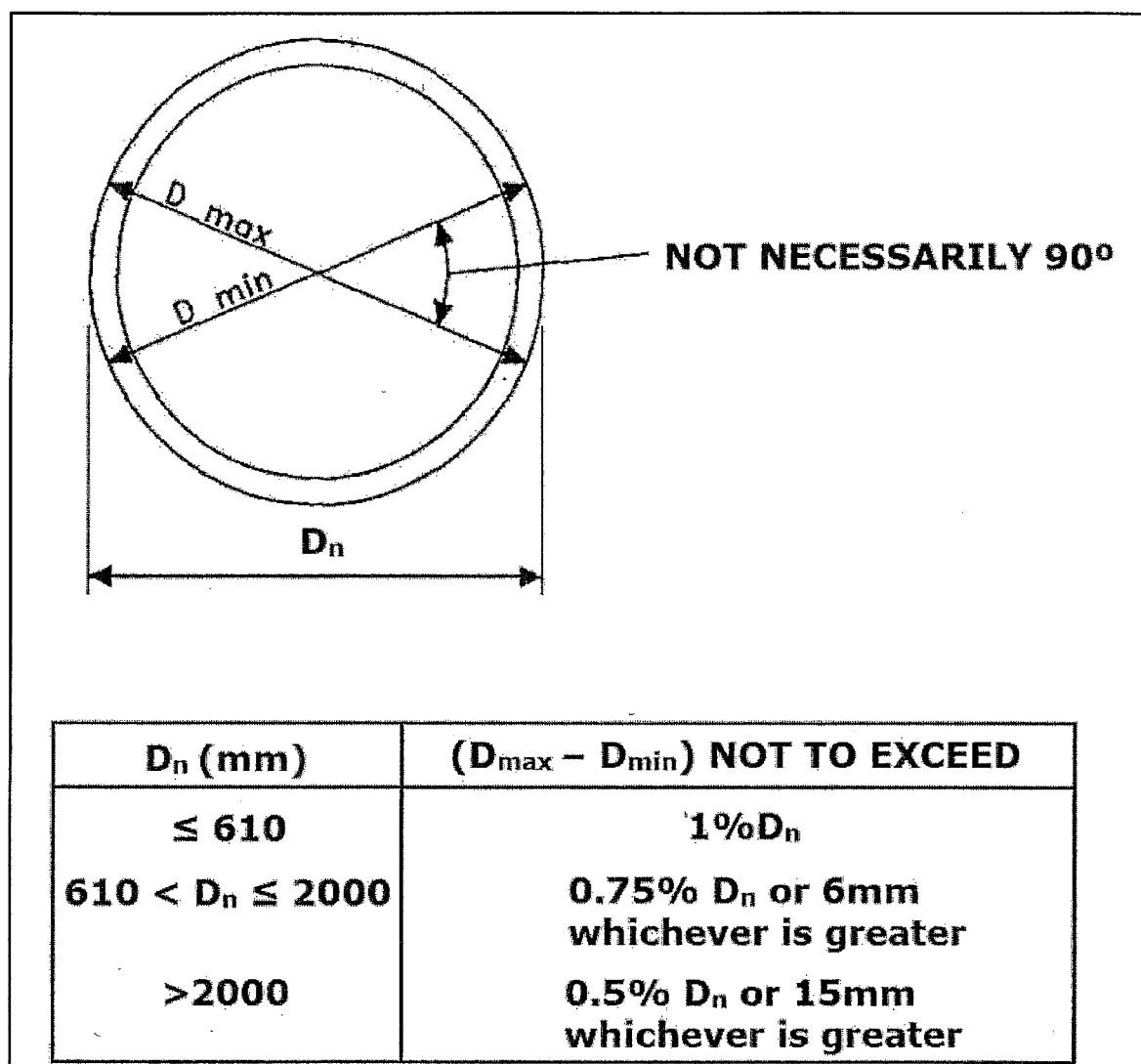
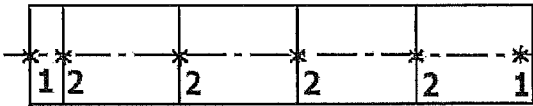
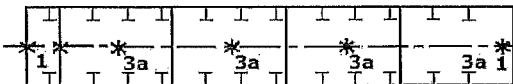
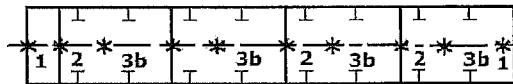
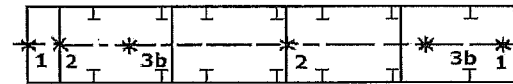
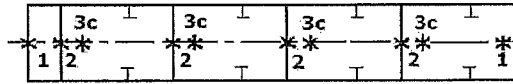
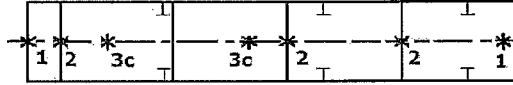
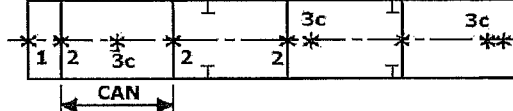
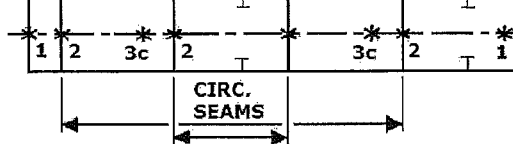
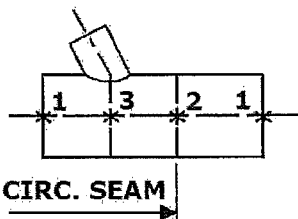


Figure 17 Ovality tolerance
(see Table 7 for checking positions)

Table 7 Checking positions for ovality and O of R tolerance

TUBULAR	EXAMPLE		CHECK POSITIONS
UN-STIFFENED			1. BOTH ENDS 2. ALL CIRC. SEAMS
STIFFENED	IRS CTS 1m		1. BOTH ENDS 2. ALL CIRC. SEAMS PROVIDED NOT CLOSER THAN 250mm TO I.R.S. 3. AT MID-POINT IN STIFFENED PANELS PROVIDED NOT CLOSER THAN 250mm TO CIRC. SEAM AND AT FOLLOWING INTERVALS
	1.5 m		
	2m		
	3m		
	4m		IRS CTRS (mm) interval a) $\geq 800 \leq 1500$ EVERY 3 rd PANEL b) $\geq 1500 \leq 2000$ EVERY ALT PANEL c) > 2000 EVERY PANEL
	5m		COMMENCED AT SECTION CLOSEST TO MIDWAY BETWEEN CIRC. SEAMS IN FIRST FULL (3mm) CAN IRS = INTERNAL RING SIFFENER PANEL = LENGTH OF UNSTIFFENED MATERIAL
	6m		
NODES			1. BOTH ENDS 2. ALL CIRC. SEAMS 3. AT SECTION WHERE BRACE ϕ MEETS NODE BARREL PROVIDED NOT CLOSER THAN 250mm TO CIRC. SEAM

Ovality shall be checked at the following places:

- Unstiffened sections (including piles):
 - at both ends;
 - at all circumferential seams.
- Stiffened cones and tubulars:
 - at both ends;
 - at all circumferential seams provided they are not closer than 250mm to a ring stiffener;
 - at the mid-point of stiffened panels provided they are not closer than 250mm to a circumferential seam and at the intervals given in Table 8:

Table 8 Ovality measuring positions

Stiffener spacing centres (mm)	Measurement position*
between 800 and 1500 inclusive	every third panel
greater than 1500 up to and incl. 2000	every alternate panel
greater than 2000	every panel

* Measurement positions shall commence at a section closest to midway between circumferential seams in the first full (3m length) can.

- Nodes:
 - at both ends;
 - at all circumferential seams;
 - at a perpendicular section of the node barrel where the centre line of the incoming brace meets the surface of the barrel. (Where the node is stiffened in this location, then the mid-panel position closest to this location shall be used as the checking point. This check may be omitted if a circumferential seam is within 250mm of this position).

Note: Attention is drawn to the fact that end dimensional tolerances of fabricated tubulars are usually more stringent than those for the tubular body. Therefore the tolerances obtained in cut tubulars may not conform to those specified for ends.

6.2.1.3 Out-of-circularity (ring stiffened tubulars only)

Out-of-circularity is defined as the difference between the actual radius and the average radius. The actual radius shall be determined from the optimum centre to the inside wall of the shell at 24 stations equally spaced around the circumference taken from the measuring centre.

The average radius, optimum centre, and out-of-circularity shall be calculated in accordance with the procedure shown in Figure 18 and Table 9.

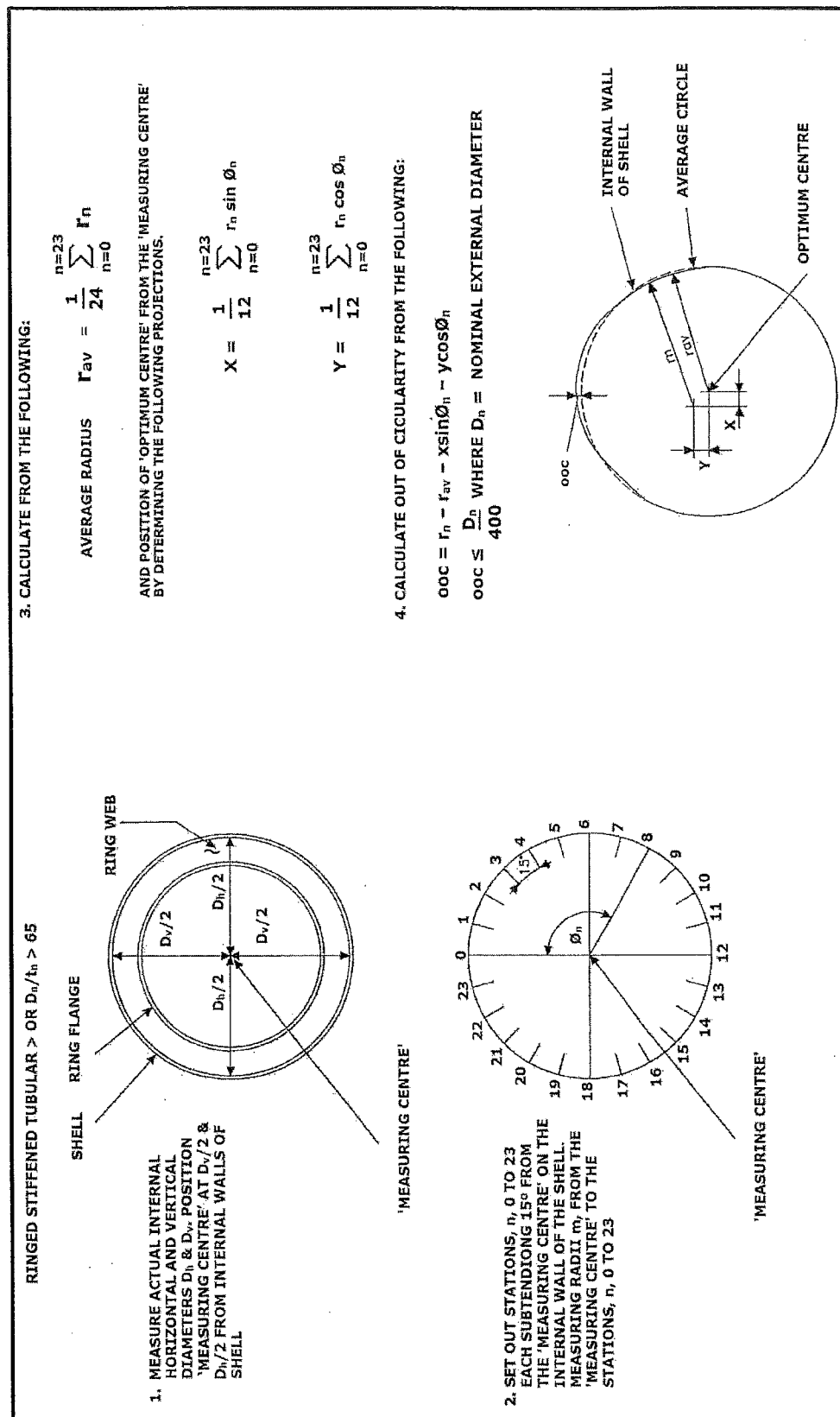


Figure 18 Procedure for determination of out-of-circularity

Table 9 Procedure for determination of out-of-circularity

n	r _n	θ _n	r _n sinθ _n	r _n cosθ _n	xsinθ _n	ycosθ _n	ooc
0	1450	0	0	1450	0	-2.5	4.8
1	1445	15	374.0	1395.8	0.4	-2.0	-0.7
2	1443	30	721.5	1249.7	0.8	-2.2	-3.3
3	1443	45	1020.4	1020.4	1.1	-1.8	-4.0
4	1442	60	1248.8	721.0	1.4	-1.2	-5.9
5	1442	75	1392.9	373.2	1.5	-0.6	-6.6
6	1443	90	1443.0	0	1.6	0	-6.3
7	1449	105	1399.6	-375.0	1.5	0.6	-0.8
8	1461	120	1265.3	-730.5	1.4	1.2	10.7
9	1465	135	1035.9	-1035.9	1.1	1.8	14.4
10	1461	150	730.5	-1265.3	0.8	2.2	10.3
11	1452	165	375.8	-1402.5	0.4	2.4	1.5
12	1445	180	0	-1445.0	0	2.5	-5.2
13	1442	195	-373.2	-1392.9	-0.4	2.4	-7.7
14	1440	210	-720.0	-1247.1	-0.8	2.2	-9.1
15	1439	225	-1017.5	-1017.5	-1.1	1.8	-9.4
16	1444	240	-1250.5	-722.0	-1.4	1.2	-3.5
17	1450	255	-1400.6	-375.3	-1.5	0.6	3.2
18	1453	270	-1435.0	0	-1.6	0	6.9
19	1453	285	-1403.5	376.1	-1.5	-0.6	7.4
20	1448	300	-1254.0	724.0	-1.4	-1.2	2.9
21	1440	315	1018.2	1018.2	-1.1	-1.8	-4.8
22	1446	330	-723.0	1252.3	-0.8	-2.2	1.3
23	1448	345	-374.0	1398.7	-0.4	-2.4	3.1
	34744		19.4	-29.6			

$$r_{av} = \frac{1}{24} \sum_{n=0}^{n=23} r_n = \frac{34744}{24} = 1447.7$$

$$x = \frac{1}{12} \sum_{n=0}^{n=23} r_n \sin \theta_n = \frac{19.4}{12} = 1.6$$

$$y = \frac{1}{12} \sum_{n=0}^{n=23} r_n \cos \theta_n = \frac{-29.6}{12} = -2.5$$

$$ooc_{max} = 14.4 \text{ mm}$$

$$D_n = 3000 \text{ mm}$$

$$ooc = \frac{14.4}{3000} 100 = 0.48\%$$

$$ooc_{TOLERANCE} = 3000 \frac{0.25}{100} = 7.5 \text{ mm}$$

∴ **FAIL**

The measuring centre shall be established by bisecting horizontal and vertical internal diameters or in accordance with the method recommended in PD 5500:2012+A2:2013.

The out-of-circularity tolerance check, as shown in Figure 19, shall be restricted to ring stiffener locations in tubulars, and shall not exceed 0.25% of the nominal external diameter. This tolerance is peculiar to ring stiffened tubulars with a nominal external diameter greater than 2000mm or with a nominal external diameter to nominal wall thickness ratio greater than 65; it shall not apply to unstiffened tubulars or at circumferential seams between ring stiffeners.

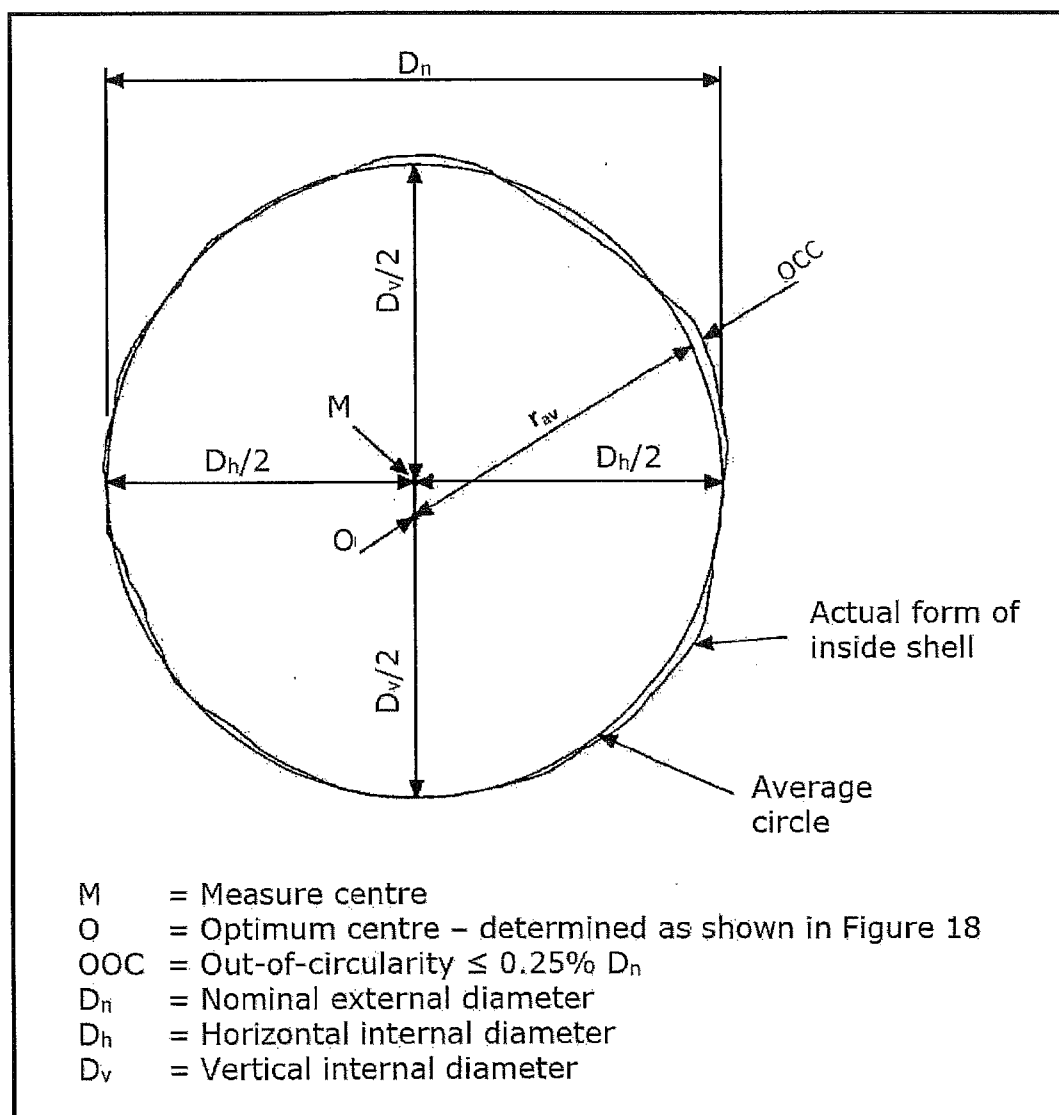


Figure 19 Out-of-circularity tolerance
(stiffened tubulars only)

6.2.1.4 Out-of-roundness

Out-of-roundness, as shown in Figure 20, is defined as the difference between the actual form and the ideal circular form of the section as measured using a 20° arc gauge. This check is required to locate unacceptable flat or high spots.

Out-of-roundness shall not exceed 0.2% of the nominal external diameter or 25% of the nominal wall thickness, whichever is the smaller. This tolerance shall be checked on the inside or outside of tubulars subject to local buckling with a nominal external diameter greater than 2000mm or with a nominal external diameter to nominal wall thickness ratio greater than 65.

These checks shall be carried out over a 360° sweep of the circumference at equal intervals of 20° and at the following locations:

- at places defined in Section 6.2.1.3 of this Specification;
- at the ends, quarter and centre points of manways after welding.

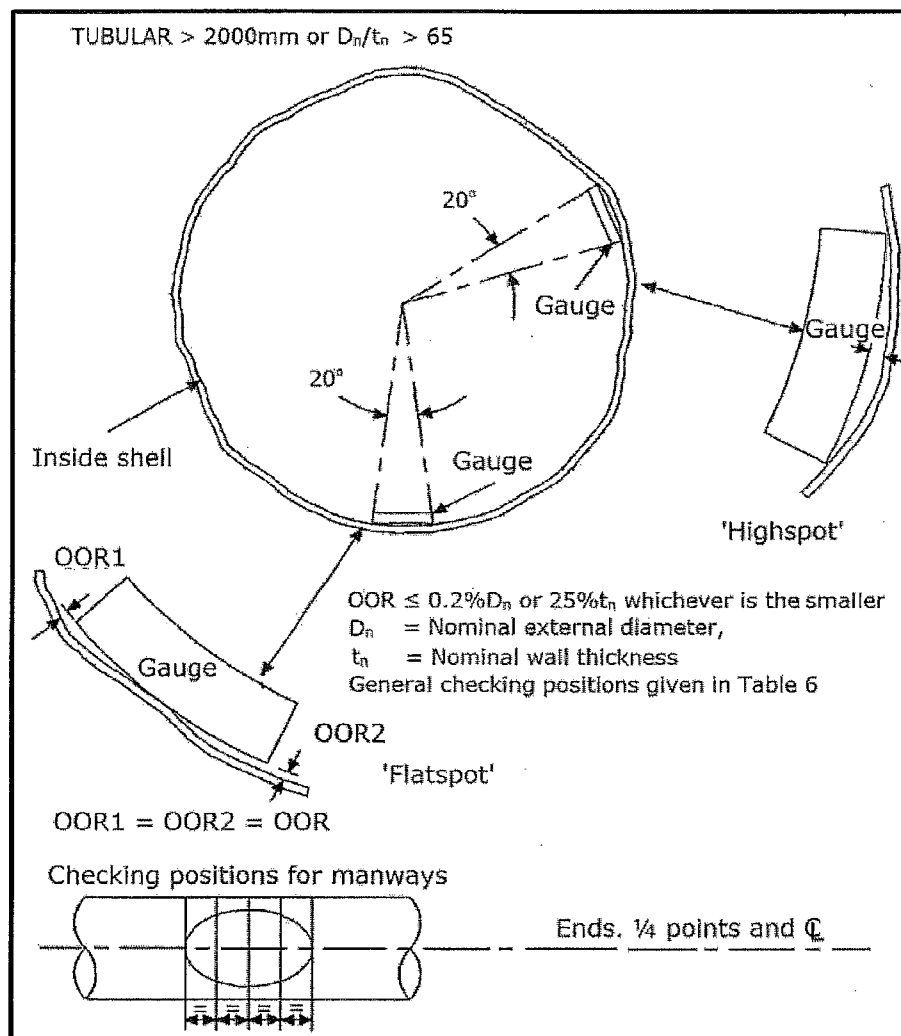


Figure 20 Out-of-roundness tolerance

6.2.1.5 Local straightness

Local straightness is defined as the deviation of the shell plate from a straight generator of length 'L' parallel to the true centre line of the tubular. This tolerance shall not exceed 20% of the wall thickness. Local straightness shall be checked on the inside or outside of tubulars subject to local buckling with a nominal external diameter greater than 2000mm or with a nominal external diameter to nominal wall thickness ratio greater than 65. These checks shall be carried out at the following locations, as shown in Figure 21:

Unstiffened tubular	: at 45° intervals of arc with L = 3000mm
Stiffened tubular	: at 20° intervals of arc with L = distance between stiffeners
At manways after welding	: at the centre and quarter points with L = 1000mm and with the straight generator centre on the transverse centre line of the manway
Node barrels	: at 20° intervals of arc with L = 1000mm

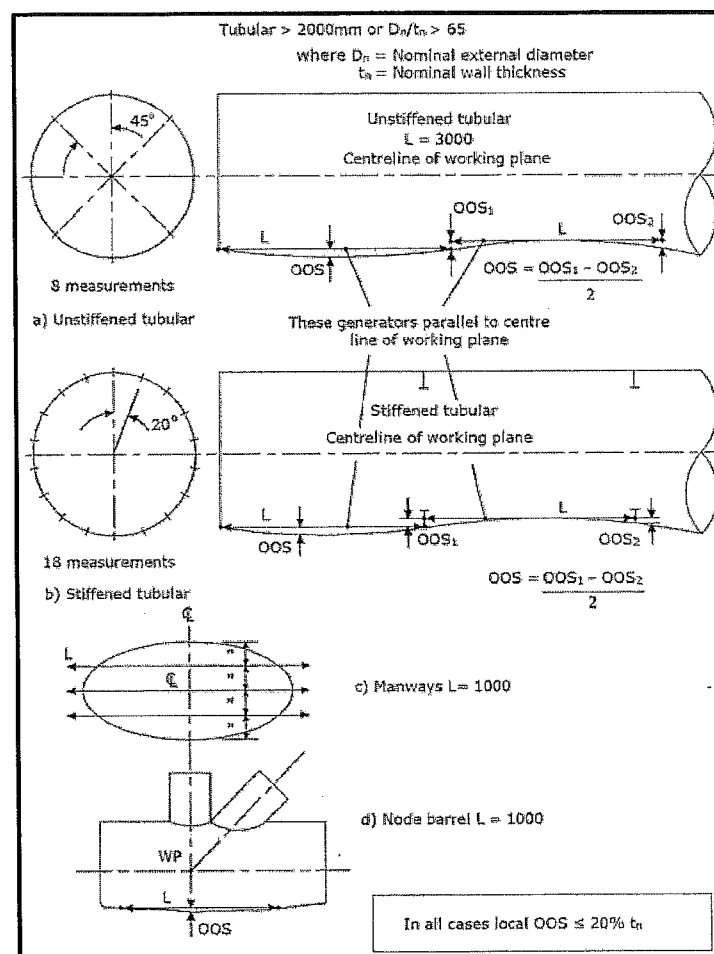


Figure 21 Local straightness tolerance for tubulars

6.2.1.6 Local dents

Local dents existing in any size of tubular shall be checked in accordance with the out-of-roundness requirements and the local out-of-straightness requirements of Sections 6.2.1.4 and 6.2.1.5 respectively of this Specification, and shall not exceed the tolerances specified. Dents shall be treated as manways when checking against these requirements.

6.2.1.7 End perpendicularity

The ends of tubulars and cones shall be cut perpendicular to the longitudinal axis within the following tolerances and as shown in Figure 22:

- tubulars of nominal external diameter $\leq 2000\text{mm}$: 3mm
- tubulars of nominal external diameter $> 2000\text{mm}$: 5mm

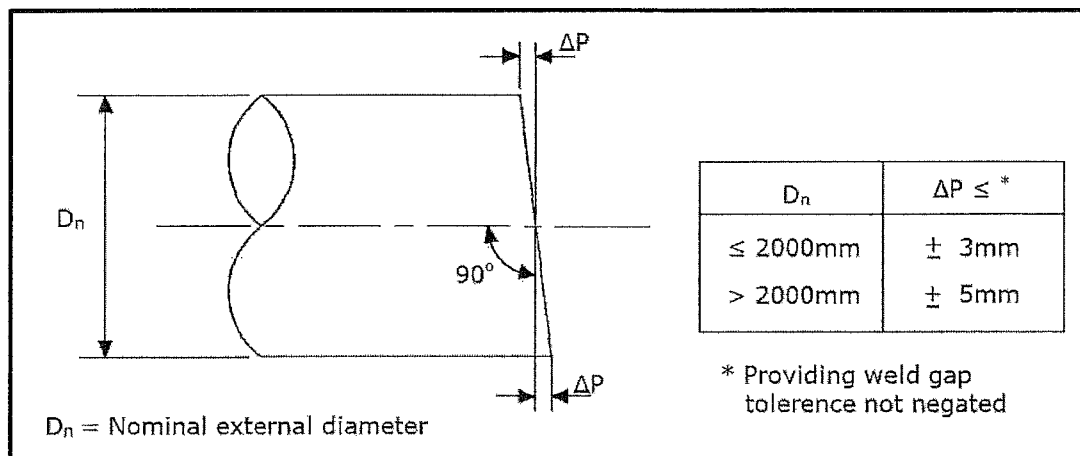


Figure 22 End perpendicularity tolerance

6.2.1.8 Node barrel length

The length of a node barrel measured from the work point to either end shall be within 0 to +10mm of the length as specified in the purchaser approved drawings as shown in Figure 23.

6.2.1.9 Node stub length

The throat length of a node stub as in Figure 23, shall be within 0 to +50mm of the theoretical length as determined from the purchaser approved drawings.

6.2.1.10 Out-of-straightness (members and piles)

Out-of-straightness shall be measured on the outside of tubulars in accordance with Figure 24 on at least two longitudinal planes separated by 90° (see also Section 6.2.1.5 for local straightness and 6.3.2 for global out-of-straightness).

Measuring centres shall be determined as defined in Figure 19.

The self-weight deflection of the member should not be included in the out-of-straightness measurements.

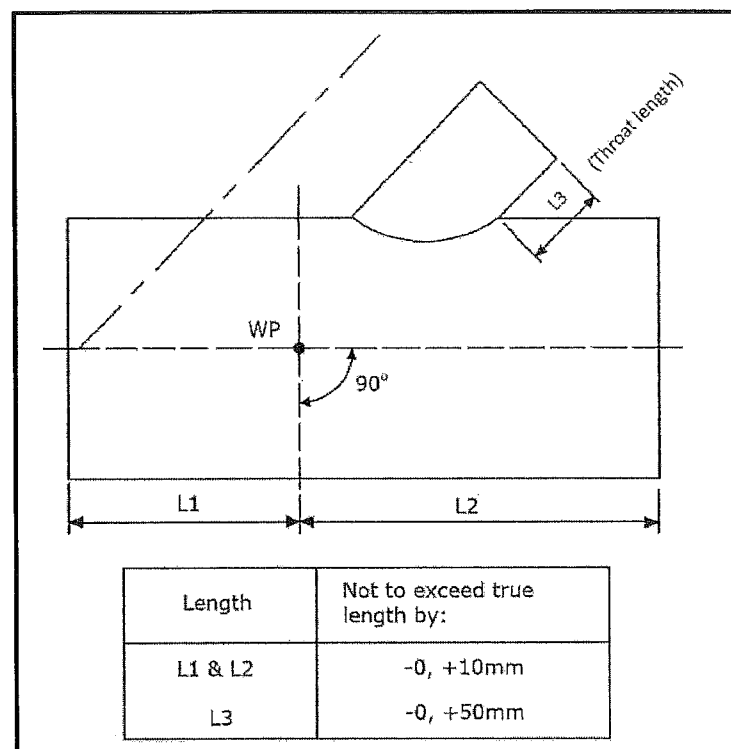


Figure 23 Node barrel and stub lengths

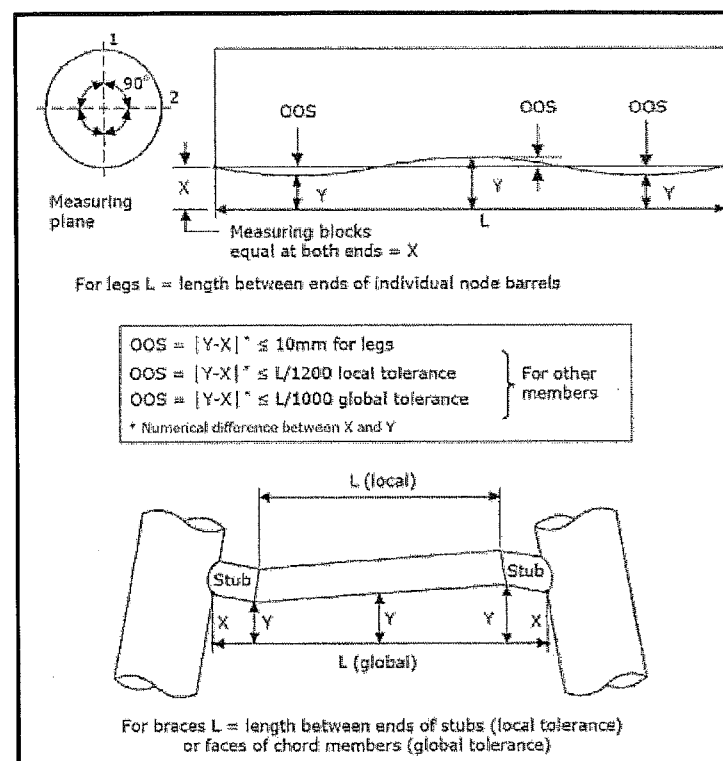


Figure 24 Out of straightness tolerance for members

Out-of-straightness shall not exceed 10mm over length 'L' for jacket legs and $\frac{L}{1200}$ for other members where 'L' is defined as follows:

legs : length between consecutive ends of node barrels
braces : length between consecutive ends of stubs

Additionally, out-of-straightness shall not exceed 12mm in any 12m length for piles, and 10mm in any 12m length for caissons that are to be pulled offshore.

6.2.1.11 Node stub location

This sub-section should be read in conjunction with Figure 25. Centre lines shall be established at both ends of the stub by bisecting the diameters which are parallel and perpendicular to the longitudinal axis of the node barrel. A node stub and associated centre lines shall be positioned on the surface of a node barrel within the following tolerances (Δm) relative to the theoretical position:

node barrels of nominal external diameter up to and including 3500mm : 5mm
 node barrels of nominal external diameter greater than 3500mm : 10mm

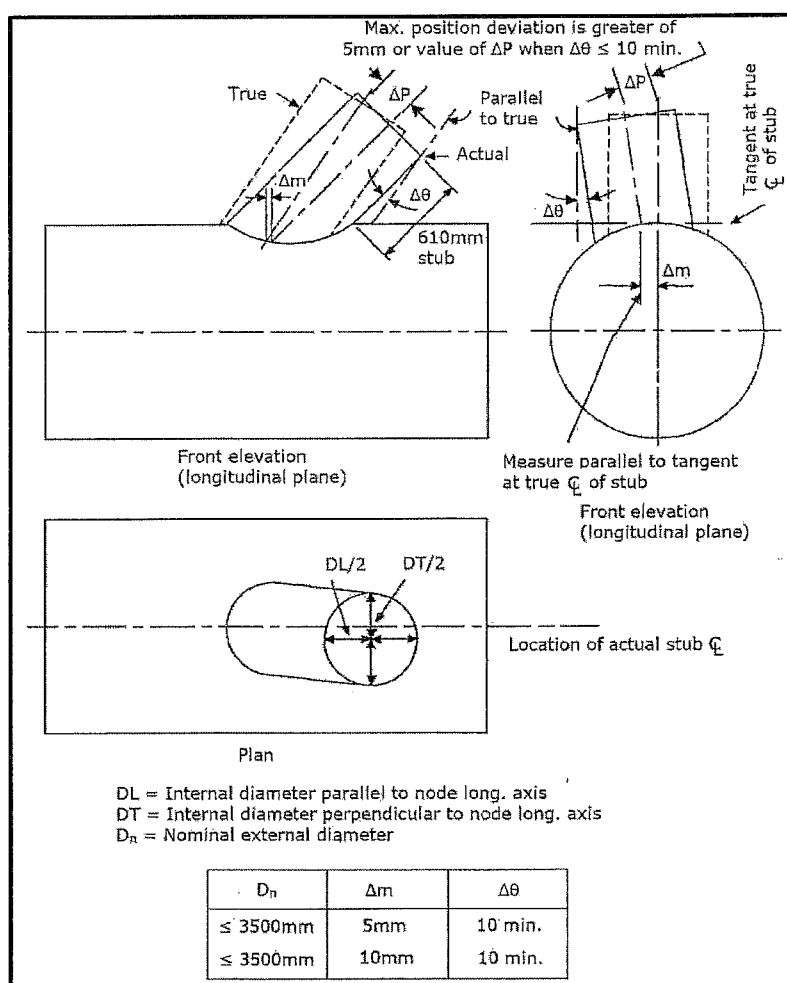


Figure 25 Node stub location

These measurements shall be made in the longitudinal direction, parallel to the node barrel centre line, and in the transverse direction, parallel to a line tangential to the surface of the node barrel at the point where it is intersected by the theoretical stub centre line.

The centre line of the stub shall lie such that the maximum allowable positional deviations, Δp , at the stub end, as shown in Figure 25, shall be the greater of 5mm or that value (of Δp) corresponding to a value of $\Delta\theta$ not exceeding 10mm. Centre line positions shall be checked both in the longitudinal and transverse planes of the node.

The above tolerances apply to nodal type construction only. Positional tolerances for jacket or deck bracing not involving node stub assemblies shall be as defined in 6.3.1.

6.2.1.12 Stiffener and diaphragm locations

Stiffeners and diaphragms shall be positioned at their point of attachment, as in Figure 26, to within the tolerances given below in relation to the true position as specified in the purchaser approved drawings:

node cones and launch legs	: 3mm
nodes (except cones)	: 5mm
other tubulars	: 10mm

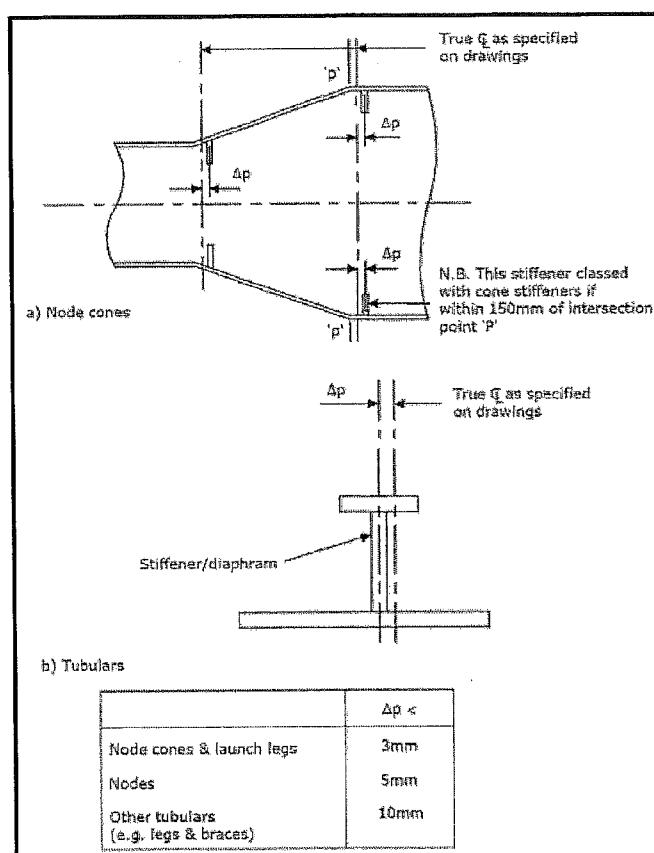


Figure 26 Node and tube stiffener locations

6.2.1.13 Ring stiffeners

Tolerances for ring stiffeners, see Figure 27, shall comply with the following requirements:

	Tolerance	Limiting value (mm)
Inclination of web	$\pm 0.025h$	± 6
Flange width	-	± 3
Bow of web	$\pm 0.01h$	± 6
Rotation of flange	$\pm 0.015b$	± 6
Eccentricity of flange on web	$\pm 0.01b$	± 6

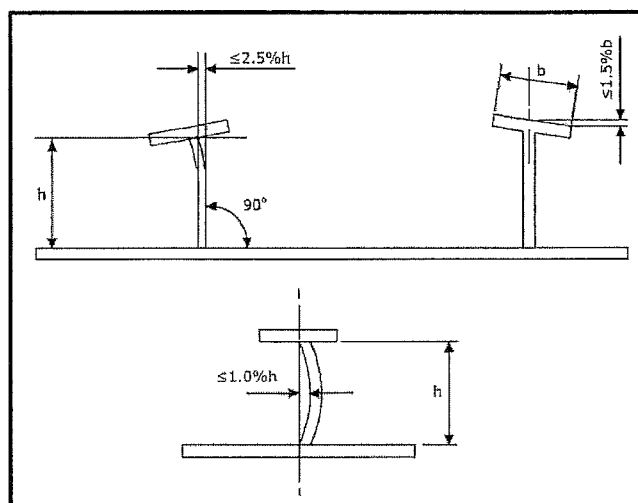


Figure 27 Ring stiffener cross section tolerances

6.2.1.14 Longitudinal and diaphragm stiffeners

The out-of-straightness of the outstand of a longitudinal or diaphragm stiffener, measured perpendicular to the web, shall not exceed 0.15% of the span, or 3mm, whichever is the larger.

The span of the stiffener is defined as the length between effective points of out-of-plane restraint as shown in Figure 28.

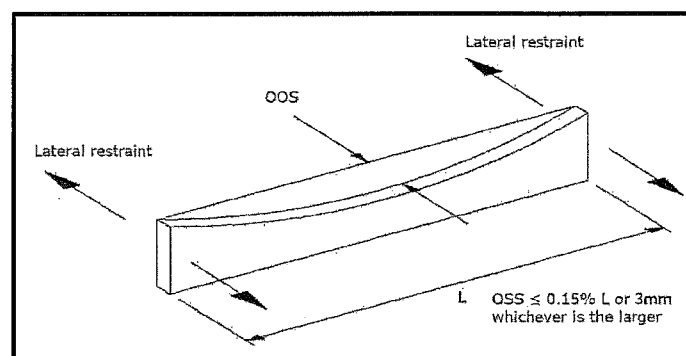


Figure 28 Out-of-straightness tolerance for stiffeners in tubulars

6.2.1.15 Pile sleeve shear plates and skirt plates

The lateral deflection of pile sleeve shear and skirt plates measured normal to the plate surface shall not exceed 1% of the distance between stiffeners. For unstiffened plates the deflection shall not exceed 1% of the distance between the pile sleeve and the jacket leg.

For vertical plates the deflection shall not exceed 1% of the distance between skirt plates or 20mm whichever is smaller.

6.2.2 Rectangular plated sections

6.2.2.1 Plate girders

Tolerances for plate girders shall comply with the requirements of Table 10 and Figures 29 and 30.

Table 10 Tolerances for plate girders

	Tolerance	Limiting value (mm)
Web depth	$\pm 0.12t$	± 5
Inclination of web and bow of web (Δw)	$\pm 0.008h$	± 10
Flange width	-	± 3
Rotation of flange and bow of flange (Δf) (excluding skid beams)	$\pm 0.0125b$	± 10
Eccentricity of flange on web (Δe)	$\pm 0.015b$	± 5
End perpendicularity (Δp)	-	± 3
Out-of-straightness (Δs): normal to web (sweep) and normal to flange (camber)	$+0.001L, -0$	$+15, -0$

Girder cross-section tolerances shall be measured at girder joints, or within 1000mm from the joint (Zone A, Figure 29). Tolerances for the central section of girders remote from joints (Zone B, Figure 29) may have the above tolerances multiplied by 1.5.

Where it can be demonstrated to the satisfaction of the purchaser that particular girders will be assembled together, then the cross-section tolerances at the joints may be multiplied by 1.5 providing the tolerances are of the same sign, i.e. either both tolerances being larger or both being smaller than the nominal cross-section dimensions.

Tolerances for plate girder stiffeners shall comply with the following requirements of Table 11 and Figure 31:

6.2.2.2 Box girders

Tolerances for box girders and box girder stiffeners shall comply with the requirements of 6.2.2.1 and the following additional checks of Table 12 and Figure 32.

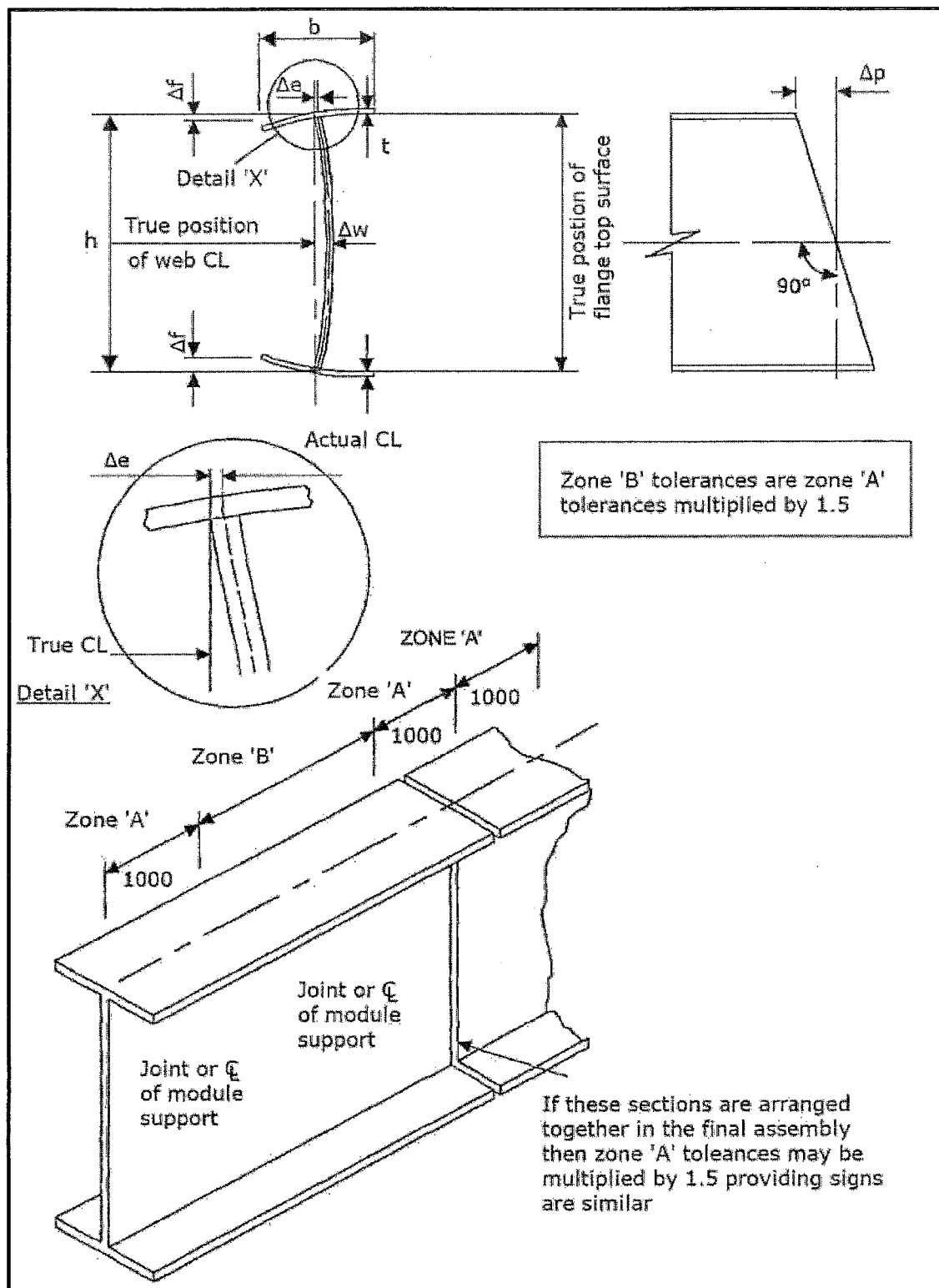


Figure 29 Plate girder cross section tolerances

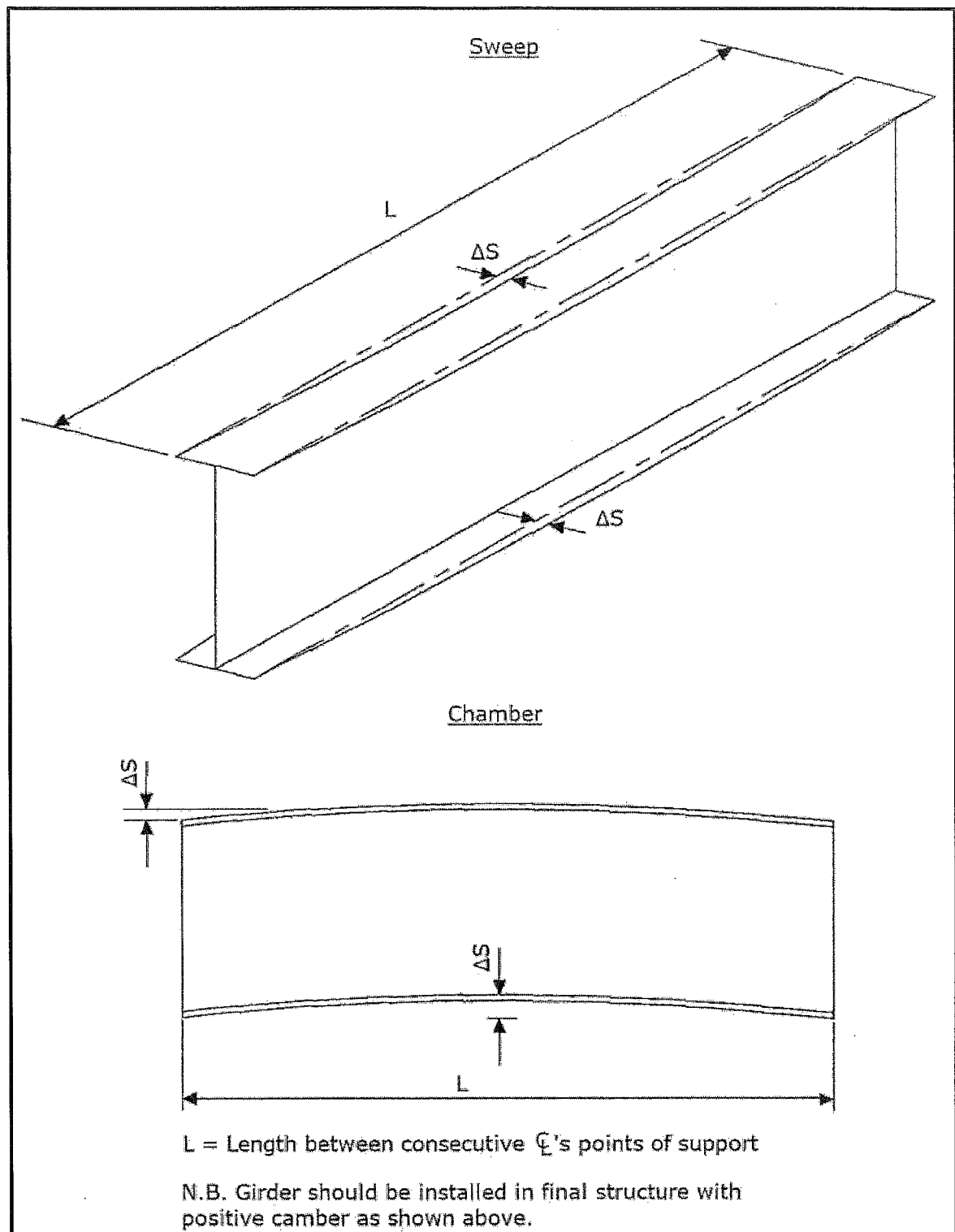


Figure 30 Plate girder out-of-straightness tolerance

Table 11 Tolerances for plate girder stiffeners

	Tolerance	Limiting value (mm)
Positional deviation (Δp)	-	± 5
Angular deviation and inclination (Δa)	$\pm 0.005h$	± 5
Out of straightness normal to girder web plane and normal to stiffener plane (Δs)	-	± 5

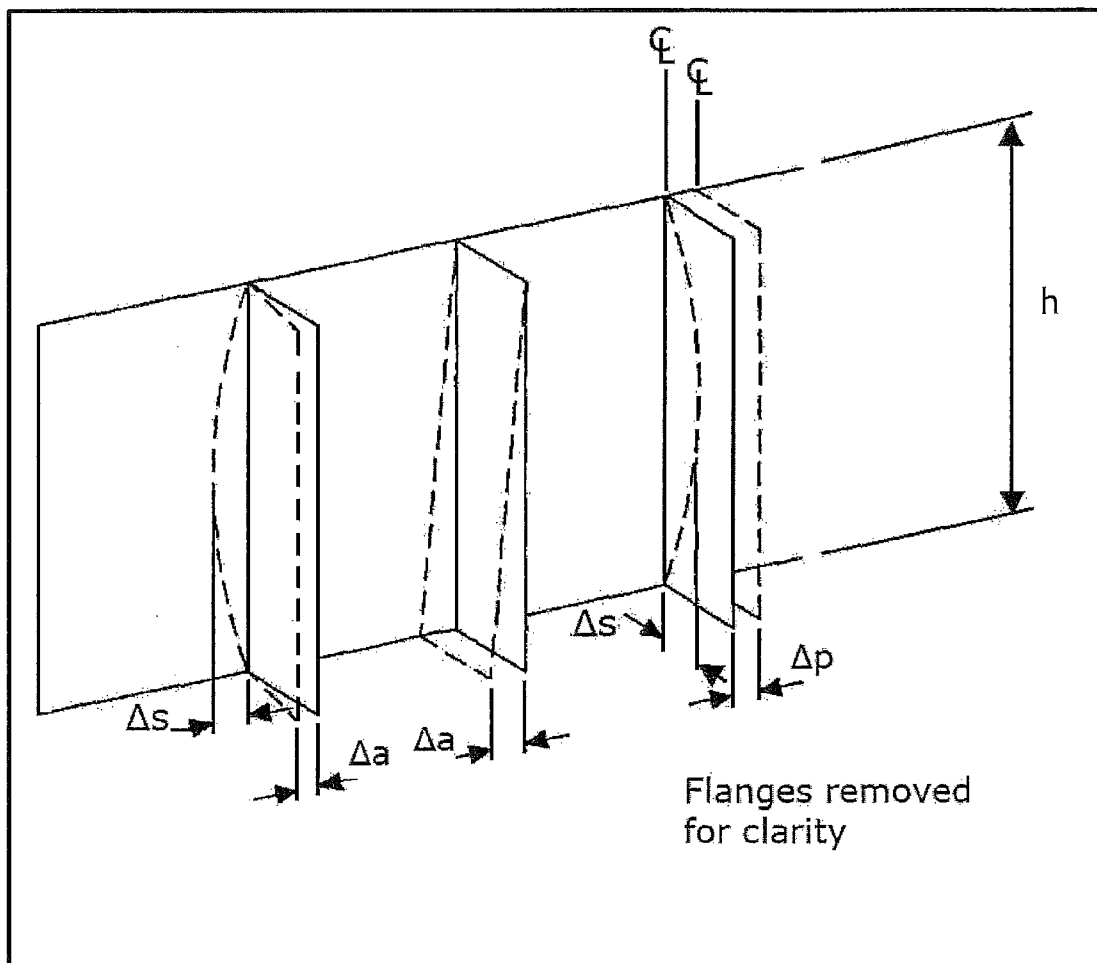
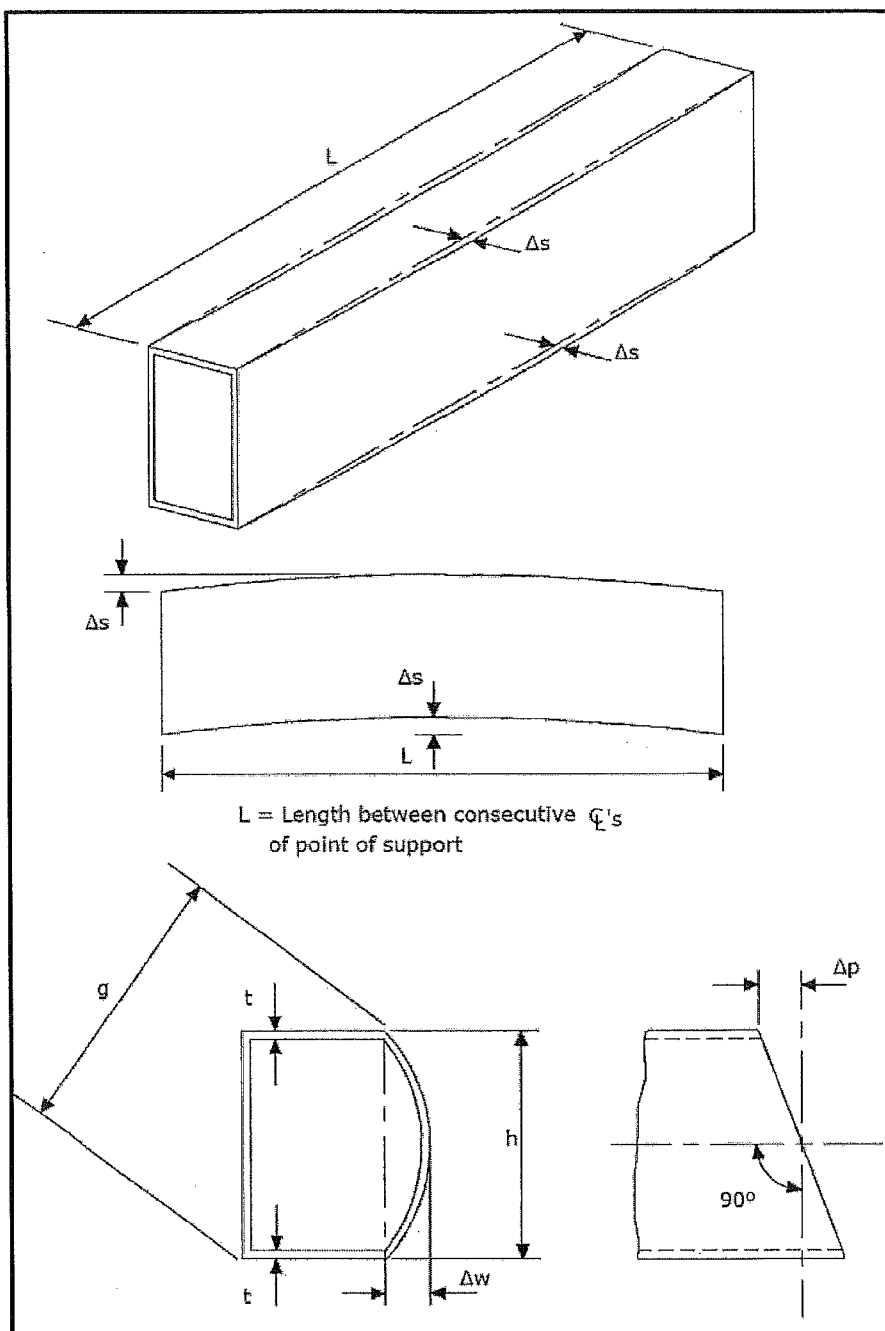
**Figure 31 Plate girder stiffener tolerances**

Table 12 Box girder tolerances

	Tolerance	Limiting value (mm)
Diagonal	$\pm 0.005g$	± 7
Twist offset between opposite ends	$\pm 0.008h$	± 10

**Figure 32 Box girder tolerances**

6.2.2.3 Skid beams

Tolerances for skid beams shall be in accordance with Section 6.2.2.1 together with the following additional requirements:

- sweep of the top flange shall not exceed 20mm over the entire length;
- flatness of the top flange shall not deviate from a level plane by more than 6mm over the entire length, and not more than 3mm over a 3m length.

6.2.2.4 Girder nodes

The length of a girder node measured from the central work point to either end as shown in Figure 33, shall be within 0 to +10mm of the length as specified in the purchaser approved drawings.

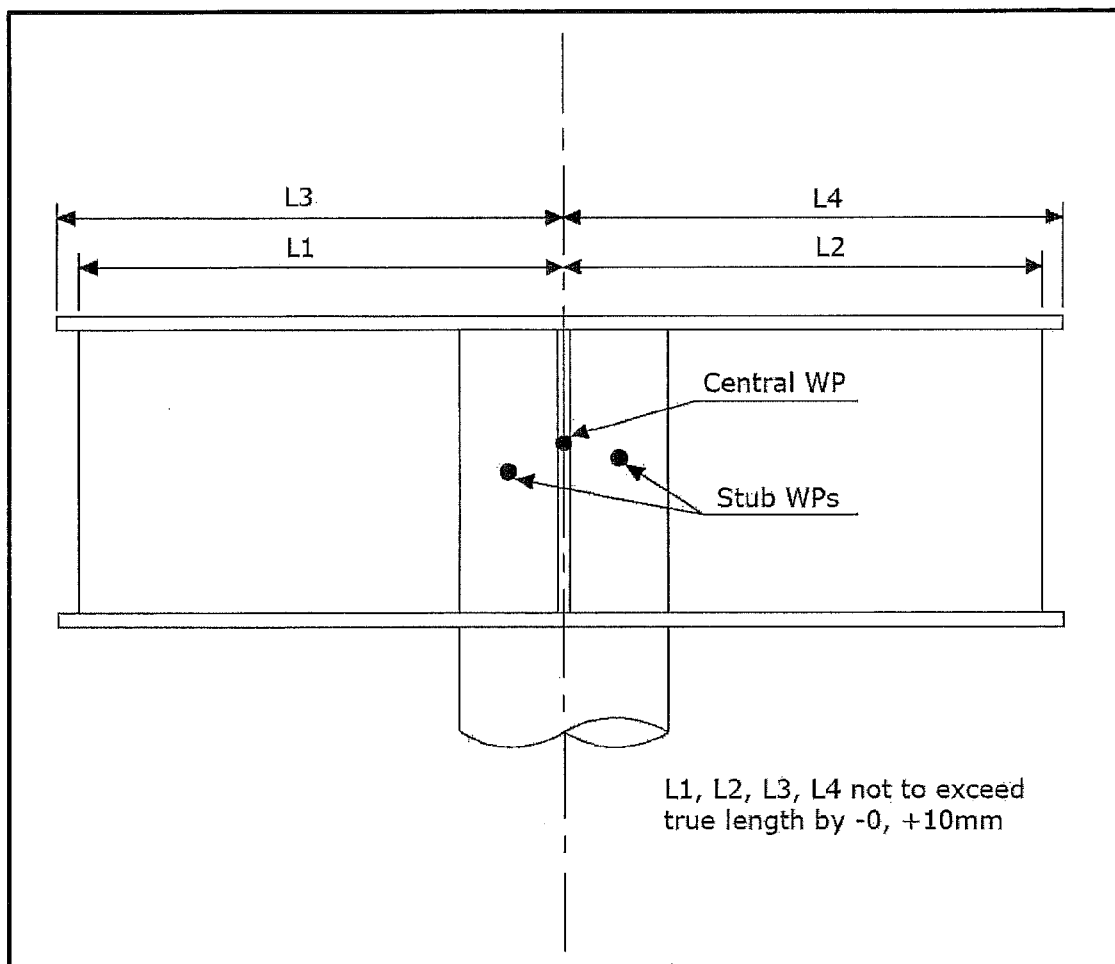


Figure 33 Girder node lengths

Tube stubs attached to girder nodes shall meet the requirements of Sections 6.2.1.9 and 6.2.1.11.

Plated sections of girder nodes shall meet the requirements of Sections 6.2.2.1 and 6.2.2.2 as appropriate.

6.2.3 Stiffened plate panels

Tolerances for stiffened plate panels carrying in-plane load shall satisfy the requirements of Table 13 and Figure 34.

Table 13 Tolerances of stiffened plate panels

	Tolerance	Limiting value (mm)
Panel plate lateral deflection (sagging or hogging) -between girders -between stiffeners	$\pm 0.0015L$ $\pm 0.01L_1$	± 20 ± 10
Plate panel stiffeners -positional deviation (Δp) -inclination (Δa)	- -	± 5 ± 5
Out of straightness: normal to panel plane and normal to stiffener plane (Δs)	$\pm 0.0015L_1$	± 5

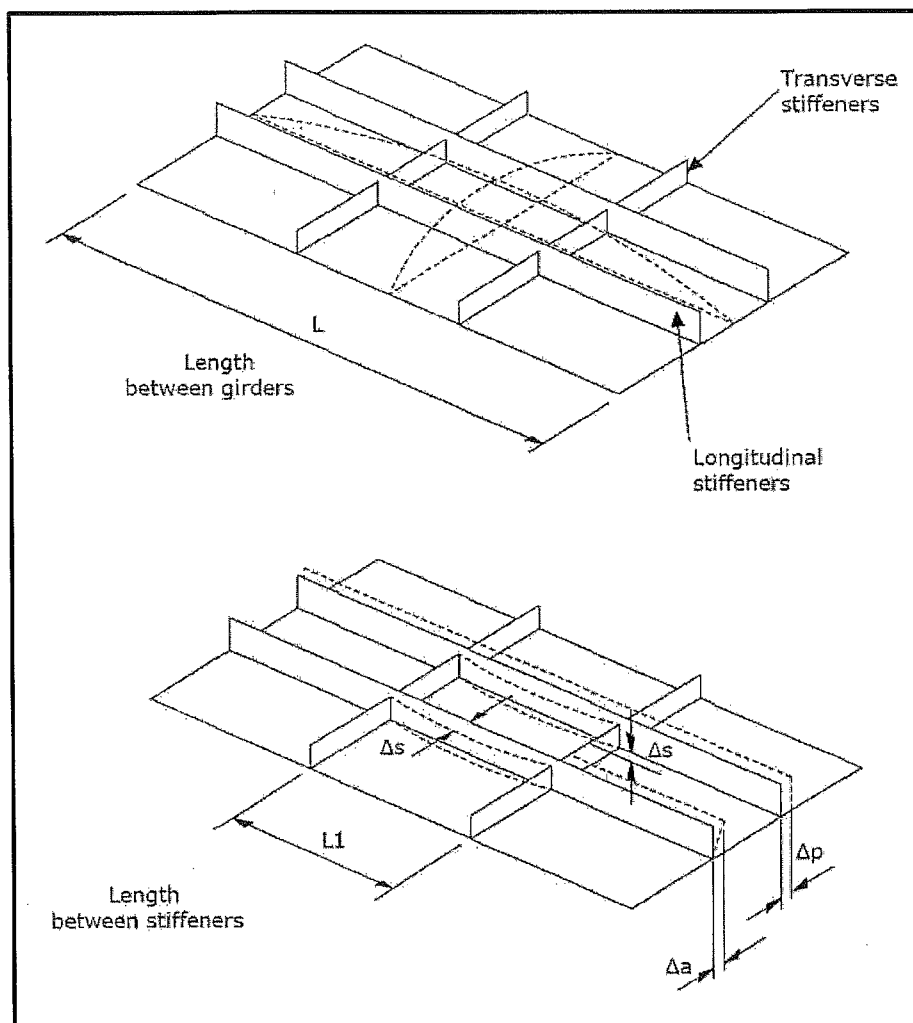


Figure 34 Tolerances for stiffened plate panels

6.2.4 Cruciform joints

Where plates carrying in-plane loads are arranged to form a cruciform joint, the misalignment shall not exceed $0.5t$, where t is the thickness of the thinnest non-continuous member or 10mm, whichever is smaller.

6.2.5 Joint misalignment

Joint misalignment in fabricated tubulars and rectangular beams shall be in accordance with fit-up dimensions applicable to the qualified welding procedures (see 4.5.2).

All misalignments greater than 2mm or 10% of the wall thickness, whichever is larger, in double-sided butt welds shall be built up with weld deposit to give a cross joint taper of 1:4 as illustrated in Figure 35.

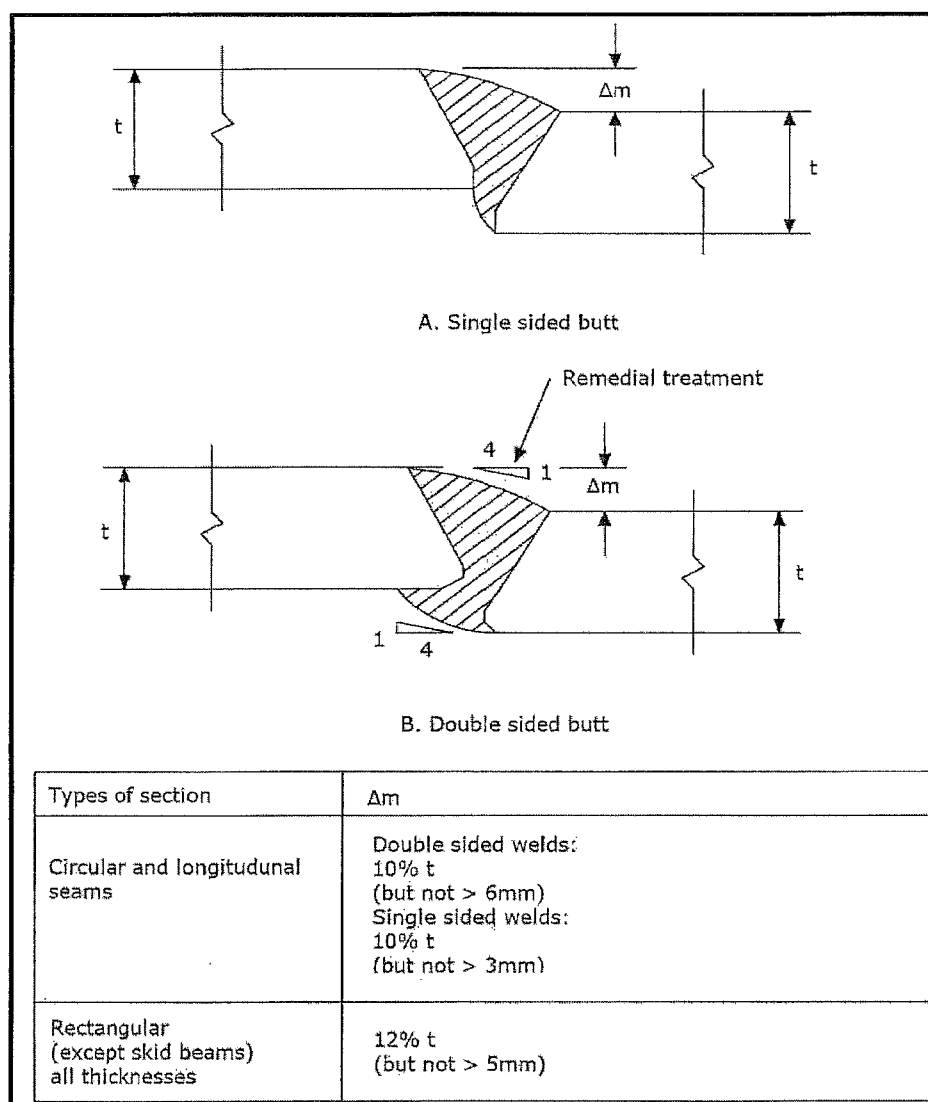


Figure 35 Joint mismatch tolerance

6.3 Global tolerances for the completed structure

6.3.1 Jacket and deck node work points

The best fit position of the achieved work point of a jacket or deck node shall be within the tolerance given below in relation to the setting-out location of the work point as derived from the geometry of the structure shown in the purchaser approved drawings - see Figure 36.

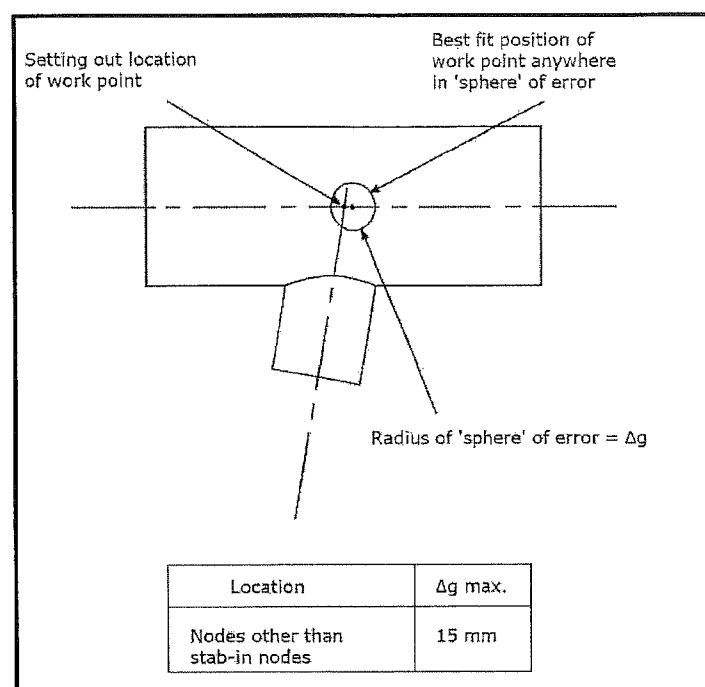


Figure 36 Global positioning tolerance for tubular nodes

In any plane critical to field assembly, such as the top of the jacket and the bottom of the deck legs, the horizontal distance from the best fit centre line of any leg to the best fit centre line of the leg adjacent in any direction shall be within a tolerance of 10mm of the net drawing dimension.

The mating surfaces for stab-in nodes shall be within 3 mm of the best fit level plane between all mating legs providing the gap between the two mating surfaces is not more than 6 mm at any point (see Figure 37).

6.3.2 Final alignment of bracings and jacket legs

Members shall be installed into the final structure in such a way that out-of-straightness does not exceed 10mm over length 'L' for jacket legs, and L/1000 for other members including buoyancy tubes and flotation tanks ('L' shall be taken as defined in Figure 24).

If the local out-of-straightness tolerance specified in Section 6.2.1.10 together with all other related local tolerances and global work point tolerances are met in full, then a final survey to check global out-of-straightness (in the fully welded as-

built condition) will become unnecessary, as this global tolerance will be automatically satisfied.

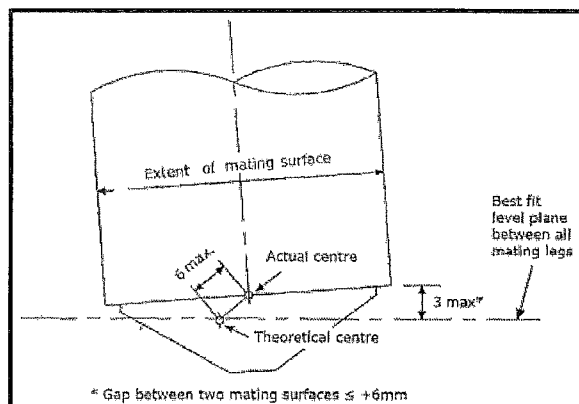


Figure 37 Tolerances for stab-in node mating surfaces

6.3.3 Appurtenances

The best-fit centre line for appurtenances, e.g. pile sleeves, conductor guides, caisson guides and J-tube guides, shall be within 10mm of the best-fit centre line of the adjacent or nearest leg at the jacket-deck interface level. At all other levels this tolerance shall be ± 25 mm.

The deviation of the measuring centre for any appurtenance shall be within 12mm of the best-fit centre line of the related appurtenances.

Figure 38, Figure 39 and Figure 40 shows these tolerances. The measuring centre shall be defined as in Section 6.2.1.3, and the best-fit centre line shall be established using recognized statistical methods, e.g. the least squares method.

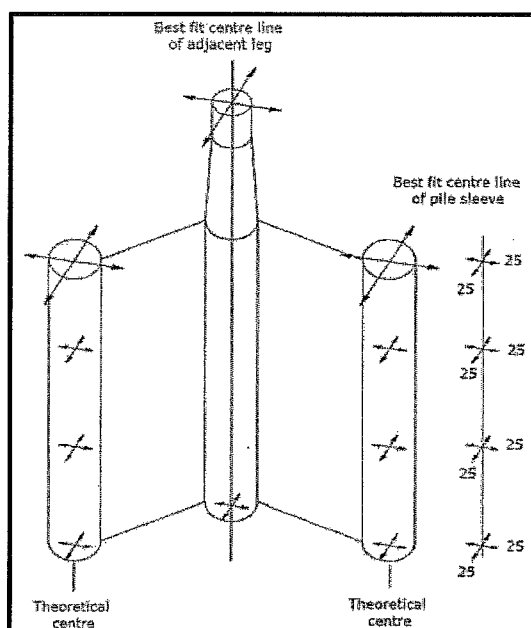


Figure 38 Pile sleeves positioning tolerances

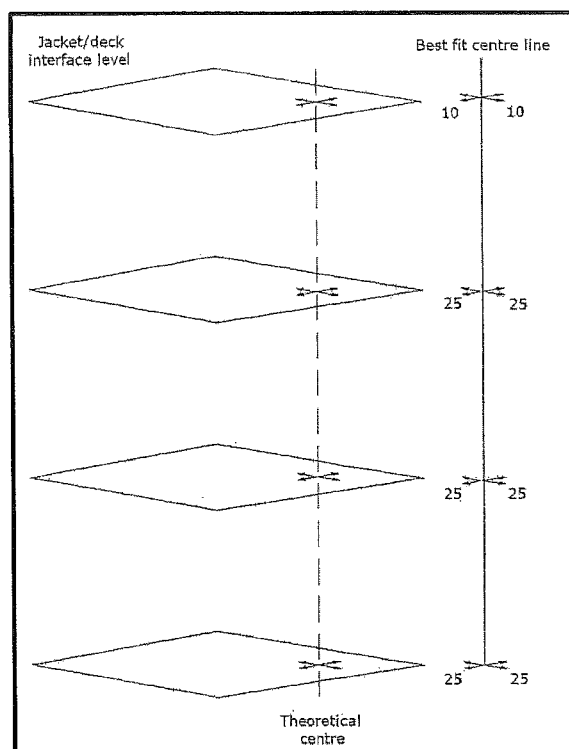


Figure 39 Conductor guides positioning tolerances

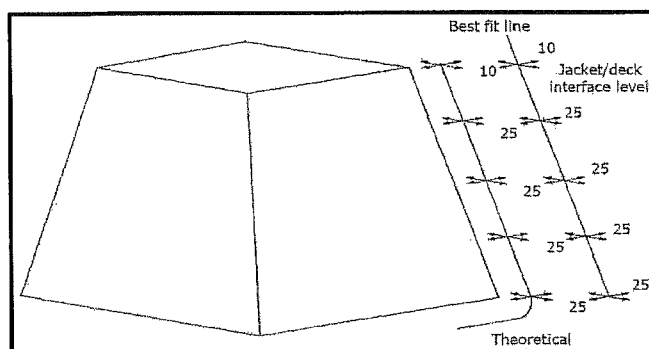


Figure 40 Caisson and J-tube guides and riser clamps positioning tolerances

The overall lengths of buoyancy tubes, flotation tanks, caissons, J-tubes and risers shall be within 25mm of the length given in the purchaser approved drawings.

Anodes shall be positioned within 300mm longitudinally and within 10° radially of the locations shown on the purchaser approved drawings. However in accordance with 5.2.3 (m), anode doubler plates shall not be attached within 75mm of any structural weld.

Mudmats shall be fabricated to the tolerances specified in Sections 6.2.2 and 6.2.3 where applicable.

6.3.4 Padeyes, padears and lifting trunnions

The actual work points of padeyes, padears and lifting trunnions shall be located within a 15mm radius sphere of error and 0.5° of the final orientation marked in the purchaser approved drawings.

Where applicable, a trial fit-up to ensure correct tolerances shall be carried out prior to fixing.

6.4 Miscellaneous structural steelwork tolerances

6.4.1 Handrails

Handrails shall be erected so that the top rail is straight to within 5mm in any 3m length measured in either the vertical or horizontal planes. Stanchions and fencing shall be plumb to within 5mm.

6.4.2 Deck plating, walkways, stairways and landings

Deck plating, walkways, stairways and landings shall be positioned in accordance with the tolerances given below in relation to the theoretical position specified in the purchaser approved drawings:

- Best fit plane of an assembly within 12mm of its true elevation;
- Out-of-straightness normal to plate within 6mm in any 3m length; and
- Plan position within 12mm.

Plating or grating at joints shall be flat without visible warping. Mismatches greater than 2mm at deck plate and grating joints shall be ground out and recoated. Joints shall only occur at points of support. The vertical distance between stair treads shall not vary by more than 3mm.

6.4.3 Openings/penetrations

The centre point of any opening or penetration shall be within 10mm of the theoretical centre point. The true size of any opening shall be within 5mm of the theoretical dimension.

6.4.4 Pile length

The overall length of a pile shall be within 300mm of the length shown in the purchaser approved drawings. Pile paint markings for use in determining pile penetration offshore shall be within 50mm of the dimensions shown on the purchaser approved drawings.

7 Inspection and non-destructive testing

7.1 General

The contractor/sub-contractor shall be responsible for undertaking all of the inspection and NDT required by this Specification.

The purchaser shall have the right to undertake NDT cross checking on complex geometry T-K-Y joints and other highly utilised joints details. Other joints may be nominated for NDT cross checking at random by the purchaser. The contractor/sub-contractor shall provide safe access to the structure to facilitate purchaser NDT cross checking.

NDT cross checking by the purchaser shall not absolve the contractor or sub-contractor of his NDT responsibilities.

The contractor/sub-contractor shall maintain a QC function, responsible for undertaking all of the inspection and NDT requirements of this Specification, which is independent of other fabrication functions.

The contractor/sub-contractor shall formulate a QP which shall be submitted to the purchaser for approval. The QP shall make reference to procedures for all inspection and NDT techniques, including proposed report formats and the names and qualifications of inspection and NDT personnel. The purchaser shall be responsible for specifying the inspection Category for all joints in the construction (see Section 7.2.1.4). If due to fabrication methods or design changes it becomes necessary to specify alternative requirements, these shall be referred to the purchaser for approval. The use of 'reporting by exception'² for inspection and NDT operations may be considered, subject to the contractor/sub-contractor furnishing evidence of appropriate procedures controlling such systems to the purchaser's satisfaction.

The contractor/sub-contractor shall provide suitable access to all parts of the structure for inspection personnel to perform inspection and the witnessing of testing in a safe and thorough manner.

7.2 Inspection and NDT

7.2.1 Extent of inspection and NDT

7.2.1.1 Edge preparation and fit-up

The edge preparation and fit-up shall be visually inspected prior to the application of the first pass of welding.

² Reporting by exception implies that a report is raised only when a defect (an unacceptable flaw) is found.

7.2.1.2 During welding

Visual inspection should be performed during the welding operation. For single-sided tubular in-line closure welds, radiography may be required before the completion of all welding (see 5.3.5).

7.2.1.3 After back-gouging

Following back-gouging, the preparation shall be fully inspected visually before the commencement of second-side welding. Where there are visual indications MPI shall be applied to ensure that the root is free from defects before welding is recommenced.

7.2.1.4 Final inspection and NDT

Final inspection and NDT shall be undertaken in accordance with the Inspection/NDT Category designated for the particular weld.

Table 2 defines the extent and type of inspection and NDT for five specific Categories.

Each weld in the structure will be assigned one of these Categories, or a special Category if appropriate, and be so designated on the purchaser approved drawings. Guidance on the application of these inspection Categories is given in Table 5.

7.2.1.5 Category III, IV and V inspection

Where welds are subject to less than 100% inspection and found to contain unacceptable flaw indications, NDT shall be extended to adjacent areas to determine the full extent and nature of the defect.

Should the weld contain any of the defects listed below, the entire length of weld shall be examined. Alternatively, should the weld be less than 1m in length, five such welds made within the same period of time shall be fully examined.

- Any flaw exceeding 3 % of the weld length examined;
- Cracking, including chevron cracking;
- Lack of fusion in mechanised and semi-automatic welding;
- Any previously noted, persistent, flaws identified by the purchaser.

The purchaser reserves the right to increase the extent of NDT if the weld quality persistently fails to meet the required standard.

7.2.2 Timing of final inspection and NDT

All visual inspection of completed welds shall be carried out as soon as is practical after the item has cooled down to ambient temperature.

NDT shall not be carried out until at least 48 hours have elapsed following completion of welding. However, for welds/items which are subject to a PWHT requirement, the specified inspection and NDT may be performed and reported immediately following completion of the PWHT process but not before the welds/items have cooled to ambient temperature.

Inspection and NDT prior to PWHT, performed in addition to mandatory inspection following PWHT, shall be at the discretion of the contractor/sub-contractor. Nevertheless, where defects requiring repair are located by this discretionary inspection a detailed report shall be submitted to the purchaser.

7.3 Qualification of inspection and NDT procedures and personnel

7.3.1 Non-destructive testing procedures

The contractor/sub-contractor Level 3 NDT practitioner shall prepare examination procedures for each of the NDT techniques proposed for use in the execution of the contract, and submit these to the purchaser for his approval prior to the commencement of any testing. The purchaser may require qualification of any of these procedures by demonstration of their ability to detect known defects.

7.3.2 Qualification of inspection and NDT personnel

The contractor/sub-contractor welding inspection personnel shall be qualified as required by Section 2.2.3.

Supervisory and interpretive NDT personnel shall be site experienced, competent and possess, as a minimum, Level 2 certification (or an equivalent approved by the purchaser) specific to weld testing for the relevant NDT techniques. Certification shall be in accordance with a scheme compliant with EN ISO 9712:2012⁽⁶⁵⁾, e.g. CSWIP or PCN, and approved by the purchaser.

Further, UT technicians examining joints of complex geometry, e.g. T-K-Y/nodal joints, shall have certification specific to that geometry, e.g. CSWIP/PCN - 3.8 Nozzles and variable configuration welds, and, 3.9 Nodes. The purchaser may, at his discretion, require such technicians to undertake an additional practical complex geometry test prior to deployment on the contract. The test joint details and defects to be included shall be agreed and verified by the purchaser.

Level 1 personnel may perform NDT operations under the supervision of Level 2 personnel.

The contractor/sub-contractor shall provide the services of a Level 3 practitioner throughout the duration of the contract.

The CV and current certification of NDT personnel shall be available for purchaser review and acceptance.

If the qualifications or competence of any NDT technician is in doubt, the purchaser may require that they not be employed on the work until they have passed appropriate practical tests.

7.4 Non-destructive testing techniques

7.4.1 Visual inspection

Visual inspection methods require approval by the purchaser and shall be capable of assessing compliance of the production weld profiles with the requirements of Section 7.5.2. Inspection aids may include samples and/or replicas of the weld

profiles, proprietary weld profile gauges, fibre optics or clipped discs as illustrated in Figure 5.

7.4.2 Ultrasonic testing

All UT examination of welded joints shall be carried out in accordance with EN ISO 17640:2010, but at the appropriate Examination Level required by Table 2 of this Specification. Whilst EN ISO 17640:2010 is based on the application of straight beam and angled beam probes the application of techniques such as TOFD (EN 583-6:2008⁽⁶⁶⁾) and phased array (EN ISO 13588:2012⁽⁶⁷⁾) may be proposed for purchaser approval.

The sensitivity for examination shall be set in accordance with Section 10 of EN ISO 17640:2010.

Regardless of the Examination Level, any indication producing a response equal to or greater than DAC minus 14 dB (20% of DAC) shall be investigated with respect to flaw type and position.

The following joint details shall be examined for transverse weld metal hydrogen cracking:

- Submerged arc welds $\geq 25\text{mm}$ in thickness – 100% of the length. The extent of this inspection may be reduced to 20% when the contractor or sub-contractor has demonstrated to the satisfaction of the purchaser that the controls being applied are adequate to avoid the occurrence of cracking; and
- Welds in strength grades $\geq \text{S420}$ - 10% of each weld length increasing to 100% if evidence of cracking is found.

Examination shall be by scanning along the internal and external weld caps using a 45°, 4 MHz probe. Scanning shall be in each direction, covering the full width of the weld. The weld caps shall be sufficiently smooth to facilitate this inspection otherwise, local grinding shall be performed. The method and sensitivity shall be in accordance with the examination level specified in Table 2. All indications shall be reported.

7.4.3 Radiography

X-radiography or gamma radiography may be used, the method being agreed between the purchaser and the contractor/sub-contractor.

Radiography shall be carried out to EN ISO 17636-1:2013⁽⁶⁸⁾.

Fine grain high contrast direct type film specified in the above Standards shall be taken to be EN ISO 11699-1:2011⁽⁶⁹⁾ Class 5.

Ultra-fine grain high contrast direct type film specified in the above Standards shall be taken to be EN ISO 11699-1:2011 Class 3.

The sensitivity shall be assessed using a wire type IQI in accordance with EN ISO 19232-1:2013⁽⁷⁰⁾.

The contractor/sub-contractor may offer digital radiographic techniques in accordance with EN ISO 17636-2:2013⁽⁷¹⁾ for consideration by the purchaser. As a minimum, the equipment shall have been subject to an independent test program, acceptable to the purchaser, demonstrating equivalent sensitivity and defect detection to EN ISO 17636-1:2013 film techniques.

7.4.4 Magnetic particle inspection

Testing techniques shall be in accordance with EN ISO 9934-1:2001⁽⁷²⁾, 2:2002⁽⁷³⁾ & 3:2002⁽⁷⁴⁾. Although dry powder methods are permitted for intermediate examination of welds when they are above 70°C, all other MPI shall be carried out in the continuous mode using the wet particle method. The AC yoke technique shall be used.

Permanent magnets and the current flow (prod) technique are not permitted unless specifically approved by the purchaser. Light dressing of parts of weld surfaces is permitted where this is necessary to aid interpretation of MPI indications.

7.4.5 Leak testing

The requirements of this clause apply to components designed to provide buoyancy during jacket installation. Items requiring a full hydrostatic test (such as risers) fall outside the scope of this Specification. Components to be leak tested include jacket leg sections (between watertight diaphragms) and buoyancy tubes, but other items may be defined on the purchaser approved drawings.

Leak testing shall be performed in accordance with a purchaser approved written procedure based on the following:

The test assembly shall be instrumented to give a permanent record of internal pressure and temperature. The range of the pressure recorder chart shall not exceed 1bar, and a manometer shall also be connected into the system.

The internal air pressure shall be raised to 0.4bar above atmospheric and held for a minimum of eight hours with the system closed. At the end of this period the pressure shall be measured and corrected for any change in temperature. If the corrected pressure is not within 10% of the original figure and no leak can be found, pressure may be held until 24 hours have elapsed when the temperature correction shall again be made. The corrected pressure shall then be within 5% of the original figure.

During the period under pressure, a check for leaks at all penetrations shall be carried out using a soap solution or similar medium. This technique should also be used to locate any leaks causing a pressure drop.

7.5 Acceptance criteria for flaws

7.5.1 General

Any imperfection which may prevent the detection or sizing of a flaw shall be investigated and repaired if necessary. When flaws are revealed using a particular inspection technique, other inspection techniques shall be applied, as necessary, to facilitate interpretation of the type and size of the flaws.

7.5.2 Visual acceptance

All welds shall comply with Table 14, be of size and shape specified on the purchaser approved drawings, and exhibit cap and root profiles blending smoothly into the parent material.

Table 14 Visual inspection acceptance criteria

Defect type	Permitted maximum
Undercut	Slight intermittent undercut permitted, depth should not exceed approximately 0.5mm.
Shrinkage grooves and root concavity	As for undercut, depth should not exceed 1.5mm.
Excess penetration (girth welds only)	3mm maximum. Occasional local slight excess is allowable.
Reinforcement shape	The reinforcement shall blend smoothly with the parent metal. Dressing is not normally required provided the shape does not interfere with the specified NDT techniques.
Overlap	Not permitted.
Linear misalignment	See 4.5.2. (k) and (l)

7.5.3 Ultrasonic acceptance

Acceptance levels are specified in Table 15.

7.5.4 Radiographic acceptance

Any indication characterised as a crack or lack of fusion is unacceptable regardless of size.

Other elongated indications are unacceptable if the length of their images on the radiograph exceed:

- 6mm for t up to and including 20mm;
- $1/3t$ for t above 20mm up to and including 60mm;
- 20mm for t over 60mm.

Rounded indications are unacceptable if:

- The largest dimension of the image is greater than $\frac{1}{4}t$ or 4mm, whichever is the smaller;
- The sum of the diameters of aligned, rounded indications exceeds t in a length of 12t. Adjacent indications not separated by more than the diameter of the larger indication shall be regarded as continuous; and/or
- Cluster porosity shall not exceed the smaller of t and 12.5mm in any direction. In all of the above, t is the weld thickness.

7.5.5 Magnetic particle examination acceptance

All surfaces to be examined shall be free of the following:

- relevant linear indications;
- relevant rounded indications greater than 4mm;
- 4 or more relevant rounded indications in a line, separated by 1.5mm or less (edge to edge).

Definitions:

- 'Relevant' indications are those caused by defects rather than by weld geometry;
- A 'linear' indication is one having a length greater than three times the width;
- A 'rounded' indication is one of circular or elliptical shape with a length equal to or less than three times the width.

Table 15 Ultrasonic testing acceptance criteria

Type of flaw	Acceptance level (see Note)	
Three dimensional flaws (i.e. slag, porosity).	a)	Indications greater than 100% of the reference curve shall be reported. The maximum acceptable length shall be $\frac{t}{3}$ or 20mm, whichever is the smaller.
	b)	Indications less than 100% but greater than 50% of the reference curve shall be reported. The maximum acceptable length shall be 2t or 50mm, whichever is the smaller.
	c)	Indications less than 50% of the reference curve are acceptable.
Two dimensional flaws other than cracks (i.e. lack of side wall fusion, lack of inter-run fusion).	a)	Not acceptable if the indications exceed the reference curve, or lie within 6mm of either surface, regardless of amplitude.
	b)	Indications more than 6mm from either surface which are less than 100% but greater than 50% of the reference curve shall be reported. The maximum acceptable length shall be $\frac{t}{3}$ or 20mm, whichever is the smaller.
	c)	Indications more than 6mm from either surface which are less than 50% of the reference curve are acceptable.
Cracks or suspect cracks.	Not acceptable.	
Incomplete penetration or lack of root fusion in single-sided welds.	Not acceptable.	
Single point reflectors: (indications which show Pattern 1 behaviour in both directions, as per EN ISO 17640:2010).	If separated by a distance of 25mm or greater, acceptable regardless of amplitude. If separated by less than 25mm, indications with an amplitude greater than 100% of the reference curve shall be reported.	

Note: t = thickness of member under test.

8 References

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26. AWS A5.18/A5.18M Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding
27. AWS A5.28/A5.28M Specification for Low Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding
28. AWS A5.36/A5.36M Specification for Carbon and Low Alloy Steel Flux Cored Electrodes for Flux Cored Arc Welding and Metal Cored Arc Welding
29. AWS A5.17/A5.17M Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding.
30. AWS A5.23/A5.23M Specification for Low Alloy Steel Electrodes and Fluxes for Submerged Arc Welding
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Appendix: CTOD testing of HAZs for welding procedure qualification

A1 Introduction

Weldability data for the steel used, indicating the response of the steel in the HAZ to welding at different heat inputs, should be available from each steel supplier.

EN 10225:2009 Appendix E defines requirements for assessing the HAZ toughness of butt welds using a normal fabrication welding procedure (apart from the square edge preparation on one side of the weld preparation). This approach has been adopted by some operators as being more representative of actual fabrication conditions.

However some other operators have required welding procedures to be used that produce sufficient grain coarsened material such that, on testing, the fatigue crack tip of the CTOD test specimen samples at least 15% of the coarse grained region. This latter approach has been adopted with a view to establishing a lower bound CTOD value. If this value can be shown to be above the minimum required for a particular fabrication (subject to meeting the requirements of Section 4.5), then it could form the basis for omitting HAZ CTOD testing during welding procedure qualification.

The purchaser will specify whether HAZ CTOD testing will also be required during welding procedure qualification, based on individual purchaser philosophy for the use of CTOD testing. In such circumstances material shall be welded with a normal fabrication welding procedure (apart from the possible use of a square edge preparation on one side of the weld preparation), and HAZ CTOD test specimens shall be tested and validated in accordance with the procedures specified in this Appendix.

The purchaser will specify whether surface notched or through-thickness notched specimens are to be used.

A2 Testing requirements

HAZ CTOD testing shall be performed at an accredited test house with experience of conducting fracture toughness tests and agreed by the purchaser.

A2.1 Number of tests

A minimum number of three tests valid to both ISO 15653:2010 and A2.4 shall be carried out. Sufficient material should therefore be welded to provide for up to 12 CTOD test specimens, in case retests are required due to invalidity and/or a low value.

A2.2 Specimen preparation

The specimens shall be prepared in accordance with ISO 15653:2010 using the rectangular section (B x 2B) for through-thickness testing, or the square section (B x B) for surface notches, where B is the plate thickness. Specimens shall be full plate thickness and shall be extracted from panels welded using the welding procedure requiring qualification. For plate thickness equal to or greater than 75mm, through-thickness notched square section (B x B) specimens may be used.

For the purpose of through-thickness notched HAZ CTOD testing, test welds containing a weld preparation incorporating one square edge may require separate manufacture.

Square section specimens, surface notched into the HAZ, may be extracted from the same test pieces as those used for the remaining welding procedure qualification tests or the inclined bevel side of the square edged test piece. In the former case, sufficient length should be retained in each specimen to allow selection of the notch location in either bevel of the weld preparation.

A2.2.1 Pre-testing metallography

Prior to removal of the CTOD specimen blanks from the test weld, macro sections shall be removed from the start and finish of the weld at least 50mm from the ends. The macro sections shall be suitably prepared in order to:

- (i) Identify the HAZ microstructures and grain sizes adjacent to the fusion line of the HAZ to be tested (Figure A1);

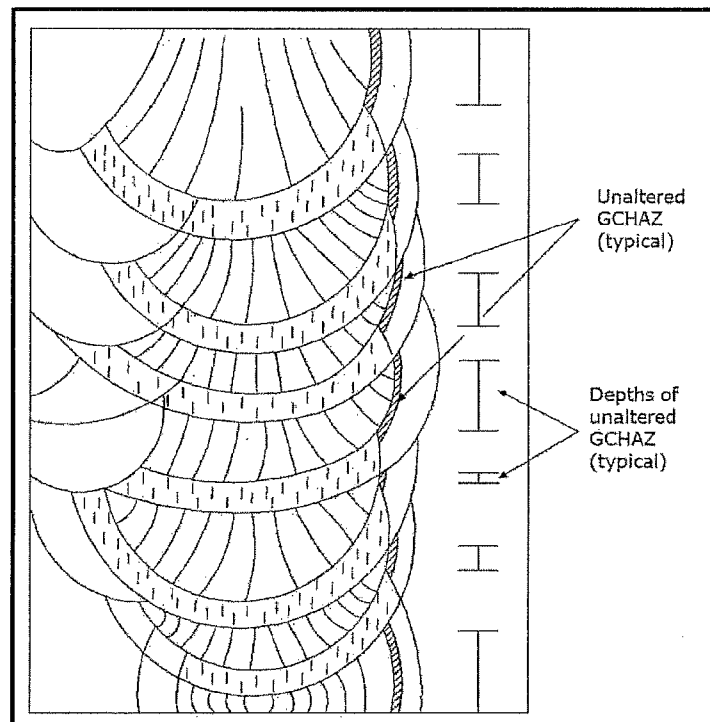


Figure A1 Illustration of Grain coarsened heat affected zone (GCHAZ) location relative to the weld beads

The microstructure and grain sizes adjacent to weld caps which overlap the parent plate need not be reported.

The HAZ shall be identified using the following ASTM E112 grain size categories:

- Coarser than 5
- 5-7 inclusive

- Finer than 7

The estimated amounts and positions of the microstructures and grain sizes shall be identified on a sketch (micro-map) with a magnification of at least 2:1 of the original plate thickness (see Figure A2). Only the percentages for the central two thirds of the specimen shall be estimated.

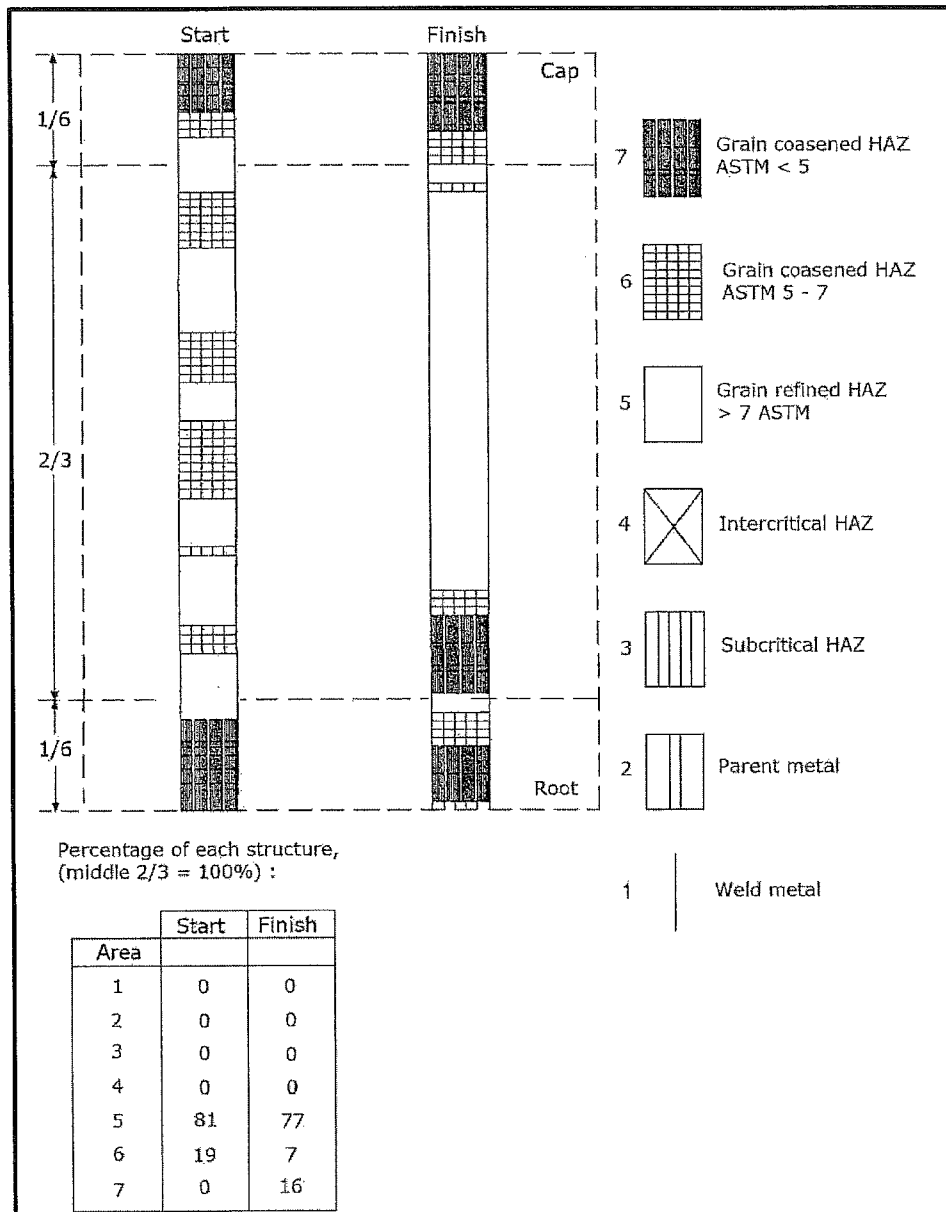


Figure A2 Sketch micro-map of microstructures and grain sizes in HAZ

(ii) Optimize the position of the CTOD test notch line with respect to the fusion line and target microstructure.

An idealised CTOD test notch line shall be marked on each start and finish macro-section as illustrated in Figure A3 to intersect the maximum amount of target HAZ microstructure as defined in A2.4.1. A micro-map showing the amounts and locations of the various microstructures along the idealised CTOD test notch line shall be prepared as shown in Figure A4.

Optimisation of the CTOD test notch line more accurately reflects the likely position of a notch in the specimen, recognizing the effects of fusion line irregularities;

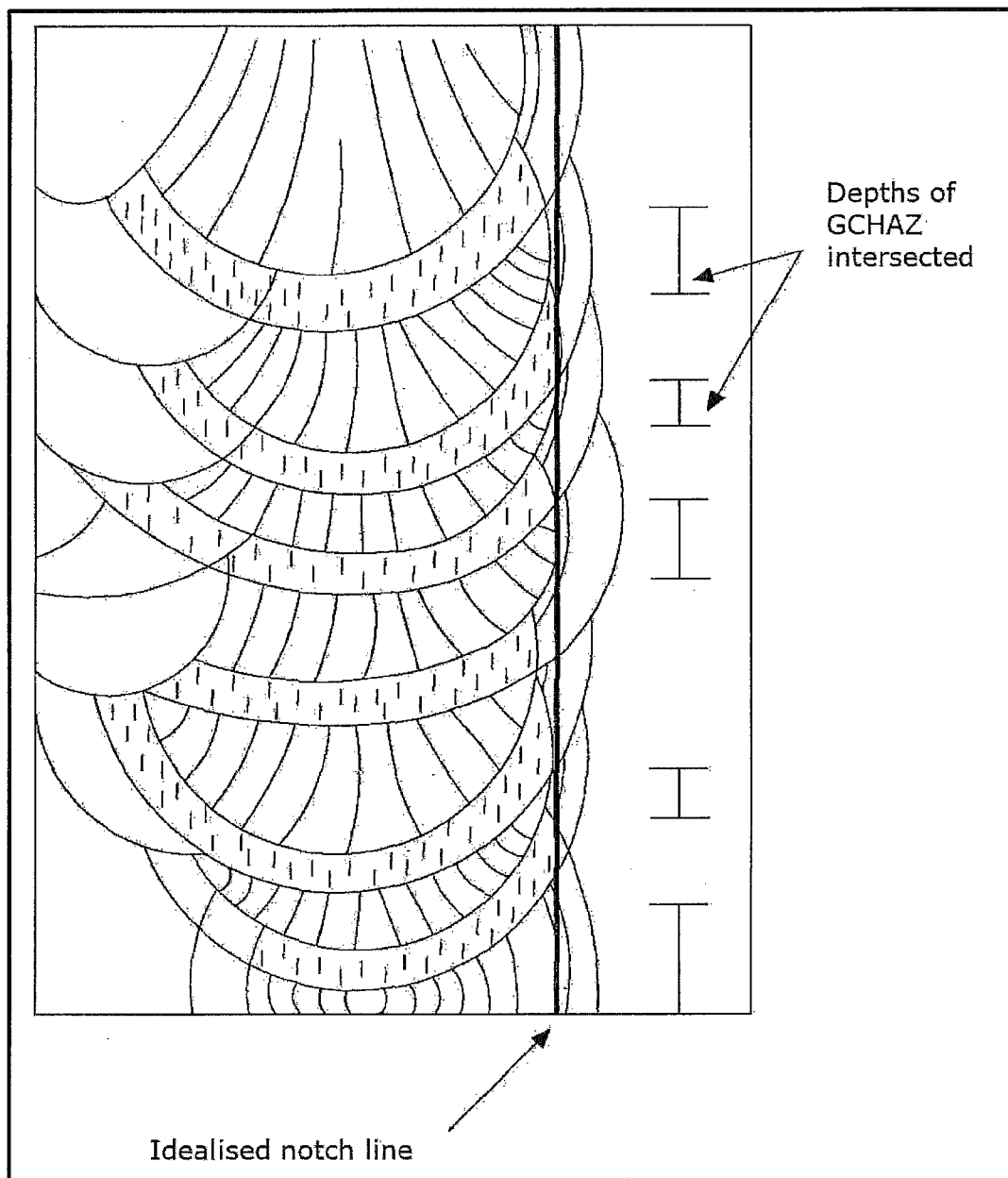


Figure A3 Illustration of idealised CTOD notch line

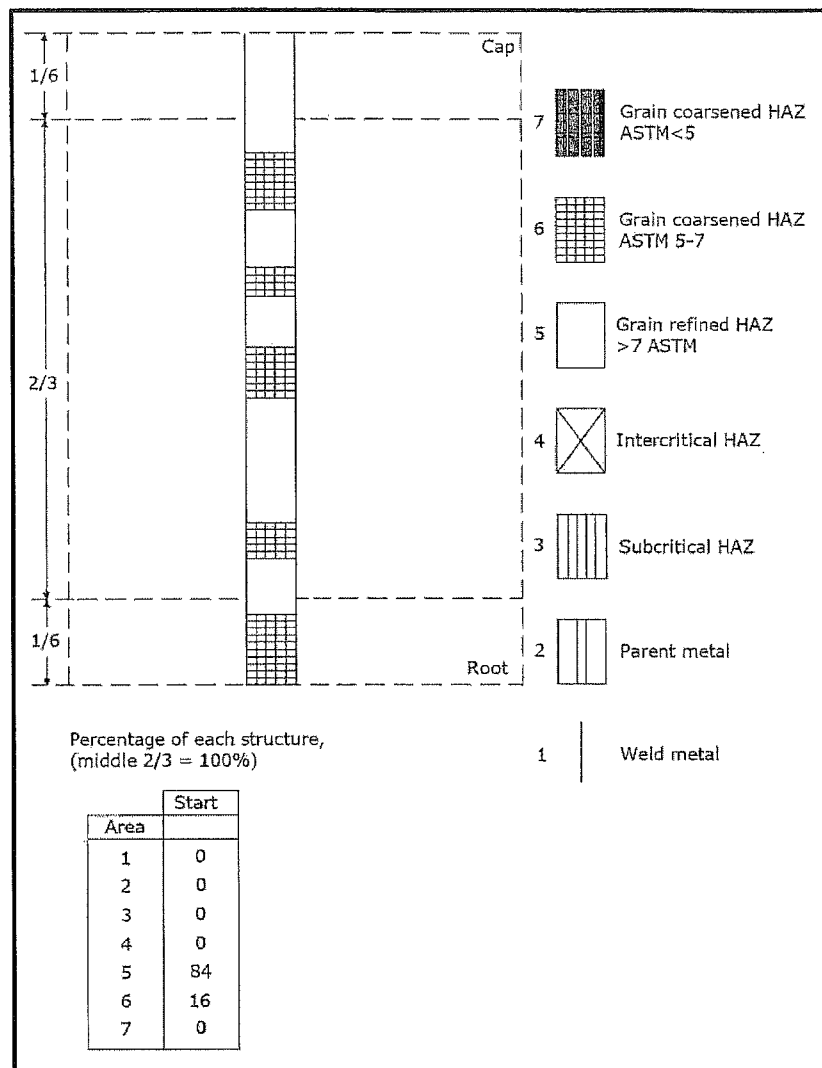


Figure A4 Idealised straight-line micro-map of HAZ

(iii) Determine the suitability of both the weld profile and HAZ profile for location of the notch and fatigue crack in the HAZ.

The test house shall notify the contractor and any sub-contractor should it consider that the profile is unlikely to result in successful placement of the fatigue crack with respect to the validation criteria specified by the purchaser (see A2.4.5). Additional macro sections may be taken, with the agreement of the contractor/sub-contractor, to identify a suitable portion of the test weld.

The test house may, with the agreement of the contractor, sub-contractor and purchaser, reject the test weld if it is considered unsuitable for testing.

Photomicrographs of each sample shall be taken for inclusion in the report;

(iv) Confirm that the number, position and sequence of the weld beads and resultant grain coarsening in the HAZ are representative of the procedure proposed for qualification and typical of that to be expected in production.

Should the purchaser consider the macro-sections are significantly different from the relevant test weld, then additional sections shall be removed to confirm the suitability of the remaining portions for testing. The purchaser may reject the test weld if its entire length is considered to be unrepresentative of the procedure proposed for qualification.

The information from (i), (ii) and (iii) shall be used to notch the CTOD specimens within the portion of the weld and HAZ considered to give the best possibility of producing a sample that will satisfy the validity criteria.

A2.2.2 Through-thickness notch placement

The notch shall be cut through, and be perpendicular to, the plate thickness and into the square side of the weld profile. The resultant fatigue crack tip shall be located in the microstructure described in Section A2.4.1, along the idealised CTOD notch line as shown in Figure A5. To achieve this, both side faces of the specimen shall be polished and etched in order to identify the HAZ microstructure.

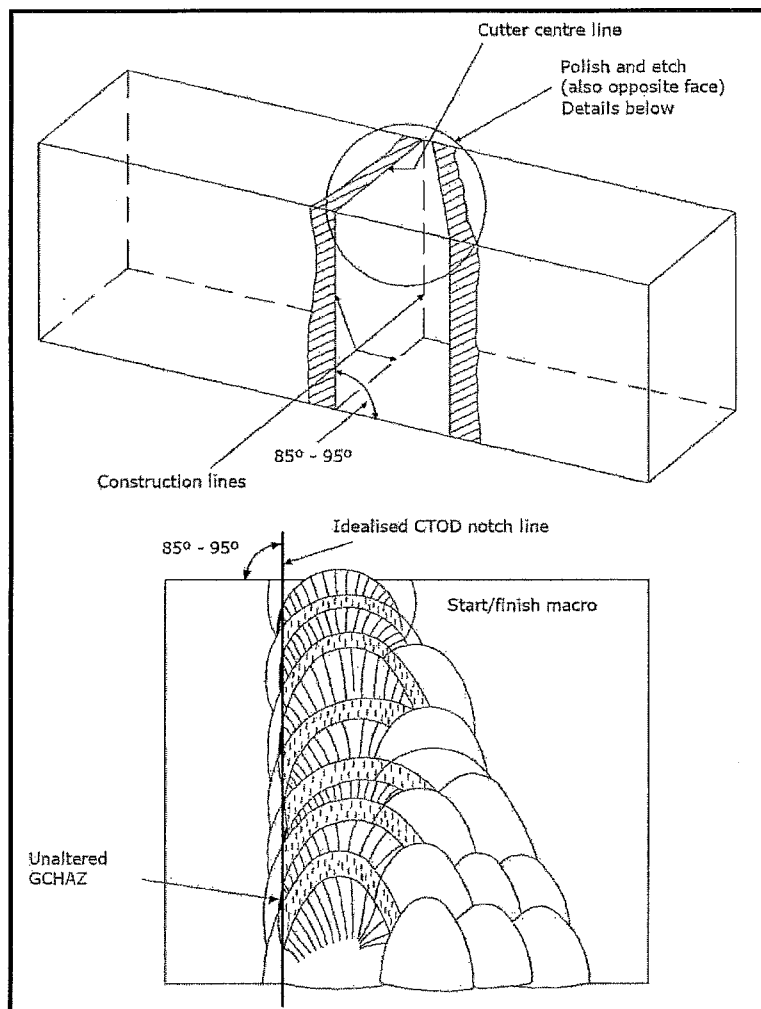


Figure A5 Details of notch placement for notched CTOD specimen

Construction lines shall be drawn across both side faces to maximise the intersection of the target microstructure in the middle two thirds of the specimen. The machined notch should be centred on and follow the line connecting the two construction lines across the specimen edge (Figure A5).

Local compression from both sides of the specimen up to 0.5% is permitted if the test laboratory considers that it will improve the fatigue crack shape. Tests should be made preferably within 21 days of the completion of welding.

A2.2.3 Surface notch placement

The surface notch shall be cut from the weld cap or root side such that the resultant fatigue crack tip shall be located in the microstructure described in A2.4.1, adjacent to the fusion line as shown in Figure A6. To achieve this, both side faces of the specimen shall be polished and etched in order to identify the HAZ microstructure.

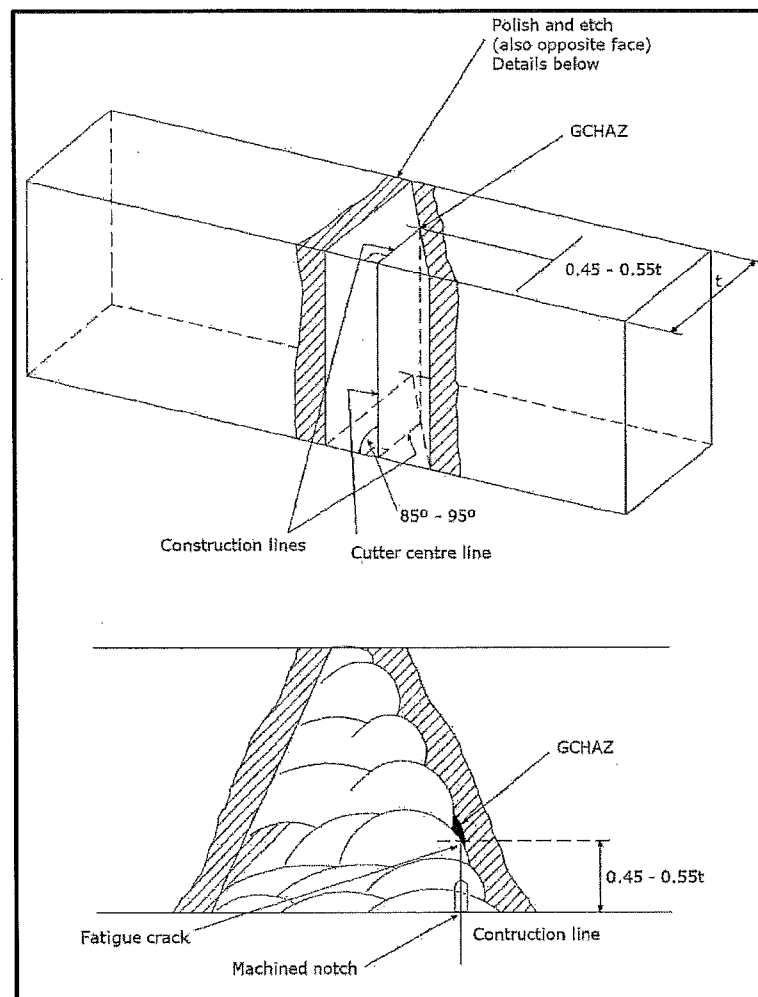


Figure A6 Details of notch placement for surface notched CTOD specimen

Construction lines perpendicular to the surface from the target zones should be drawn to provide the centre line for the machined notch (Figure A6).

Local compression of 0.5% on each side face is not normally required for surface notched specimens but may be permitted by the purchaser if the test laboratory considers that it will improve the fatigue crack shape. Tests should be made preferably within 21 days of the completion of welding.

Note: To allow for fatigue crack bowing, fatigue crack extension should be stopped 1 to 1.5mm from the target at the specimen edges.

A2.3 Testing

All testing shall be performed in accordance with ISO 15653:2010, and the testing machine shall be operated in displacement control mode. The first critical event on the load/clip gauge trace shall be reported (i.e. delta-c, delta-u or delta-m) including any significant 'pop-ins' when assessed against ISO 15653:2010. However, if the temperature at the fatigue crack tip deviates by more than $\pm 2^{\circ}\text{C}$ from the nominal value before this occurs, the test shall be abandoned and the value achieved when the temperature exceeded the tolerance shall be reported.

CTOD values shall be determined using either the parent material or weld metal yield strength (as specified by the purchaser) in accordance with ISO 15653:2010.

It is advisable to test HAZ samples in small batches to minimise the risk of unforeseen problems (such as poor fatigue crack shape) invalidating a large number of specimens, leading to excessive and unnecessary testing.

A2.4 Procedure for validation

A2.4.1 Definition of target microstructure

The target microstructure is defined as the high temperature fully transformed microstructure developed adjacent to the fusion line as a result of heat from the welding arc. This microstructure will not have been refined by the thermal effects arising from the deposition of adjacent weld beads (Figure A1).

Typically there is one such region associated with each weld pass along the fusion line adjacent to unrefined columnar grained weld metal.

Should bead placement generate a fully refined HAZ microstructure, or if small amounts of GHAZ are identified, which would be impractical to sample with the fatigue crack front, the target shall be the microstructure adjacent to the unrefined columnar grained weld metal, generally within 0.5mm of the fusion line.

A2.4.2 Sectioning/examination of through-thickness notched specimens

Following testing, each CTOD specimen shall be examined in accordance with ISO 15653:2010 and as detailed below to confirm that the fatigue crack tip has sampled the target microstructure.

- (a) Remove a 15mm slice containing the fracture face from each specimen half (see Figure A7a) and photograph one fracture face;
- (b) The weld metal side of the fractured CTOD specimen shall be sectioned across the mid two thirds region at a small distance back from the fatigue crack front, (Figure A7b). The distance from the fatigue crack front will be governed by the shape of the fatigue crack.

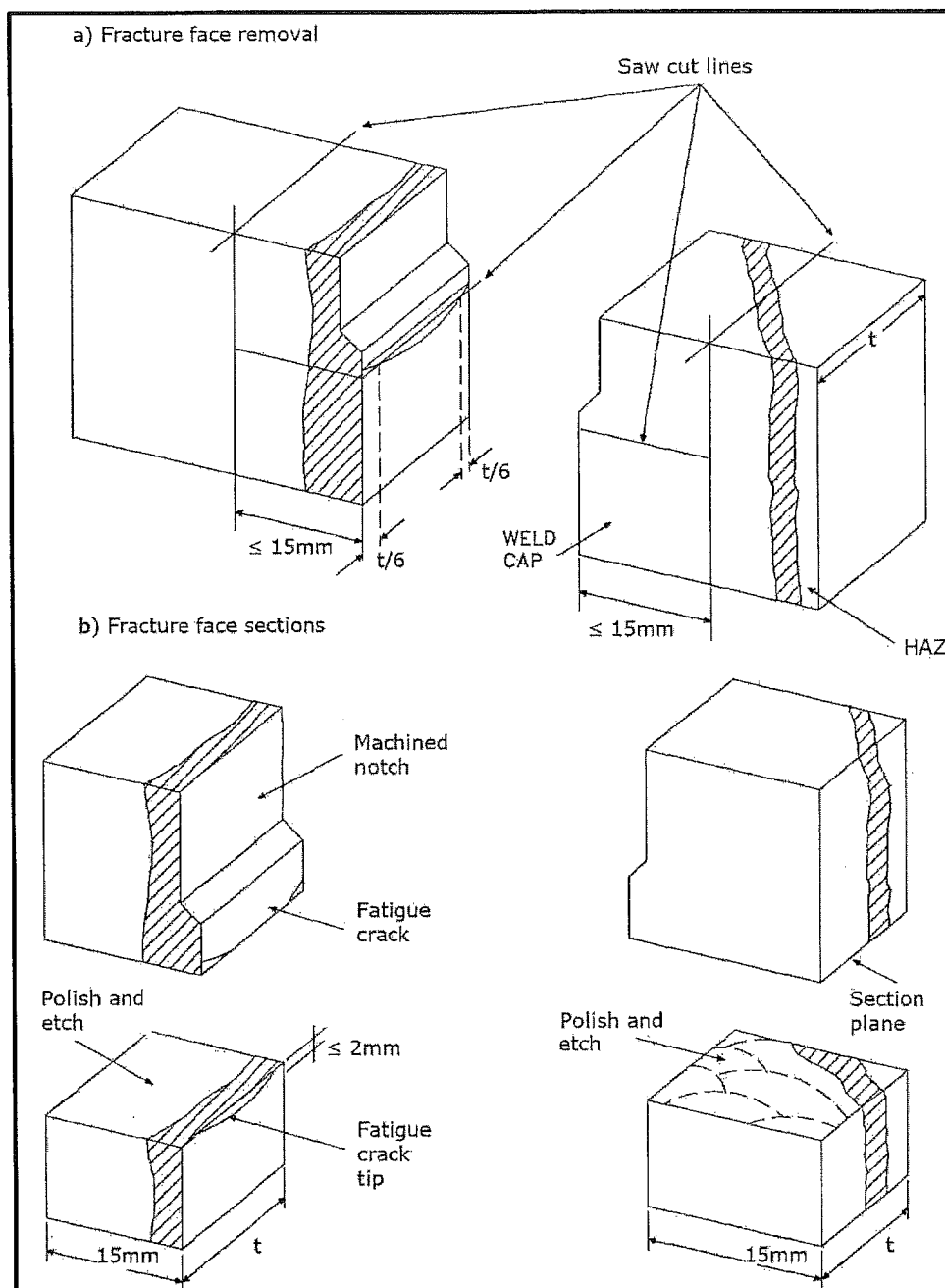


Figure A7 Details of post-test sectioning for through thickness specimens

In the case of a symmetrical fatigue crack, the section shall normally be taken as close as possible to the fatigue crack tip while still sampling the fatigue crack over the middle two thirds of the specimen. Normally this position is approximately 2mm or less from the position of maximum depth of the fatigue crack front. If it is possible to take the section through a distinct point of initiation while satisfying the aforementioned requirements, then this shall be done.

Where mounting is unavoidable a clear plastic compound shall be used.

The section shall be prepared for microscopic examination to record the microstructures and ASTM E112 grain sizes sampled by the fatigue crack front.

These shall be grouped into the following categories and the amounts reported.

- Weld metal
- GHAZ coarser than 5
- GHAZ grain sizes 5-7
- GHAZ finer than 7
- Intercritical HAZ (report grain size)
- Subcritical HAZ (report grain size)
- Parent metal (report grain size)

If there is a distinct initiation site, the location, microstructure and grain size shall be identified.

The amounts and locations of the above shall be detailed in sketch form at a magnification of at least 2:1 of the original plate thickness (Figure A8);

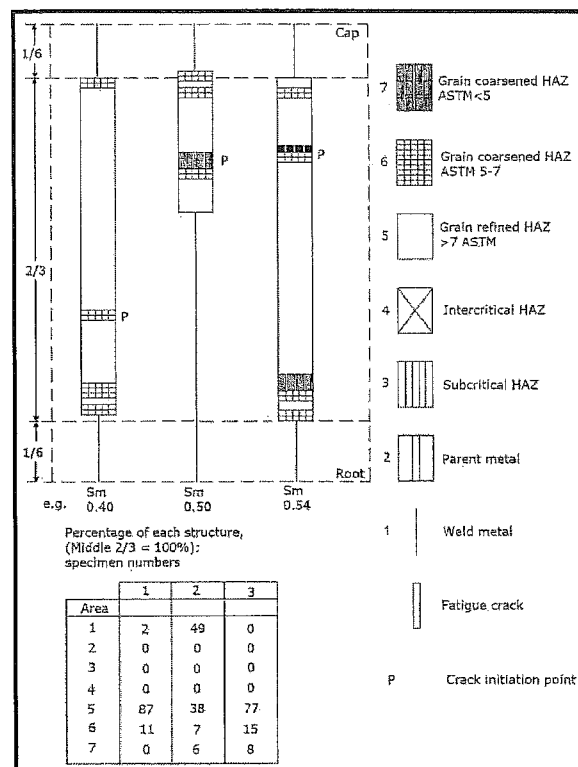


Figure A8 Micro-map showing microstructures and grain sizes

- (c) If the initial section fails to demonstrate that the specimen has satisfied the requirements of the validation criteria stipulated in A2.4.4, further sections may be taken with the agreement of the contractor/sub-contractor and purchaser. However, examination of the initial section may indicate that better validation is unlikely to be obtained.

Where further sections are required, these shall be obtained by grinding closer to the fatigue crack front. The distance ground back will depend on the shape of the fatigue crack. The aim of this is to examine the microstructure very close to the fatigue crack front and report the same information as required by (b) above, for the initial section.

If most of the fatigue crack front is in weld metal, the parent metal side shall be examined microscopically to determine the specimen validity. This option shall be considered upon examination of the initial section. If the fatigue crack front is in weld metal in the initial section, it is very unlikely to have deviated into the HAZ at the location of subsequent sections.

The parent metal side of the section shall be examined microscopically to determine whether the fatigue crack front has sampled the HAZ. If this is the case, the same validation techniques as required for the sections on the weld metal side shall be implemented.

A2.4.3 Sectioning and examination of surface notched specimens

Following testing, each CTOD specimen shall be examined to confirm that the fatigue crack tip sampled the target microstructure. Specimens shall be prepared as follows:

- (a) Remove a 15mm slice containing the fracture face from each specimen half (see Figure A9a) and photograph both fracture faces;
- (b) If a distinct initiation point is visible on the fracture face, section the fracture face perpendicular to both the original plate surface and the fracture face through the initiation point, as shown in Figure A9b;
- (c) If no distinct initiation is visible on the fracture face, then section as in (b) above, but through the centre line of the fracture face or the deepest point of the fatigue crack (but within the central two thirds of the specimen) as agreed with the purchaser;
- (d) Polish the whole side face of the specimen section associated with the event defined in either (b) or (c) to a standard suitable for metallographic examination;
- (e) Etch and record evidence of the microstructure sampled at the fatigue crack tip.

Where mounting is unavoidable a clear plastic compound shall be used.

If the fatigue crack does not conform to a smooth shallow parabolic shape or if other specified requirements are unresolved, additional sections may be necessary which should be agreed with the purchaser.

If the observations from the first fracture face are inconclusive it may be necessary to repeat the exercise on the second fracture face. This should be done by agreement with the purchaser.

Examination should be carried out using an optical microscope capable of taking photomicrographs of the relevant micro-structures.

Selection of the appropriate magnification shall be by agreement with the purchaser at the time of examination. A magnification of x50-100 is generally adequate.

The examination shall clearly identify the fatigue crack and evaluate the microstructure immediately adjacent to the fatigue crack tip, taking special note of the proximity of the fusion line and the adjacent weld metal microstructure.

Quantitative assessments of HAZ grain size shall also be performed in accordance with ASTM E112.

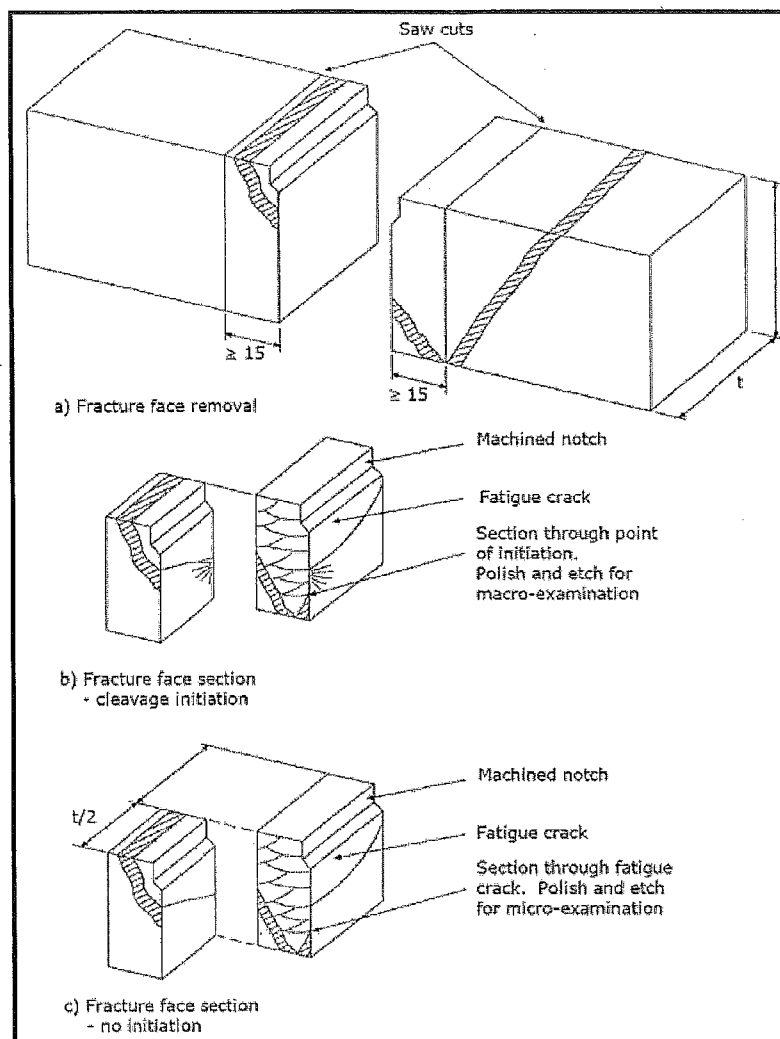


Figure A9 Details of post-test sectioning for surface notched specimens

A2.4.4 Test validity

To be considered a valid test, the crack plane and its associated geometry shall meet the requirements of ISO 15653:2010.

A2.4.5 Metallurgical validity

Through-thickness notched specimens

Unless otherwise agreed with the purchaser, the fatigue crack location shall only be considered valid when more than 50% of the fatigue crack front is located in the visible HAZ. This portion of the fatigue crack front shall maximise the amount of GCHAZ microstructure potentially available for sampling in this length and shall lie within 0.5mm of the fusion line. The target micro-structure shall be grain coarsened HAZ coarser than ASTM E112 grain size 5, if this is present, or grain size 5-7 in the absence of any coarser microstructure.

The amount of coarse grain potentially available shall be determined from examination of the start and finish macro-sections with the idealised CTOD test notch line as defined in A2.2.1(ii). The GCHAZ sampled by the crack front shall be reported as a percentage of that potentially available. Whichever of the start-stop macro-sections contains the lower percentage of GCHAZ shall be used in this assessment.

Surface notched specimens

The CTOD test shall be considered valid if, at the point of section, the fatigue crack tip samples the coarsest HAZ microstructure available, or if the coarsest HAZ microstructure available lies ahead of the fatigue crack tip by not more than 0.5mm.

A2.5 Reporting

All documents shall be of a standard format approved by the purchaser.

Traces, validity evaluations (including metallographic reports), calculations and results shall be submitted to the purchaser for all tests performed. The data shall include the applicable sketches and photographs detailed below:

(a) Test welds

Original and straight line micro-map sketches for microstructures and grain sizes at weld start and at weld finish.

Photomicrograph -weld start (general) and weld finish (general).

(b) All specimens

Photograph - weld metal side of fracture face.

Photograph - parent material side of fracture face.

(c) Each through-thickness notched specimen

Micro-map sketches for microstructures and grain sizes evident in initial section.

Photomicrograph - complete view of section.

Photomicrograph - principal area of grain coarsened HAZ sampled.

The reporting for any additional sections should be in the same manner as above.

(d) Each surface notched specimen

Photomicrograph of fracture face section showing the fatigue crack tip and adjacent microstructure relevant to the validation.

A2.6 Acceptance criteria and retesting

The CTOD value required for each application shall be specified by the purchaser.

Additional testing shall be allowed if one valid specimen (see A2.4.4 and A2.4.5) fails to meet the specified value. For acceptance, a minimum of five valid results shall then meet the specified value unless otherwise approved by the purchaser.

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