

RECOMMENDED PRACTICE
DNV-RP-F113

PIPELINE SUBSEA REPAIR

OCTOBER 2007

DET NORSKE VERITAS

FOREWORD

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Amendments and Corrections

This document is valid until superseded by a new revision. Minor amendments and corrections will be published in a separate document normally updated twice per year (April and October).

For a complete listing of the changes, see the "Amendments and Corrections" document located at: <http://webshop.dnv.com/global/>, under category "Offshore Codes".

The electronic web-versions of the DNV Offshore Codes will be regularly updated to include these amendments and corrections.

This DNV-RP-F113 replaces the previous DNV-RP-F104 which was issued in 1999.

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1. General

1.1 Introduction

This Recommended Practice (RP) applies to fittings used for repair and tie in of submarine pipelines. These fittings include: Couplings, Clamps, T-branch connections and Isolation Plugs. Mechanical means connect these fittings to the pipeline, however, sleeves/couplings and T-branches may also be welded.

The section on the strength of the mechanical attachments is also applicable to pipeline recovery tools.

Refer to Figure 1-1 for typical fitting applications.

Couplings connect pipes by direct attachment to the pipe walls via mechanical or welded joints. Flange connectors differ from mechanical couplings as flanges join pipes via thick, machined pieces of additional material that is welded or forged to the pipe ends prior to installation.

Clamps are fitted externally to the pipeline to prevent leaks or add strength.

Hot-tap T-branch connections are fitted externally to the pipeline assembly even during operation. A pressurized pipeline would be machined open to allow fluid flow through the branch.

Pipeline isolation plugs are pumped with the pipeline fluid to the repair site and then activated in order to form an isolating barrier that can resist differential pressure.

The pipe itself represents the key member of the repair assembly with consequential limitations such as, but not limited to, pipe wall strength, surface irregularities, and deviations in shape. Fittings for subsea repair must be installed with caution to reduce the likelihood of damage, (e.g. seal damage).

Coupling strength shall be sufficient in resisting stresses from all relevant loads, within a factor of safety as defined in Sec.4.6.

Pipeline damage

Pipeline damage after installation may be caused by internal and external corrosion, hydrogen induced stress cracking (HISC), unstable seabed conditions, anchors, and dropped objects from the surface. The risk of damage depends on the intensity of surface activities such as ship transport and off-shore operations, depth, seabed conditions and the design of the pipeline itself. The extent of possible damage will vary from insignificant to a fully buckled or parted pipeline. Consequently, the repair and repair preparedness strategy depends on this. Ref. 10 & 11 (CODAM & PARLOC) gives an overview of pipeline damage statistics. This is illustrated in Figure 1-2.

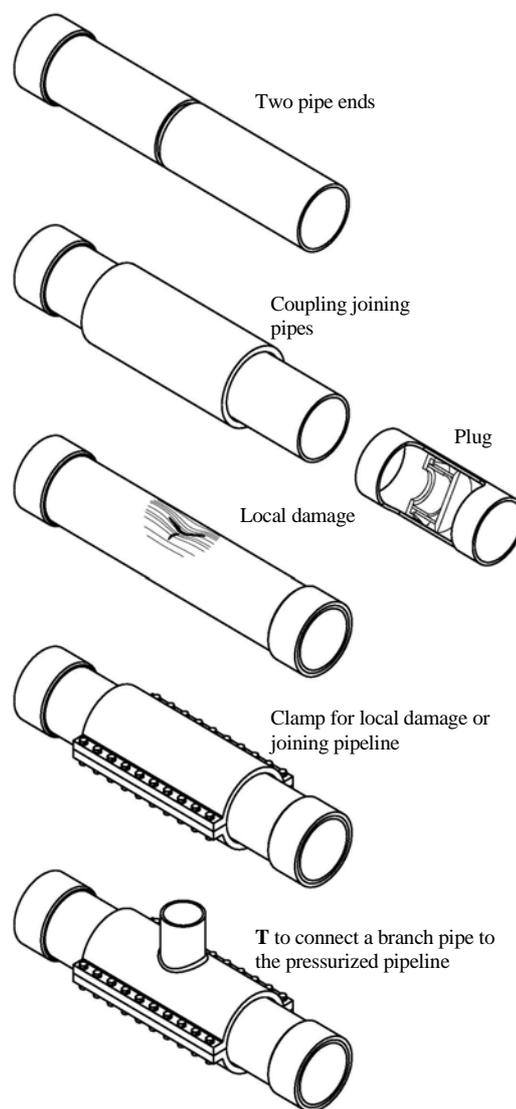


Figure 1-1
Typical installed fittings for repair

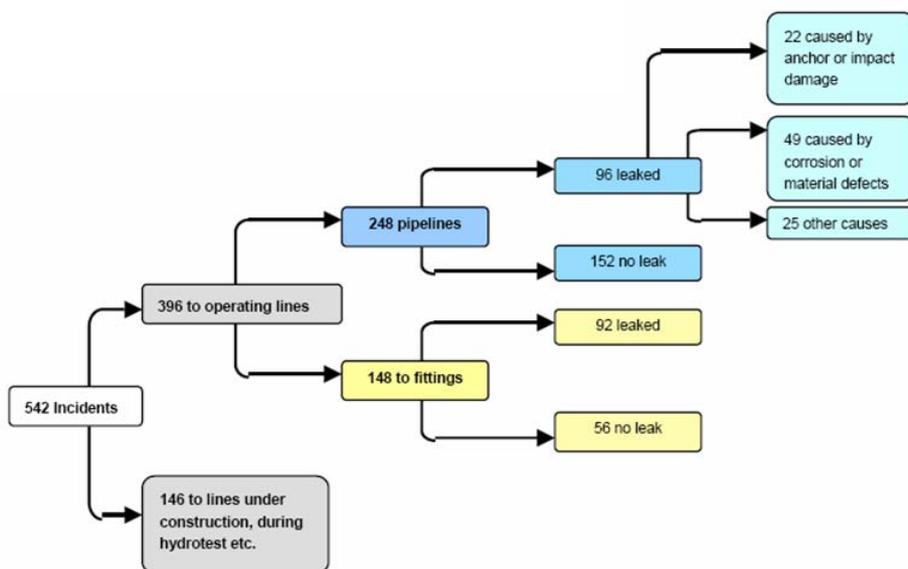


Figure 1-2
PARLOC2001; 542 reported pipeline/riser incidents in the North Sea (at the end of 2000)

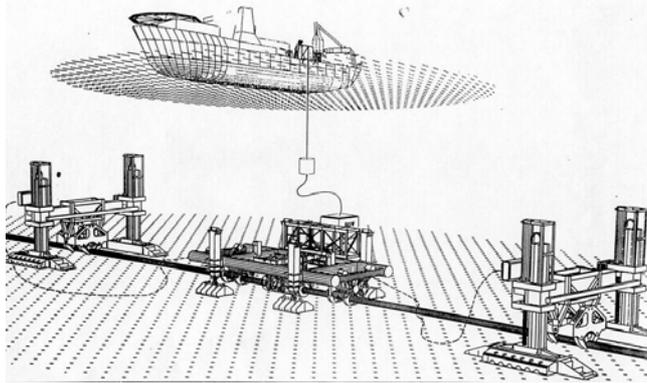


Figure 1-3
Typical support systems for a pipeline repair

Figure 1-3 illustrates the complexity of a subsea pipeline repair.

Historically shallow water repair have mostly been performed by divers. The water pressure, however, limits human hyperbaric intervention to a few hundred meters water depth due to the human physiology. National authorities further regulate this diving to more shallow depth limits as a mean to safeguard the divers. 180 m water depth presently represents such a limit in Norwegian waters. This depth limit is only a small step to the 2500 m viable for present deep water pipelines.

Consequently, pipeline repair in deeper waters has to be carried out based on remotely controlled techniques.

A pipeline repair in general requires a range of planning and investigations prior to the actual repair:

- Investigation of the damage, the pipe condition and consequences for the pipeline operation, i.e. will any repair be required? Should pollution counter measures be started? Should water ingress in the pipe be limited?
- Planning of uncovering and seabed preparation for the repair including calculations of the pipeline response from this action.
- Planning the repair operation based on the state of emergency preparedness and the results of the investigations. (Planning, ordering of equipment and support)
- Seabed preparations, pipeline pressure adjustments, repair
- Test to confirm the repair quality, protection of the repaired section, clean up and finish.

1.2 Application

This Recommended Practice (RP) is intended to provide criteria and guidelines for the qualification of fittings and systems used for pipeline subsea repair and/or modifications and tie-ins. It includes aspects relating to the design, manufacture, installation and operation of such fittings and systems.

This RP is intended to be used as a supplement to the DNV-OS-F101; Submarine Pipeline Systems, and is therefore also applicable to risers and topside parts of pipelines.

1.3 Structure of Recommended Practice

This document consists of the following main elements:

General (Sec.1) gives general information on the fittings, their application, relationship of this document to the DNV offshore standards, and the classification of the fittings with respect to strength and sealing.

Basic philosophy (Sec.2) establishes the basic qualification principles. A system for following up issues of concern for the

qualification is tabulated in Appendix C.

Pipeline (Sec.3), *Pipeline forces (Sec.4)* and *Installation (Sec.5)* deals with the interaction of the fittings with the pipeline.

Welding (Sec.6) covers subsea hyperbaric dry welding by remote operations.

Design (Sec.7) deals with main principles in design. Further guidance/discussions are given in Appendix A.

Testing (Sec.8) deals with the test philosophy relevant for the various development phases. Typical tests are described in Appendix B.

Documentation (Sec.9) deals with documentation requirements and certification relevant for the various development phases.

The specifications given in this Recommended Practice are supported by guidance, which is shown by Guidance notes.

1.4 Coupling function

Common locking principles showing a cross-section of the pipe wall and the coupling sleeve are illustrated in Figure 1-4.

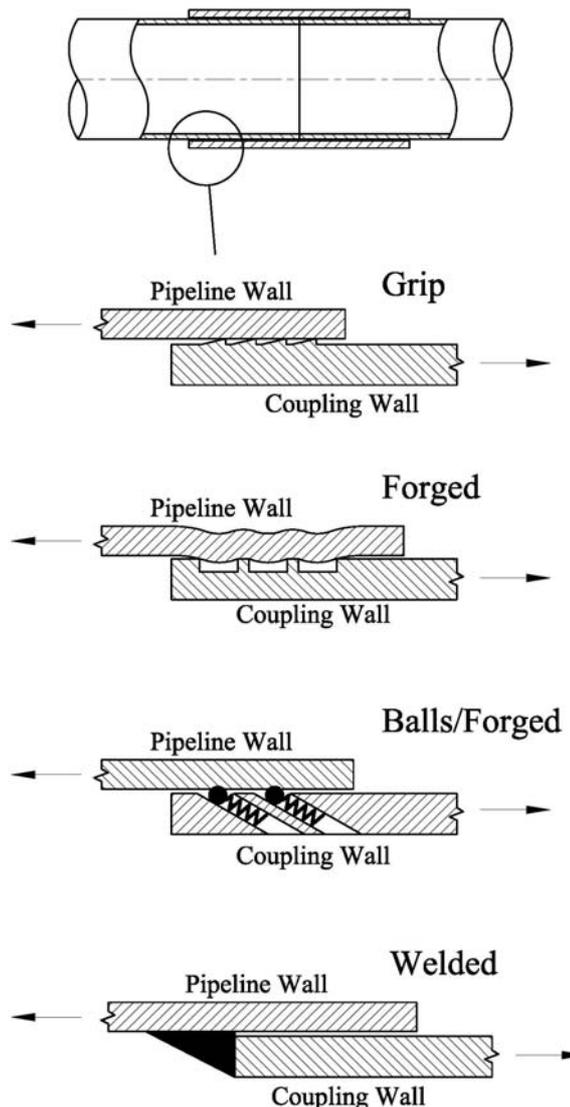


Figure 1-4
Locking principles

The *locking principles* can be divided into two main groups:

- 1) Mechanical attachment between the pipe wall and sleeve, as caused by the actions of auxiliary local attachments and/or friction.
- 2) Fillet welds between a sleeve and the pipe.

Furthermore, the main mechanical coupling *attachment methods* are based on the following two principles:

- 1) External compression of pipe “compression couplings”.
- 2) Internal expansion of pipe “expansion couplings”.

The radial contact forces between the mechanical coupling and the pipe is based on the initial pre-compression and/or the pipe tension. The latter can be an effect from designs using wedges or similar.

The main sealing principles for mechanical couplings are illustrated in Figure 1-5.

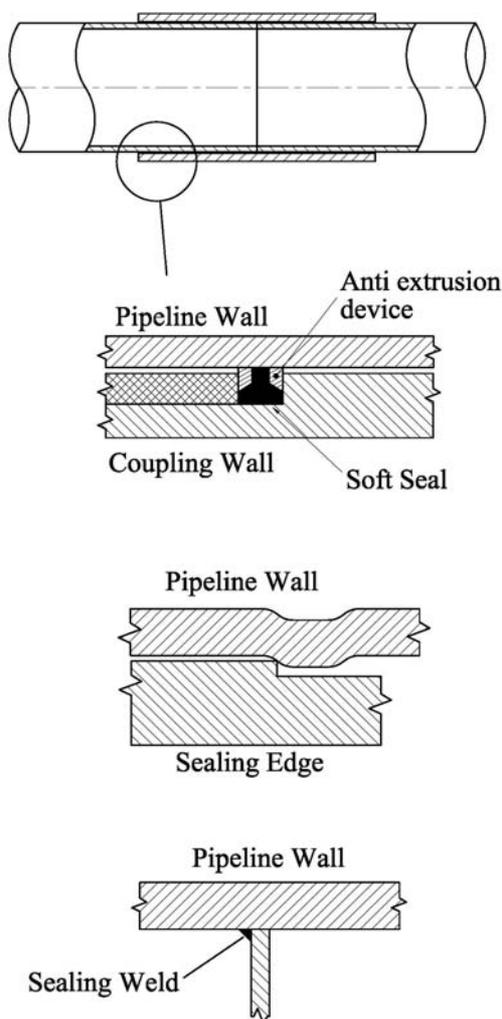


Figure 1-5
Sealing principles

- 1) Metal ribs or corners of grooves in the sleeve.
- 2) Pre-compressed soft seal enclosed by anti extrusion rings.
- 3) Pre-compressed soft seals strengthened by fibres.
- 4) Seal welds.

Some types of seals can be sensitive to damage if they touch the pipe before seal activation.

1.5 Specifications

The specification of pipeline subsea repair fittings shall include a list of all limiting parameters and relevant parameter combinations for installation and operation. Furthermore, it shall describe the minimum requirements (main specifications) for tools which are required to enable coupling installation within safe limits.

1.6 References

- 1) DNV-OS-F101: Submarine Pipeline Systems, referred to in this document as: “DNV-OS-F101”.
- 2) DNV-RP-A203: Qualification procedures for new technology.
- 3) API Bul 63 Testing of Oilfield Elastomers.
- 4) NORSOK M-710: Qualification of non-metallic sealing materials and manufacturers
- 5) API spec 6H Specification on End Closures, connectors and swivels.
- 6) DNV-RP-F104: Mechanical pipeline couplings. Which in 2007 is replaced by this DNV-RP-F113
- 7) API RP 2201: Safe Hot Tapping Practice in the Petroleum & Petrochemical Industries
- 8) ISO 17642-2: Destructive tests on welds in metallic materials -- Cold cracking tests for weldments -- Arc welding processes -- Part 2: Self-restraint tests
- 9) EN 1418: Welding personnel - Approval testing of welding operators for fusion welding and resistance weld setters for fully mechanized and automatic welding of metallic materials
- 10) CODAM: Pipeline damages - Damages and incidents, Petroleumstilsynnes Norway
- 11) PARLOC: The update and loss of containment data for offshore pipelines, HSE UK

1.7 Definitions

<i>Locking</i>	=	mechanical or welded firm connection
<i>Locking capacity</i>	=	strength of the attachment to the pipe
<i>Safety factor</i>	=	see Sec.2
<i>Sleeve-type coupling</i>	=	coupling enclosing the pipe as a sleeve. This applies to all current pipeline couplings.
<i>Fittings</i>	=	In this publication the term "fittings" is limited to: Couplings, Clamps, Hot-tap T branch connections and Isolation plugs intended for submarine pipelines.

Other definitions are given where relevant in the text.

1.8 Abbreviations and Symbols

Where used in this document, the following symbols are defined as:

A_e	=	External pipe cross section area
		$\frac{\pi}{4} \cdot D^2$
A_i	=	Internal pipe cross section area
		$\frac{\pi}{4} \cdot (D - 2 \cdot t)^2$
A_s	=	Pipe steel cross sectional area
		$\pi \cdot (D-t) \cdot t$
AUT	=	Automated Ultrasonic Testing
a	=	Misalignment angle (radians)

b	= Misalignment between the pipe ends (radians)	n	= Axial length from the coupling entrance to the end of the same inner diameter. (Length of equal internal diameter)
D	= Outside pipe diameter	p_i	= Internal pressure
D_c	= Couplings/Sleeve bore diameter	p_e	= External pressure
E	= Modulus of elasticity	Δp_i	= $p_{i,operation} - p_{i,depressurised}$
e	= Diametric clearance (considering constant internal diameter): $D_c - D$	R	= Average bending radius
e_f	= Change in diameter due to tension force	s	= Defined in text as either: <ol style="list-style-type: none"> 1) Straightness of a pipe/section specified in % of L 2) Safety distance (say 0.3 mm) to compensate for deflections and possible protrusions on the pipe end
e_o	= Out of roundness (OOR, ovality) tolerance	S	= Effective axial pipeline force, i.e. forces transferred by soil friction, supports etc. (Tension is positive)
e_l	= Straightness tolerance for the pipe section of concern	S'	= $S/(A_s * f_y)$
e_m	= Tolerance combination	SLS	= Serviceability Limit State
e_p	= Change in outer diameter of pipe	$SMYS$	= Specified minimum yield stress
e_c	= Change in internal diameter of coupling/sleeve respectively	$SMYS^T$	= $SMYS$ de-rated due to elevated temperature
E_t	= Defined in text as either: <ol style="list-style-type: none"> 1) External diameter tolerance 2) "shrink fit" 	ΔT	= Temperature-difference
e_{tm}	= Shrink fit produces a contact pressure, which generate a fraction of yield stress of pipe	T_o	= Operational temperature for sleeve
ECA	= Engineering Criticality Assessment	T_m	= Make up temperature
$f_{u,temp}$	= Ultimate strength de-rating due to temperature in excess of 50°C	ULS	= Ultimate Limit State
fc_b	= the characteristic burst material strength	WIP	= Welding Installation Procedure
FL	= Fusion lines (See Sec.6)	t	= Wall thickness
f_y	= Yield strength to be used in pipeline design according to "DNV-OS-F101"	α	= Temperature-expansion coefficient,
	= $SMYS^T \cdot \alpha_u$	α_A	= The anisotropy factor; (in the 2007 update of DNV-OS-F101 this factor has been removed)
$GMAW$	= Gas Metal Arc Welding	α_{fat}	= Allowable damage ratio for fatigue
$GTAW$	= Tungsten, Inert Gas Arc Welding	α_u	= Material strength factor according to DNV-OS-F101: 0.96 for normal materials 1.00 for materials to supplementary requirements U
$HWPS$	= Hyperbaric Welding Procedure Specification	σ	= Stress
$pHWPS$	= Preliminary Hyperbaric Welding Procedure Specification	$\sigma_{eq, nom}$	= The equivalent stress averaged over the thickness
$HWPQR$	= Hyperbaric Welding Procedure Qualification Record	γ	= Resistance and load factors with the following notifications: <ol style="list-style-type: none"> γ_1 = Load factors γ_F = Functional loads γ_E = Environmental loads γ_A = Accidental loads γ_p = Pressure loads γ_c = Condition load system pressure test γ_2 = Resistance/resistance (Capacity) factors γ_{sc} = Safety class resistance factor γ_m = Material factor γ_{mw} = Weld Material factor γ_e = Resistance strain factor
l	Length of fitting/sleeve/coupling for $l/L < 0.5$	η_s	= Usage factor for pressure containment
L	= Defined in text as either: <ol style="list-style-type: none"> 1) Length of line pipe section (normally 12 m) or specified section 2) Length of contact surface between sleeve and pipe 	ν	= Poisson's ratio
m	= Gravity force of pipe with internal fluid and possible concrete per unit length, i.e. combined weight and buoyancy	μ	= Friction coefficient simulating lateral soil resistance
N	= Pipe wall axial force, i.e. the axial force as imposed on the coupling (Tension is positive)	x_1	= Sleeve eccentricity (offset from centre line) at entrance
N'	= $N/(A_s * f_y)$	x_2	= Offset between pipe ends
N' with the following notations:		y_1	= Overlap length i.e. degree of sleeve displacement over the pipe(s) at the moment of time considered. Maximum y_1 is the length of the coupling.
N'_{pt}	= Pressure test	y_2	= Half coupling length (bridging one pipe end)
N'_o	= Operation	y_i	= Distance from the coupling entrance to the seal.
N'_a	= Pressure effects only		
N'_b	= Restrained pipe case, either in compression or tension		
N'_c	= Pipe in a curve - moving cases		
NDT	= Non-Destructive Testing		
Numbers	= 1, 2, 3 and 4 are related to: <i>expansion forces</i> due to: 1) pressurised and hot, 2) depressurised and hot, and <i>contraction forces</i> due to: 3) pressurised and cold, 4) depressurised and cold.		

2. Basic philosophy

2.1 Safety philosophy

The safety philosophy for the repaired/modified pipeline shall comply with the requirements specified in DNV-OS-F101. Generally Safety Class Low will apply to installation and testing (provided the content during testing is water). Safety Class Normal or High will apply during operation with hydrocarbons, depending on the location being considered.

Repair/modification of an oil or gas pipeline may include temporary opening to the environment or opening of a pressurized pipeline e.g. in conjunction with a plug operation and "hot-tapping". These temporary operational phases should satisfy the Safety Class "Normal" criteria when the consequences to the environment (pollution, personnel) from failure would be comparable to that from a leaking pipeline. For less consequences the temporary phase safety class could be "Low".

Guidance note:

Isolation plugs can form a double or single pressure barrier in the pipeline. In general barriers are termed double when each can retain the full pressure alone, each are tested, their integrity can be monitored and they are "independent" from each other.

The total plugging system shall satisfy the Safety Class requirements described above.

It is common to use double barriers where personnel can be affected (i.e. divers for subsea work)

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2.2 Qualification

The qualification of fittings should, in general, be based on verification of compliance with given functional specifications and safety margin against possible failure modes.

Reference is also made to DNV-RP-A203: Qualification procedures for new technology. This publication gives general guidance for qualification of new technology as well as proven technology.

This qualification should be based on the following principles:

- 1) Functional requirements shall be quantitative.
- 2) Possible failure modes shall be identified (See Sec.7.1).
- 3) Theoretical analysis/calculations shall be used as the main tool to document fulfilment of the functional specifications and safety against failures. The theoretical calculations shall be verified by tests.
- 4) The safety factors shall be established based either on recognised standards, or on combinations of all uncertainties and inaccuracies used in the data, operation, calculations and tests. This applies to loads, strength, sealing and function. (Acceptable failure probabilities versus Safety Class is defined in "DNV-OS-F101". The Safety Class "high" applies for general use because it covers all classes.)

- 5) Measurements and tests shall be used as the main tools to document that manufacturing gives fulfilment of the functional specifications.
- 6) A systematic approach shall be applied to ensure that all functional specifications are fulfilled for new concepts/applications. This shall be based on a combination of an analytical/numerical approach and prototype tests.
- 7) Experience which is intended to be used as proof of fulfilment of the specifications and safety against possible failures modes shall be documented.
- 8) Tests or reference to recognised literature shall identify limiting material and functional parameters.
- 9) Alternative methods to those described in this document may be used provided that they are supported by equivalent evidence for the suitability of their application.

2.3 Analytical methods

2.3.1 General

An analytical/numerical approach should be applied as the main tool to enable qualification. This type of approach will establish the individual and combined effects of the different parameters.

Guidance note:

Finite Element Analysis (FEA) may be used for detailed study of stresses and deflections from symmetric and unsymmetrical loads, including material plastic yielding, friction, contact, collapse and motions, i.e. combination of a range of non-linear effects.

A theoretical model including all parameters and effects will be complex to use, and so it is often more practical to apply simpler models for analysis of separate parameter effects. Such models can also be studied by FEA, and/or by "simplified analysis". Programs such as "mathematical" programmes (e.g. Mathcad) are the most convenient for handling simplified analysis. The advantage of using a "mathematical" programme rather than a spreadsheet is that the method (formulas) is easily documented. Spreadsheets are widely used, but require additional documentation of formulas which are actively used in the computations.

"Simplified Analysis" may be used when the behaviour is understood and the computation model is representative. But it may be difficult to apply when all relevant effects are combined and may also have larger inaccuracies than complex FEA.

Elastic - formulas

Formulas can be developed either by derivation from textbooks or based on test results. Software with formulas from some textbooks such as "Roark's formulas for stress and strain" is available. These formulas are limited to elastic analysis.

Plastic - formulas

Formulas for plastic yield can be developed, but normally require calibration by test and/or FEA. Practical applications would be to establish possible plasticity of the pipe shell, both through the wall and by hard bodies (seals and grips) forced into the surface.

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3. Pipeline Design Basis

3.1 General

The pipeline design basis shall be specified, and shall include:

- Design pressure, fluid temperature and description of transported fluid,
- Water depth and sea temperature,
- External pipe diameter, wall thickness, corrosion allowance and material specification,
- Reference standard for manufacturing and dimensional tolerances.

Guidance note:

The pipeline standards specify most of these tolerances related to pipe fabrication and pipeline installation. Dimensional tolerances of concern with design are dealt with in the following.

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3.2 Dimensional Tolerances

3.2.1 Welds and surface imperfections

The weld itself can cause a local discontinuity on the pipe surface. Surface roughness and discontinuity tolerances are of concern with respect to the seals. The coupling shall be qualified for the pipe either:

- with the quantified surface imperfection, or
- after removal of the surface imperfection.

3.2.2 Line pipe

External diameter tolerance, e_t is mainly derived from the measurement of the circumference and therefore represents an average.

Out of roundness (OOR, ovality) tolerance, e_o is measured by a gauge.

Local out of roundness tolerance, e_l , reflects dents and peaking.

Straightness of the pipe section, is normally measured by a taut string between the ends, and measures the greatest distance to the pipe surface. Straightness within the length of the fitting is normally not specified and therefore special considerations must be made.

Straightness of the pipe section of concern e_s is within the length of the fitting. The following formula applies to a possible “S” shaped pipe:

$$e_s = (2l/L)^2 \cdot s \cdot L / 100$$

l = Length of fitting for $l/L < 0.5$

L = Length of line pipe section (normally 12 m) or specified section

s = Straightness of pipe/section specified in % of L

3.2.3 As installed

The installation procedures can, in particular cases, cause additional flattening (out of roundness) due to bending of the pipe.

3.2.4 Extreme Maximum & Minimum diameter

The maximum and minimum internal “no touch” fitting diameter to cover the tolerance combination e_m , which is due to each of the above extreme tolerances excluding the possible flattening effects from the installation, is:

$$e_m = \pm e_t \pm 0.5 \cdot e_o \pm e_l + e_s$$

Provided the installation effects (above subsection) can be neglected, this represents a conservative extreme limit. A less extreme and more realistic limit can be based on procedures described in the next subsection.

Guidance note:

The effects of the straightness (e_s) should also be dealt with separately for assessing the alignment during installation (see Sec.5).

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3.2.5 Statistical Maximum & Minimum diameter

Guidance note:

The extreme tolerance combination is unlikely to occur for most pipeline types.

The fitting design is sensitive to the pipeline dimensional tolerance. Specification of an over conservative tolerance combination could be difficult to cover with one size of the fitting.

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Statistical evidence shall be used to establish the likely maximum tolerances, if not the unlikely extreme tolerance combinations presented in the subsection above is applied.

4. Pipeline Exposures

4.1 Fundamental pipeline forces

Tension and torque forces in the pipeline are removed when cutting the pipeline subsea.

The changed pipeline conditions after coupling installation generate the following forces:

- 1) Soil friction. This force is dependent on the friction coefficient and the force/displacements caused by:
 - axial expansion forces due to increased temperature
 - axial expansion due to changed pressure, or
 - subsidence of the sea bottom resulting in lateral displacements e.g. as in the ekofisk area in the north sea.
- 2) Forces in the pipeline caused by internal pressure.
- 3) Forces caused by the repair operation and gravity, such as tension/compression, bending moment and torque.
- 4) Forces released after the repair operation, such as tension forces in steep slopes
- 5) Possible changes in pipeline support/soil conditions e.g. causing free spans.
- 6) Possible external transverse loads from fishing gear.
- 7) Possible hydrodynamic forces caused by current and wave actions.
- 8) Accidental loads identified to be of concern e.g. caused by mud slides and dragging anchors.

Guidance note:

Torque can be caused by the connecting operation when curved spool pieces are used. Normally of most concern will be the tension in operation.

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Mechanical and welded sleeve type couplings and pipe branch connections are subject to:

- bending moments and
- axial forces transferred from the pipeline
- forces generated in the coupling by fluid pressure acting on areas protruding from the pipe internal cross section.

Guidance note:

The following fundamental assumptions should be considered to apply with respect to force exposure using a mechanical or welded sleeve type coupling or branch connection:

- 1) Pressure testing of the pipeline after repair is to verify the repair location and not the entire pipeline. The test pressure is therefore determined in accordance with DNV-OS-F101 Sec 5 B202, i.e. to exceed the local incidental pressure at the repair location by a factor of 1.05.
- 2) Repair is normally planned with well-known sea-bed conditions and where necessary intervention (e.g. rock-dumping) has been made. Therefore there should in general be no need to apply factors for "uneven seabed" (e.g. from DNV-OS-F101)
- 3) In accordance with DNV-OS-F101, all loads are to be established for a non-corroded section.

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A load condition of concern to a sleeve type coupling is tension, with no internal pressure. This is a rare case which can occur if;

- 1) The pipeline, in a hot condition, changes position due to the temperature expansion (snaking), and thereafter the fluid transport is stopped. The pipeline then cools off and the pressure is relieved.

- 2) A Free span is developed underneath the coupling and the adjacent pipeline, either in an expansion loop or on a large slope.
- 3) The pipeline is subject to subsidence, mud slides or dragging anchors.
- 4) The connection operation applies large external forces to join the two pipe ends.

Item 1 is only of concern to pipelines with elevated temperatures and for some soil conditions.

Item 2 is also predictable and can be controlled by inspection.

Item 3 is only seldom of concern.

Item 4 is easily predictable based on the joining tool capacity.

4.2 Maximum Axial Pipeline Forces

4.2.1 Scenarios

The couplings are subject to the forces conveyed from the pipeline (true wall forces), forces generated in the coupling by fluid pressure acting on areas protruding from the pipe internal cross section and pretension forces.

The following descriptions relates to the true wall axial forces. The maximum forces depend on:

- Pipeline soil interactions
- Operating conditions.

The following three scenarios represent the limiting conditions:

- a) Free pipeline, elbow or free end of pipeline, all with internal over-pressure. The axial pipeline forces caused by internal pressure is governed by the pressure and hence the test pressure force dominates.
- b) Restrained pipeline. The axial pipeline force is governed by rigidity of the restraint.
- c) Pipeline on seabed with expansion loops or imperfections. The force is less than half the force determined for an imaginary completely fixed pipeline, provided that the possibility of locking of the pipe (e.g. by sand settling) in an expanded (e.g. by temperature and pressure) configuration is avoided.

In general these scenarios should be included when considering the relevance of the following load cases:

- a) Pressure test - maximum tension
 - at manufacturer
 - of pipeline.
- b) Pressure test of pipeline - maximum compression
- c) Operation - (maximum tension)
- d) Operation - (maximum compression)
- e) Operation - fatigue 1 (tension)
- f) Operation - fatigue 2 (compression).

Combined load cases with bending moments shall be included for coupling types which also are sensitive to bending moments.

Guidance note:

1a): The implied limits in OS-F101 (0.96SMYS/0.84SMTS) for system pressure testing are for a very large number of joints and are not relevant for the capacity assessment of a single test pipe on which a coupling is mounted for testing. Most fittings will be tested at the manufacturer to a test pressure exceeding the pipeline's local test pressure after installation. Pressurising to 105% or even 110% SMYS is commonly practiced.

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4.2.2 Free pipe end “end cap”, (scenario a)

This load case is typically related to the conditions during factory pressure test and installations in expansion loops with negligible friction. The normalised force relative to the pipe yield strength is:

$$N'_a = \frac{p_i A_i - p_e A_e}{f_y \cdot A_s} \quad (1)$$

This maximum axial tensile force will be established as:

- $N'_a = N'_{pt}$ during pressure test
- $N'_a = N'_o$ at design pressure
- p_i = the internal pressure at the condition considered.

Guidance note:

The maximum internal seal diameter in the coupling governs the internal pressure term of the axial force.

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4.2.3 Restrained pipeline, (scenario b)

Compression(Initially restrained pipe)

The maximum obtainable compression forces through the coupling occur if the pipeline at each side of the coupling has been rock dumped before pressurisation. This restricts coupling expansion completely, giving a force relative to the pipe strength of:

$$N'_b = -\frac{\Delta p_i \cdot A_i}{f_y \cdot A_s} \cdot (1 - 2 \cdot \nu) - \frac{E \cdot \Delta T \cdot \alpha}{f_y} + \frac{p_i \cdot A_i - p_e \cdot A_e}{f_y \cdot A_s} \quad (2)$$

This condition is considered conservative. At elevated temperatures, the adopted design configuration may allow the pipe to buckle.

High temperature is of concern for export pipelines close to platforms, and flowlines close to wells. The tie-in arrangement normally allows for axial pipeline expansion and therefore this force will be smaller than above in most cases.

Tension (Initially free, then restrained pipe)

The shutdown includes pressure release and cooling. Given that the pipeline is initially free to expand longitudinally without any resistance in order to accommodate temperature and pressure effects, then subsequent restraint can be caused by, e.g.

- soil penetration beneath an upheaval buckle;
- soil cover on the expansion loop, restricting movement back to the original position; or
- the pipeline has been rockdumped whilst in operation.

Eq. 2 also applies for the tension force provided that the following definitions are made:

- Δp_i Internal pressure after shut down (pressure at installation) minus internal pressure before.
- ΔT Temperature after shut down minus temperature before.

The signs will be changed for the two first terms of Eq. 2:

With pressure and cooled down

$$N'_{b3} \approx \frac{E \cdot |\Delta T| \cdot \alpha}{f_y} + \frac{p_i \cdot A_i - p_e \cdot A_e}{f_y \cdot A_s} \quad (3)$$

After pressure relief & cooled down, i.e. p_i is reduced to its minimum and Δp_i and ΔT increased to their maximum in Eq. 4.

$$N'_{b4} = \frac{|\Delta p_i| \cdot A_i}{A_s \cdot f_y} \cdot (1 - 2 \cdot \nu) + \frac{p_i \cdot A_i - p_e \cdot A_e}{f_y \cdot A_s} + \frac{E|\Delta T| \cdot \alpha}{f_y} \quad (4)$$

4.2.4 Expansion loop effects, scenario c)

The axial forces are within the limits identified by scenario a) and b). An expansion loop or a pipeline with an initial imperfection may respond to the axial force by deflections of the pipeline curvature, governed by the resistance to this deflection.

This is illustrated by Figure 4-1 which shows the effects of lateral soil resistance on axial force.

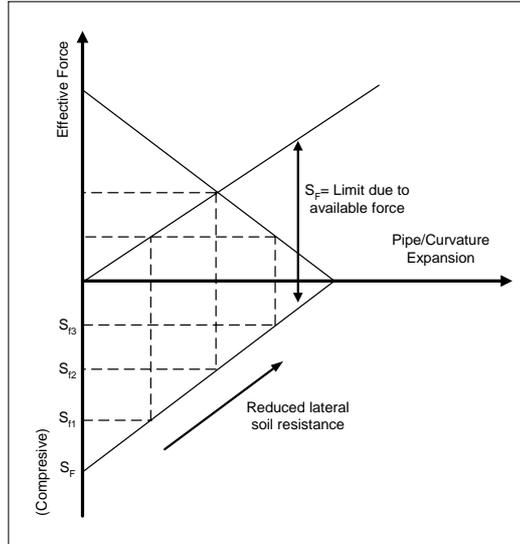


Figure 4-1
The effective force “S” in the restrained pipe as function of the pipe expansion in the curvature. This expansion is limited by the lateral soil resistance.

Guidance note:

This figure represents an ideal case which considers:

- equal lateral friction coefficients for expanding and contracting motions, and
- pipeline curvature radius, which is not affected by the motion.

The maximum pipe tension and maximum positive effective force, can only be obtained when:

The friction coefficient, curvature radius and weight are all relatively high.

At start-up of the pipeline, the friction will first cause compressive forces in the pipeline until the friction resistance capacity is exceeded. The pipeline will then start to move laterally. The lateral resistance corresponds to an axial capacity of S_{F1} , S_{F2} or S_{F3} .

The remaining part of S_F causes the motion by “Pipe/curvature Expansion” as shown by the figure. This expansion continues until the compressive force is reduced to a level which is equal to the soil capacity for the curved pipe. Thereby this compressive force remains in the pipe when it stops.

When the pipeline is shut down, and thereby cools down and depressurises, it will contract, i.e. be offloaded and subject to tension due to the soil interaction. This remaining tensile force:

- will be limited by the soil friction capacity,
- cannot be larger in magnitude than the compressive force,
- is created after the initial compressive force is released.

These limits are indicated on the upper part of the figure by the two 45° lines. Possible tension Effective Force is below these limits.

Therefore the maximum tension force is limited to half the possible restrained Effective Force when the end cap force is neglected.

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The maximum pipe relative tension force in the expansion loop, when conditions enabling scenario b) can be neglected, is:

$$N'_{c4} \approx \frac{|\Delta p_i| \cdot A_i}{2 \cdot A_s \cdot f_y} \cdot (1 - 2 \cdot \nu) + \frac{E \cdot |\Delta T| \cdot \alpha}{2 \cdot f_y} + \frac{p_i \cdot A_i - p_e \cdot A_e}{f_y \cdot A_s} \quad (5)$$

Eq. 5 is equivalent to Eq. 4 except for the terms expressing the "effective" pipeline force which has been halved for this depressurised (small p_i and large Δp_i) and cold pipe (large ΔT). The contraction of the pipe tends to straighten the curvature of the pipe.

With pressure (high p_i) and cooled down:

$$N'_{c3} \approx \frac{E \cdot |\Delta T| \cdot \alpha}{2 \cdot f_y} + \frac{p_i \cdot A_i - p_e \cdot A_e}{f_y \cdot A_s} \quad (6)$$

Figure 4-2 shows the actual pipe forces in an expansion loop configuration.

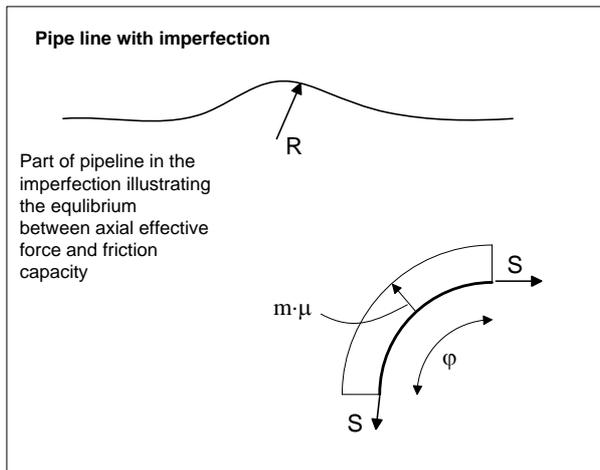


Figure 4-2
Simplified calculation of required pullback forces

During a pipeline contraction, the maximum tension force relative to the pipe strength is:

$$N'_c = \frac{R \cdot m \cdot \mu}{f_y \cdot A_s} + \frac{p_i \cdot A_i - p_e \cdot A_e}{f_y \cdot A_s} \quad (7)$$

The lateral soil resistance ("friction") coefficient is dependent on the weight of the pipe, soil type, character of motion and length of motion. Complex methods are available to predict such coefficients.

Guidance note:

Typical soil resistance coefficients are given in Table 4-1:

Table 4-1 Typical pipe/soil friction coefficients		
Soil type	Axial	Lateral
Sand	0.5 to 0.6	0.6 to 1.0
Clay	0.2 to 0.5	0.2 to 1.0

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4.3 Force boundaries

The maximum residual tensile forces relative to the pipe's yield strength given by the previous three scenarios are plotted in Figure 4-3 for a typical pipeline. The "Normal" safety class is considered and no external pressure is included.

Figure 4-3 shows as a function of changing temperatures the tensile force N'_a for a pipeline free to move during the pressure test, N'_b for the extreme case when the pipeline has been free to move and then restrained, and N'_c for the pipeline in an expansion loop. Denotations for cases with (3) and without (4) pressure are indicated.

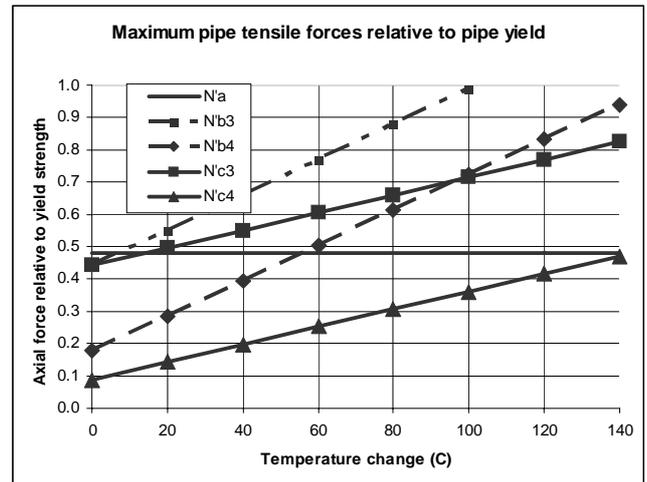


Figure 4-3
Maximum tensile forces in a pipeline for the three scenarios described

4.4 Limiting displacements

The cutting of a pipeline with maximum internal tensile stress implies that the effective force in the pipeline is released and reduced to zero.

The following general calculation can be modified. S_t is the maximum tension force and μ_s is the axial "friction" coefficient between the pipe and the sea bottom (N/m):

The axial displacement " Δl " of the pipe end is:

$$\Delta l = \frac{1}{E \cdot \pi \cdot t \cdot (D - t) \cdot 2} \cdot \frac{S_t^2}{\mu_s} \quad (8)$$

4.5 Fatigue

Fatigue can for some types fittings and load types be an issue if they are more sensitive to fatigue loads than the pipeline itself.

Typical "fatigue" loads in the "high" frequency range are caused by wave actions transferred from the pipes to the coupling (via a riser or direct wave actions at shallow water) or by vortices in free pipeline spans. These loads would normally result in bending loads for which the sleeve on a mechanical coupling tends to stiffen the pipeline section and make it more resistant to high frequency from such sources. The critical section would often be the pipe itself in its permanent deformations caused by the gripping arrangement.

In the low frequency load range the number of pressure cycles for the pipeline is of concern, i.e. the number of full depressurisation cycles during the lifetime.

In general the fatigue failure mechanism of concern can be similar as for a pipe, i.e. development of cracks. But mechani-

cal fitting's failure mechanism can also develop differently. Some types may sustain only a limited number of depressurisations before leaks could be expected, caused by the function of locking and sealing mechanisms. Therefore only parts of DNV-OS-F101 are relevant to fatigue loads, in particular to "low cycle fatigue". The expression "fatigue" can therefore be misleading for "low cycle fatigue" in this context.

4.6 Safety factors

DNV-OS-F101 applies partial safety factors to compensate for submarine pipeline uncertainties. These safety factors related to forces and strength termed "load effect factors" and "resistance factors" (the latter is related to the design in Sec.6) are presented in the following with some modifications.

Type factors	Ref. to DNV-OS-F101	During repair and testing	During operation	Comments
Load factors	γ_1			γ_1 the combined load factor
Functional loads	γ_F	1.1	1.1	Includes trawl interference
Environmental loads	γ_E	1.3	1.3	
Accidental loads	γ_A	1.0	1.0	
Pressure loads	γ_p	1.0	1.0	together with p_{li} (operation) or p_{lt} (testing)
Condition load system pressure test	γ_c	0.93	1.0	no additional factor of 1.07 is to be applied for uneven sea-bed
Resistance factors ¹⁾	γ_2			γ_2 the combined resistance factor. To be applied in conjunction with Sec 6
Safety class resistance factor	γ_{sc}	1.04	1.04 ^x 1.14 or 1.26	^x for safety class low, and all safety classes in particular cases ²⁾ . For safety class normal or high respectively ¹⁾
Material factor	γ_m	1.15	1.15	¹⁾
Weld Material factor	γ_{mw}	1.25	1.25	Applies to fillet weld of welded sleeve solution
Resistance strain factor	γ_e	2.0	2.5 3.3	for welded sleeves, for safety class Normal and High respectively
Allowable damage ratio for fatigue	α_{fat}	-	0.2/0.1	for Safety Class Normal/High related to crack type failures. Other types of failure mechanisms must be considered separately
¹⁾ The resistance factors are related to failure modes for typical pipelines, i.e. like ductile fractures etc. Fittings can have different failure modes both for the attachment to the pipe and the seals requiring other partial factors. A "brittle" type failure mode for the attachment to the pipe should increase γ_{sc} by 10%. Material factors γ_m for soft seal materials should be considered together with the documentation of this material and the life time extrapolations based on the qualification tests. ²⁾ The particular case is related to typical coupling internal displacement load condition, e.g. that the make up axial preload on the pipe end(s), the abutment load, is reduced without affecting the actual capacity. This is the case for several coupling types and applies to the SLS condition only, for all Safety Classes.				

Guidance note:

The design of a coupling may be considered a local design check and hence only combination b in the table: "Load effect factors and load combinations" in DNV-OS-F101 "local buckling design criterion" need be considered. Generally the design of couplings and sleeves is not dominated by pressure containment but by axial capacity. The wall thickness to be used in establishing the capacity should be the nominal wall thickness (where relevant minus the corrosion allowance), i.e. t_2 in DNV-OS-F101.

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The application of the partial safety factors is further illustrated in Sec.7.3.5.

4.7 Electrical potential

Subsea fittings are normally protected against corrosion by cathodic protection (CP) systems which cause formation of

atomic hydrogen at the metal surface, and thereby facilitate risk for hydrogen induced stress corrosion cracking. 0.8 to 1.1 V represents the potential range for CP by aluminium or zinc based anodes. (See DNV-RP-B401 October 2005). This exposure may limit the strength and hardness of carbon steel and stress utilisation of high alloy steels.

4.8 Service

Subsea fittings resting on the sea floor can be subject to a Hydrogen Sulphide (H₂S) rich environment which has to be specified.

Internally the corrosion rate will depend on the pipeline conveyed fluid which has to be specified. The content of H₂S and CO₂ shall be specified to enable assessments of their possible effects.

5. Installation and attachment to the pipeline

5.1 General

The limiting installation conditions shall be specified and calculated. An outline installation procedure shall be established.

Guidance note:

These conditions are in particular related to item 6, 7, 8 and 9 of the following operations:

- 1) Seabed preparations to enable carrying of heavy frames.
- 2) Installation of pipe end manipulating devices (H frames) if required.
- 3) Cutting and removal of pipe ends.
- 4) Coating removal if applicable and preparations of pipe ends.
- 5) Manipulation and aligning of pipe ends or excavations.
- 6) Subsea measurements and surface adjustments of possible intermediate pipe section and the fitting.
- 7) Deployment of the fitting, its installation tool and the intermediate pipe section.
- 8) Installation and activation of the fitting and possible welding.
- 9) Testing of and inspection of the repair including possible seal testing.
- 10) Pressure testing of pipeline, if required.
- 11) Deployment of the repaired pipe section to the sea-floor from the lifting frames, if used.
- 12) Seabed preparations/protection.

The pipe ends shall be prepared for the coupling installation. Couplings are fitted to the external parts of the pipe and normally require removal of the pipe coating. Most couplings also require a certain evenness of the pipe end and surface. Therefore subsea chamfering, grinding or machining can be required.

Installation of the coupling on to the pipe ends may require strict control to avoid damage to seals. Therefore special tools may be required to control the coupling installation, as well as for coupling activation and testing.

In most cases, it will be practical to join the pipeline ends using a spool piece (intermediate pipe section).

After aligning the pipe ends, the coupling is moved to the correct position and activated.

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5.2 Entry

The limiting parameters related to the following cases shall be established, and shall include:

- misalignment angles and offset;
- limiting bending moments, contact forces allowed during installation, and related friction forces to overcome during installation.

Such entry cases shall include the following:

Case 1 - Entry on pipe end 1. The angular and radial motion of the coupling is normally governed by the rigidity of its suspension system. The pipeline is held in position by the installation system. Misalignment is less than maximum possible misalignment for the coupling (based on clearance between pipe and coupling). Final entry is obtained by radial compliance of the coupling's suspension system.

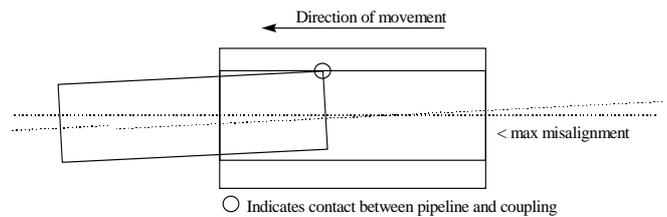


Figure 5-1
Case 1

Case 2 - Entry on pipe end 1. The misalignment is larger than the maximum misalignment for the coupling based on clearance to the pipe. Final entry is obtained by angular and radial compliance of the coupling's suspension system. The risk of jamming is to be considered.

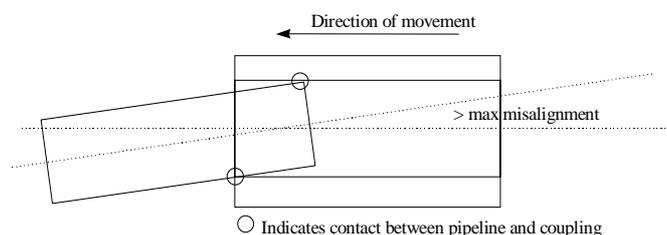


Figure 5-2
Case 2

Case 3 - Misalignment is less than maximum possible misalignment for the coupling (based on clearance between pipe and coupling). Entry on pipe end 2, when pipes are misaligned and offset relative to each other. Both pipe ends are held in position by the installation system. Angular and radial motion of the coupling is governed by the rigidity of its suspension system. The pipeline is held in position by the installation system.

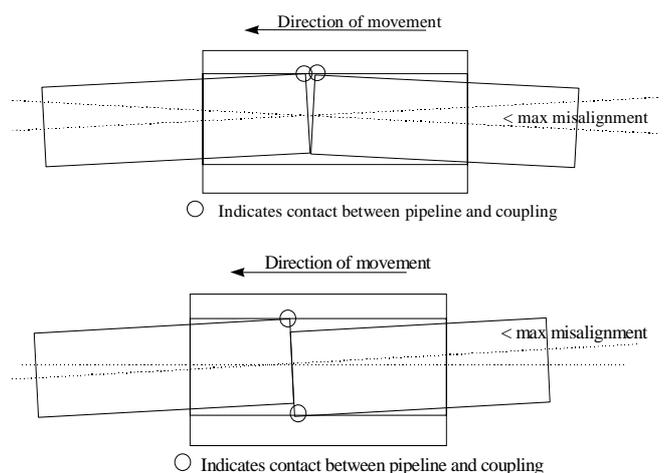


Figure 5-3
Case 3

Case 4 - Entry on pipe end 2, as case 3, but the alignment tolerances, as governed by clearances, are exceeded. The flexibility of the pipe suspension system including the pipes themselves must be considered.

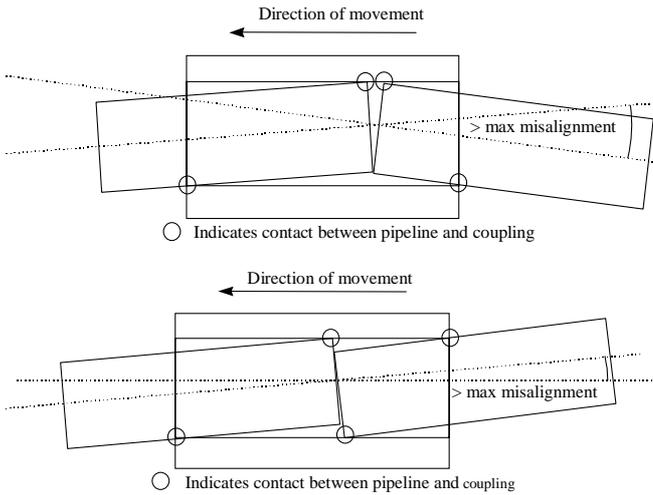


Figure 5-4
Case 4

5.3 First end entry control

Two categories of installation sensitivity are defined:

- 1) The *sensitive* type: No touch between pipe and coupling allowed prior to activation
- 2) The *less sensitive* type: Limited interaction forces are allowed.

Category 1 requires a strict control of geometric installation parameters, and therefore an accurate monitoring and control system. The limiting combination of in-plane eccentricity “*x*” and misalignment angle “*a*” (see Figure 5-5) are represented by (Case 1):

$$e/2 > x_1 + a \cdot y_1$$

where:

- e* = diametric clearance (considering constant internal diameter): $D_c - D$
- D_c = Coupling bore diameter
- D* = Pipe external diameter including tolerances
- x_1 = eccentricity (offset from centre line) at entrance
- a* = Misalignment angle (radians)
- y_1 = Overlap length i.e. degree of sleeve displacement over the pipe(s) at the moment of time considered. Maximum y_1 is the length of the coupling.

For installation systems with active control to give the optimum position of the actual offset from centre at entrance, the limit is (Case 2):

$$e > a \cdot y_1$$

These limits also apply to Category 2 couplings, but the degree of control and monitoring can be relaxed.

Guidance note:

The shape of the coupling can be used to guide the installation e.g. with a funnel to guide entry during the initial installation.

A practical method for control of the interaction forces, is obtained by compliant radial support of the coupling during the installation.

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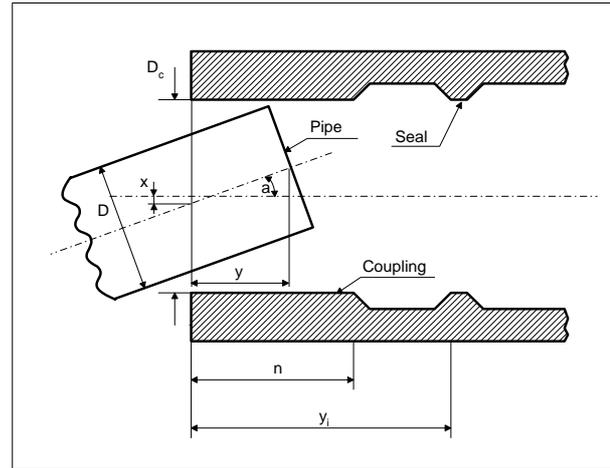


Figure 5-5
Misalignment and eccentricity

5.4 Seal protection design

The seal is the most sensitive part of a coupling, and hence no interaction with the pipe prior to activation is preferable, i.e. the above category 1. However, the seal design must compensate for less accurate installation systems. This may for example be obtained by use of a sealing system which is retracted from the inner circumference of the coupling. This system requires an increase of the inner radius of the seal relative to that of the coupling of at least:

$$e \cdot (y_1 - n) / n + s$$

where:

- n* = axial length from the coupling entrance to the end of the same inner diameter. (Length of equal internal diameter)
- y_1 = Distance from the coupling entrance to the seal.
- s* = Safety distance (say 0.3 mm) to compensate for deflections and possible protrusions on the pipe end.

Furthermore, this system requires that the seals remain concentric in the coupling until activation, and that no axial internal friction force inside the coupling can activate the seals.

5.5 Water block

Water trapped in cavities which are to become sealed off by the installation can resist further displacements and shall be avoided, unless proven to have no such adverse effects.

Guidance note:

This is of particular concern to designs with several main seals in series.

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5.6 Second end entry

Installation of a coupling onto the second pipe end requires careful alignment of the pipes. For plane misalignment of Category 1 couplings with position control during installation (Case 4), then:

$$e > (b \cdot y_2 + x_2) / 2 \text{ when } b \cdot y_2 > x_2$$

Otherwise

$$e > x_2$$

where:

- b* = Misalignment between the pipe ends (radians).
- x_2 = offset between pipe ends

y_2 = Half coupling length (bridging one pipe end)

For Category 2 couplings, the misalignment angle b is calculated based on deflections caused by the contact forces inside the coupling.

The pipe straightness tolerance shall be included, either as an addition to the pipe diameter, or as part of the misalignment angle b .

5.7 Misalignment limitations

The above illustrates in-plane limitations. The global misalignment and offset, i.e. in two planes, must be used to control actual conditions. For this purpose, the root of the sum of squares for conditions in two 90 degrees planes can be applied.

Example:

For second entry, plane “ v ” and “ h ”:

$$b = \sqrt{b_v^2 + b_h^2}$$

$$x_2 = \sqrt{x_{2v}^2 + x_{2h}^2}$$

5.8 Activation

The bending moment caused by the activation process of the coupling shall be calculated. This applies to couplings which bridge two misaligned pipe ends, each with stiff supports.

The calculation of this moment shall include:

- 1) misalignment,
- 2) pipe straightness,
- 3) stiffness of pipe ends and their fixation,
- 4) ability of the coupling to absorb the misalignment without aligning the pipes.

The stresses of the internals of the coupling caused by the activation shall be evaluated. This shall include a risk assessment for:

- 1) over-stressing causing unacceptable deformations or breakage,
- 2) collapse of the coupling or parts of it,
- 3) malfunction of mechanisms inside the coupling,
- 4) uneven seal loads around the circumferences caused by eccentricity between coupling and pipe.

The pipe stresses, deflections and safety against collapse during the activation shall be established.

5.9 Seal test

The mechanical coupling and clamps shall be designed to allow for a seal test without requiring pressurisation of the pipeline.

The radial seal load during the seal pressure test shall be established and compared to the limiting seal load. The limiting seal load shall be based on tests or documented experience.

Guidance note:

The seal test pressure could be applied to an annulus external to the pipe, and could therefore be lower than the pipeline test pressures. This is because the internal pressure normally improves the sealing capability due to the pipe expansion compared to external pressure, which compresses the pipe. However, an external differential water pressure due to depressurisation of a gas pipeline will have the opposite effect and must also be considered.

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5.10 Monitoring and control

5.10.1 General

Diverless installation of subsea pipeline fittings requires:

- 1) A system to control the forces and displacements.
- 2) Forces to displace and manipulate the fitting.
- 3) A monitoring system to verify that manipulations are made within the limits for the pipe and fitting.
- 4) A monitoring system to verify that the fitting is installed properly. Monitoring of welding shall comply with Sec.6.
- 5) A test and monitoring system to verify the seals function.

Guidance note:

The monitoring system may comprise a range of TV cameras, sensors for alignment, sensors for displacements and force and pressure sensors, etc. The monitoring system shall verify that each parameter that can cause a failure is within acceptable limits.

A general principle for the monitoring system design is that:

- Failure of a monitoring system (sensor) shall not stop the operation.
- A redundant system or alternative method is required to control and monitor the operation. On this basis, the design should be such that a TV can monitor all critical issues. This could include monitoring without sensors.

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5.10.2 Acceptance criteria

The connection operation shall be planned and conducted in such a manner that the specified functional requirements are met, i.e.:

- controlled within the established limitations
- monitored
- that the fulfilment of the functional requirement (e.g. seal test) is recorded.

The records shall serve as documentation of the fulfilment of the requirements.

The manufacturer of the fitting shall identify and list the functional criteria to be checked.

6. Welding

6.1 General

This section covers subsea hyperbaric dry welding by remote operation, i.e. automated welding without personnel attendance in the habitat. Remote hyperbaric dry welding comprises fillet or butt welding used as a primary strength member or for sealing purposes, and may be used in connection with pipeline repair, modification and tie in.

Diver assisted hyperbaric welding for pipeline repair and tie-in (dry habitat welding, mechanised and manual welding), is covered in Appendix C of DNV-OS-F101. The requirements in the following are based on the principles in those requirements, and are extended to cover remote welding operations including and exceeding the water depth that can be reached by divers. Thereby this document represents a supplement to the requirements specified in DNV-OS-F101.

Figure 6-1 shows a typical fillet weld at welding start and a macro section of a completed GMA weld with a large number of passes. It is intended to be used for deep water remote operated welding of a sleeve to a pipeline.

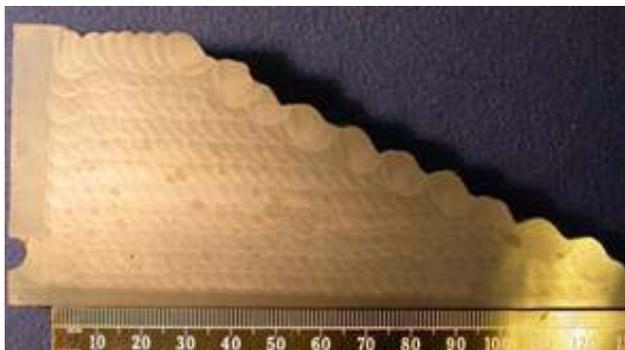


Figure 6-1
GMAW welding setup and completed fillet weld.

6.2 Welding Concept

A Welding Concept shall ensure that welding is repeatable and result in welds with consistent properties and freedom of injurious flaws. This implies that:

- a qualified welding procedure shall be followed
- essential variables shall be established, adhered to and be monitored
- non destructive testing (NDT) shall be performed to ensure that weld defects are within defined maximum acceptable limits or, if NDT is *not performed* then welding shall be performed by systems qualified for defect control through process parameter monitoring, and
- visual monitoring shall ensure that geometrical deviations are within defined maximum acceptable limits.

A Welding Concept shall be established in order to achieve the required characteristics for remote operated hyperbaric welds.

A Welding Concept is defined by the following main parameters:

- welding process(es)
- type of weld (butt or fillet)
- weld geometry
- *extent* of NDT.

Welding Concept base cases

This document describes general principles and in particular two welding concept base cases, with associated qualification routes. The base cases are:

- a) Qualification of both equipment and welding procedures.
- b) Qualification of welding procedures for a particular application using already qualified equipment.

Further details for the qualification routes for the welding concept base cases are given in Sec.6.9.

6.3 Hyperbaric welding

6.3.1 General

Welding shall, as a minimum, conform to the definition “Mechanised welding” in DNV-OS-F101, Appendix C:

“Welding where the welding parameters and torch guidance are fully controlled mechanically or electronically but may be manually varied during welding to maintain the required welding conditions.”

6.3.2 Welding processes (informative)

The following aspects should be considered when selecting welding process and consumables for hyperbaric welding:

Operating tolerances:

- arc stability for relevant habitat pressure, including sensitivity to residual magnetism
- metal transfer characteristics
- bead stability
- cooling rate: preheat and interpass temperature requirements.

Weld robustness:

- weld metal strength and toughness
- hydrogen level (risk of hydrogen entrapment from welding environment) and potential risk of hydrogen induced cracking (cold cracking).

Productivity:

- Deposition rate
- Maintenance requirements (e.g. grinding).

The possible incidence of welding defects and other failure mechanisms should be considered during the selection of welding process and material combination, and the development of welding parameters when planning.

The current range of experience with automated welding processes suitable for remote operation is limited to Gas Metal Arc Welding (GMAW) and Tungsten Inert Gas Arc Welding (GTAW). Hence relevant characteristics for these processes are given below.

GMAW

The major advantage with GMAW for hyperbaric dry welding is the ability to maintain a stable arc across a wide pressure range, deposition rate and flexible filling capability. However, this necessitates special control techniques which modify the static and dynamic characteristics of the power supply according to the demands of the welding arc. A limiting parameter is the inability to perform uphill welding. Nozzle wear may limit

the arc-on-time and hence the choice of nozzle and wire is essential to obtain large welds.

Depending on the welding parameters excessive levels of weld spatter may result in poor bead shape and cause clogging of the nozzle.

GTAW

Very low levels of impurities of the weld may be expected for GTAW.

Wear of the tungsten-electrode and associated arc instability particularly at higher pressures, are limiting factors for remotely operated GTAW. The "Marangoni effect", being the surface tension and weld pool flow effect on the bead shape and penetration is stronger for hyperbaric GTAW than GMAW and is affected by the pressure and S and P content of consumable and base material. Hence at high pressures control of the weld pool may be less predictable for GTAW than for GMAW.

Other welding processes

If welding methods other than GMAW or GTAW are considered for remote operated hyperbaric welding the technology of the considered solution should be qualified according to DNV-RP-A203.

Plasma welding is a process proven of high pressure capability, up to 2 500 m, and operation may also be well suited to mechanisation, but is also subject to tungsten electrode and orifice wear.

The arc voltages necessary to operate plasma welding may be several hundred volts, necessitating the use of special welding power sources.

6.4 Materials

6.4.1 Pipe material

The following data for the pipe material shall be assessed.

- Chemical composition; carbon equivalent (weldability) and inclusion shape control (risk of laminations).
- Dimensional tolerances – diameter – ovality – dents/flat spots – peaking – weld reinforcement height of longitudinal weld seams – for pipe body and pipe ends as relevant.
- Lamination control preformed – NDT type and extent.

If such data is unavailable or uncertain, they shall be collected as part of a pre-survey.

6.4.2 Auxiliary component material

The material to be used for the hyperbaric weld joint shall be compatible with the pipe material. The material shall either be tubular material in accordance with the specification for line-pipe in Sec.7 in DNV-OS-F101 or be forged in accordance with Sec.8 of DNV-OS-F101. Tubular material shall be subject to NDT as required by Sec.7 in DNV-OS-F101. Forged material shall be subject to NDT as required by Sec.8 in DNV-OS-F101.

6.4.3 Consumables

All welding consumables and gases shall be in accordance with DNV-OS-F101, Appendix C, and the following additional requirements:

Filler wire

The filler wire used during production welding shall be from the same batch as used during qualification of the hyperbaric welding procedure specification (HWPS).

Tungsten electrodes

For GTAW it shall be possible during production welding to monitor the tungsten electrodes tip geometry. If required it shall be possible to replace the electrodes directly or by another

qualified method. The effect of wear/blunting of the electrode tip shall be assessed during qualification.

Shielding gas

Shielding shall be provided by use of an inert gas with qualified purity including moisture limit. Gas purity and composition in all containers shall be certified and traceable to the gas storage containers.

The gas purity and moisture content shall be verified after purging the gas supply system prior to start of welding. The moisture content of the shielding gas shall be monitored at/near the torch during welding operation.

Guidance note:

The dew point temperature at atmospheric pressure (1 bar) is often used to specify the upper level acceptance criteria for the moisture content in shielding gases. However, for hyperbaric conditions, even a low dew-point temperature (e.g. -30°C for an Argon gas) can result in condensation of water at the relevant working depth/pressure and temperature (e.g. at 165 m at 5°C). This means that the gas is saturated with water when used at this depth and condensed water will be present at greater depths.

In general the acceptance level for the water content in the shield gas must be specified precisely. The use of "ppm" alone is not sufficient. It must be related either to volume or weight of the gas.

It is the water concentration in the gas at the working depth/pressure which is essential. This can be specified as weight of the water per volume unit (mg H₂O/m³) or partial pressure of the H₂O (millibar H₂O).

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The maximum allowable water content in the shield gas used in the actual welding is governed by the moisture content of the gas used during the qualification welding, with a safety margin.

6.5 Welding personnel

Personnel involved in welding operation (the welding co-ordinator and the welding operators) shall be qualified. The welding operation includes execution as well as maintenance, preparations, control and monitoring of the key equipment. Key equipment are: welding control software, welding control system, habitat, welding equipment, consumable handling system, gas handling system, power system, and monitoring and recording systems both subsea and on the support vessel.

The responsible welding co-ordinator shall be qualified by experience and training in accordance with DNV-OS-F101, Appendix C, and shall be present during welding qualification and execution.

Welding operators shall be qualified to EN 1418 by performing a test using the actual equipment under simulated/realistic field conditions and hyperbaric pressure, e.g. in an onshore welding facility. A minimum of three test pieces representing the actual weld configuration (butt weld or fillet weld) and size, shall be welded by each welding operator. The test pieces may be weld sections provided the size is sufficient to obtain the test specimens required in DNV-OS-F101, Appendix C. For fillet welds the test pieces shall be subjected to macro examination and non-destructive surface testing. For butt welds the test pieces shall be subjected to macro examination and volumetric non-destructive testing.

Acceptance criteria for the testing shall be that acceptable bead build-up has been obtained and that no defects are larger than qualified for the relevant hyperbaric welding procedure specification. The qualification is valid only for the welding equipment used during qualification welding, the actual weld configuration used and within a variation of ½ to 2 times of the load bearing material thickness.

A Training Programme for all welding operation personnel according to DNV-OS-F101, Appendix C shall be established.

6.6 Equipment and systems

6.6.1 General

All welding equipment shall be in accordance with DNV-OS-F101, Appendix C.

The suitability for all equipment used (including NDT equipment if applicable, ref. DNV-OS-F101, Appendix D) shall be documented prior to qualification welding. This may be based on previous experience or by an equipment qualification test. The documentation shall include all items listed under equipment qualification test below.

All equipment shall be properly maintained according to a documented procedure.

6.6.2 Process monitoring and control

General requirements to monitoring and control are given in Sec.5.10. The process monitoring and control shall assure a sufficient degree of continuous monitoring to enable confirmation that the welding parameters and related parameters stay within the defined safe parameter (programmed range plus combined system accuracy) range. Further it shall give alarm for deviations outside the essential variables range, i.e. safe parameter limits. The sampling frequency of the monitoring signals shall be sufficient to enable an assessment of the effect of possible short time parameter deviations. The amount of data recorded can be reduced from monitored amount provided they are processed prior to recording. This processing shall include conclusions on parameter performance. In particular the effect from short time parameter deviations shall be concluded with respect to the weld quality, i.e. if the weld is outside specification or not. Algorithms for such conclusions shall be qualified. All process monitoring shall be based on calibrated feedback signals, not input or demand signals.

6.7 Equipment and systems qualification test

An equipment qualification test shall be performed to verify adequate functioning for test welding, under actual or simulated field conditions. The purpose of the tests listed below is to assure that the equipment provides specified tolerances and boundary conditions to allow test welding to be performed under repeatable and optimum conditions. The test shall be performed according to a documented procedure and as a minimum address the following:

Mechanical systems:

- 1) tightness/leak rates of temporary sealing systems for compliance with specified leak tolerances
- 2) the total motion envelope of the equipment to be used in the habitat for the actual dimensions of pipe and weldments
- 3) accuracy control of wire guide / contact tube and electrodes motions for compliance with the tolerance requirements
- 4) accuracy control of consumable feeding for compliance with the tolerance requirements
- 5) accuracy control of the other robots used for handling of cameras, grinders and other tools
- 6) alert system to notify motions outside the tolerances for the control.

Power system:

- 7) electrical insulation resistance at high voltage
- 8) electrical power at maximum consumption
- 9) hydraulic power piping systems sealing performance at maximum test pressure
- 10) hydraulic power at maximum consumptions
- 11) power alarm systems for electricity and hydraulics.

Gas and moisture:

- 12) gas supply capacity at maximum estimated (to be specified) leak rate.
- 13) gas cleaning capacity at maximum gas contamination level (to be specified)
- 14) gas cleanness and moisture monitoring
- 15) gas cleanness and moisture alarm.

Temperature:

- 16) pre-heating or post-heating capacity to obtain the maximum temperature of the work piece heat input
- 17) pre-heating control tolerances (number, positioning, attachment method and calibration of thermocouples or pyrometers)
- 18) related temperature alarm
- 19) cooling capacity to obtain the maximum cooling
- 20) cooling control tolerances.
- 21) related temperature alarm.

Electricity for welding:

- 22) voltage, current and pulse frequency at the welding arc for maximum power
- 23) minimum tolerance limits for these parameters
- 24) system to notify deviations from the qualified tolerances (alarm system).

Control system

- 25) execution of the control commands with resulting actions within the qualified tolerances.

Monitoring system:

- 26) monitoring signals to comply with the accuracy tolerance specification for the relevant habitat environment
- 27) TV monitors visibility and resolution under the relevant habitat environment with respect atmospheric contaminations, temperature, humidity and motion characteristics.

Recording system:

- 28) signal sampling frequency compliance with qualified sampling rates
- 29) batch processing of signals enabling identification and correct actions from short time parameter deviations from the qualified tolerances
- 30) recording of signals directly or via pre-processor to verify the current weld quality and to document its quality
- 31) display systems
- 32) display system ergonomics for compliance with personnel's capabilities in controlling the weld and inspection of it (perform quality assurance of it)
- 33) display system resolution.

NDT equipment (when relevant):

- 34) functioning.

6.8 Welding concept base cases qualification routes

6.8.1 Base case A: Qualification of both equipment and welding procedures.

In the qualification routes not including NDT of the final weld, absence of defects shall be ensured by a qualification programme such that the level of confidence in the weld integrity is equivalent or higher than by performing NDT.

Means to ensure the quality of weldments – to compensate for the absence of NDT – shall include the relevant welding tests

to the tolerance limits, defined process monitoring and control limits as described in this document.

6.8.1.1 A1. Butt weld subjected to NDT

Welding differs from DNV-OS-F101 in that no personnel is available in the habitat for visual inspection and for preparation/rigging of NDT equipment. Hence the qualification programme should be as in DNV-OS-F101 and modified in Sec.6.9. The following differences related to NDT shall at least be covered:

- consequence of incorrect rigging of welding equipment
- surface NDT method capabilities to detect weld surface irregularities
- consequence of incorrect rigging of NDT equipment.

6.8.1.2 A2. Fillet weld subjected to NDT

An inherent feature of fillet welds is the root defect, which in general is not possible to characterise by use of automated NDT equipment such as automated ultrasonic testing (AUT). NDT of fillet welds for detection of other volumetric and planar defects will in some cases be possible depending on weld size and access for inspection.

The consequence of the presence and detectable size of the inherent root defect and other defects shall be evaluated and the probability of detection shall be assessed by pre-qualification testing along the lines in Sec.6.9.

6.8.1.3 A3. Fillet weld without NDT

The absence of NDT requires that additional measures shall be taken to ensure weld integrity by means of process control and monitoring as the recommended method. Welding parameters shall be developed as outlined in Sec.6.9 to ensure weld integrity.

Guidance note:

In principle as large number of passes is recommended due to the common relationship between the weld pass size and the maximum weld defect size and thereby reducing the effects from possible defects.

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6.8.2 Base case B: Qualification of welding procedures only

For this base case (by using the already qualified equipment)

an existing HWPS cannot be used for a specific application within the limits and ranges of the variables originally qualified. Hence a new pHWPS covering the intended application shall be prepared and qualified as required in Table 6-1 and Sec.6.9 for applications with and without NDT.

6.9 pHWPS development

The preliminary Hyperbaric Welding Procedure Specification (pHWPS) shall specify the ranges for all relevant parameters.

The effect of the parameters variation on weld quality, including the accuracy and tolerances of the monitoring equipment, both in terms of mechanical properties and defect level, shall be quantified.

The activities listed in Table 6-1 shall be included in the development of the pHWPS as relevant for the selected Qualification Route. The following includes further details for clarification:

Design

The design shall generally be in accordance with this publication.

Failure modes

All possible failure modes shall be identified and assessed. Fillet welds are susceptible to fatigue failure due to high stress concentration at root (defect). Hence a qualification scheme to verify a margin to fatigue failure may be relevant (see Sec.4.5).

Allowable defect size

Engineering critical assessment (ECA) shall be performed when required by and in accordance with Appendix A of DNV-OS-F101 and for relevant load cases (including cyclic loads). Allowable defect sizes shall be calculated based on a realistic range of fracture toughness values.

Welding parameters development

All welding parameters shall be identified. The effect of welding parameters variation on mechanical properties and defect level shall be established. Parameter sensitivity tests shall be used to determine the limits still resulting in acceptable mechanical properties and absence of flaws exceeding the allowable defect sizes. Confirmation of acceptable parameters limits and ranges shall be based on welding tests where the relevant parameter or set of parameters are varied (max. and/or min.) sufficiently to be able to operate with a safe margin to failure.

Phases	Activities	Activities relevant for each qualification route ¹⁾			
		A1	A2	A3	B
1. Definition phase	a. Define the boundary conditions for the weld connection with respect to forces to be transferred, its environment and the welding environment				
	b. Define welding concept; weld type/geometry				
2. Pre-qualification phase (iteration process)	c. Design of the weld connection including strength calculation with the effects from gross defects and misalignment				
	d. Identify the possible failure modes and mechanisms and their respective criticality				2)
	e. Determine allowable defect sizes (including ECA)				2)
	f. Identification and ranking of welding parameters that may affect weld quality				
	g. Define preliminary parameter variation range and include this in the pre-qualification welding test programme				3)
	h. Define size and boundary conditions for test pieces for qualification testing. Document conservatism				3)
	i. Perform test welding				3)
	j. Mechanical and restraint testing, and other relevant testing as required from assessment of failure modes and mechanisms				3)
	k. NDT for location of flaws followed by systematic sectioning to determine flaw sizes (height and length)	na	na		3)
	l. NDT for confirmation of weld acceptance			na	3)
	m. Define final pHWPS including ranges for all essential parameters that can affect the weld and margins between operational limits and test qualification limits				

Notes:
na not applicable
 1) Shaded boxes indicate applicable activities for each qualification route.
 2) Applicability of indicated items shall be evaluated, based upon weld criticality.
 3) To the extent that previously qualified data can be utilised for a new application.

Based on the welding tests, variation tolerances shall be established for each welding parameter or group of welding parameters.

The following Figure 6-2 illustrates:

- a) Upper and lower parameter limit as illustrated by assumed probability distribution (dotted curve).
- b) Upper and lower safe limits given by vertical lines.

- c) safety margins for:
 - material and test method (dark grey)
 - control and monitoring tolerances (light grey)
 - set point variation (white).
- d) results from welding test; diamonds illustrates test results, acceptable (white) or unacceptable (black).

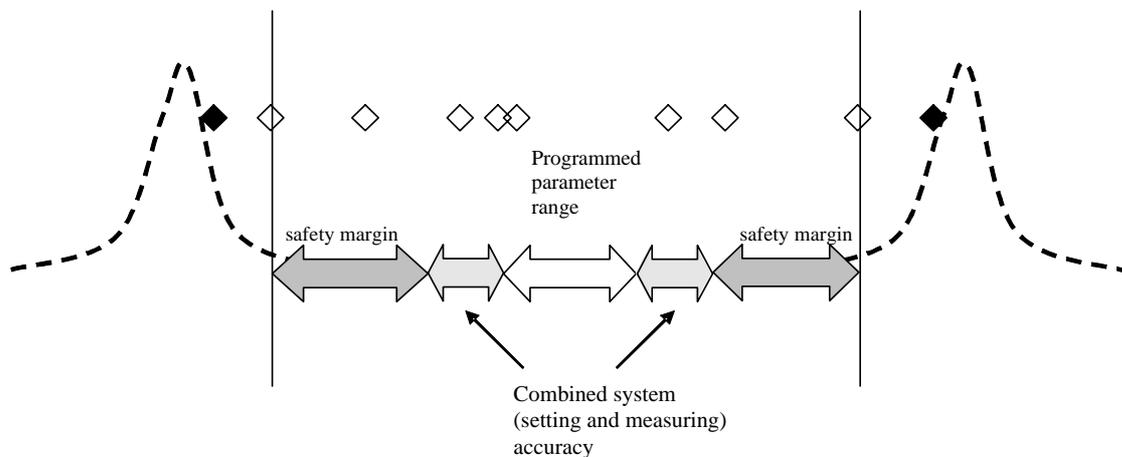


Figure 6-2
Parameter variation and tolerances.

The variation tolerances shall include:

- safety margins to cover all uncertainties, and

- the inaccuracies and tolerances of the monitoring and control equipment.

The resulting parameter window shall be sufficient to allow the setting of each parameter or group of parameters within the ranges required.

Thereby there will be two windows for parameter variations. One ultimate variation tolerance window and a smaller variation tolerance window for the planned weld operation.

Arc stops

Arc stops shall be simulated and resulting defect size determined and evaluated for possible removal or not.

Small scale tests vs. full scale tests

The size of the pressure chambers used for qualification welding as well as practicalities may imply limitations to the size and fixture of test pieces. Additional means to control weld temperature and cooling rates as well as restraint conditions may be necessary. Hence it shall be demonstrated/documentated that the influence of a possible reduced size of the test pieces used for qualification welding will represent the actual or conservative conditions with respect to:

- restraint, and
- cooling.

Cooling rate

Influence on weld cooling rate due to the external and internal pipeline environment (the pressurised circulated atmosphere, water on the outside and on the inside, or possible other fluids inside the pipeline) shall be taken into account. The cooling rate identified by numerical analysis or measurements shall be simulated during pre-qualification welding. If weld properties are significantly affected by the cooling it shall also be conservatively applied during qualification.

Hydrogen pick-up

Hydrogen pick-up for the welding parameters used shall be assessed based on testing at conservative conditions of humidity in the shielding gas for given pressure, ref. Sec.6.4.3.

Restraint

The effect of residual stresses caused by weld solidification and thermal shrinkage shall be taken into account. Possible adverse effects are caused by:

- weld/bead dimensions and shape
- material properties
- content of diffusible hydrogen
- rate of cooling.

Weld cracking

The sensitivity towards weld cracking shall be assessed by testing such as Tekken type self restraint test according to ISO 17642-2 or modified restraint tests with documented conservatism.

Systematic sectioning

The welds performed in order to determine parameter tolerances for parameters identified as critical for the weld defect level shall be subject to destructive examinations by systematic sectioning.

The maximum defect size shall be determined by systematic (macro) sectioning of test welds. Systematic sectioning is also useful to verify any applicable NDT systems. The systematic macro sectioning shall be based on volumetric NDT to determine the indications that will be subject to sectioning.

The systematic macro sectioning shall determine the type, height and length of the indications from the volumetric NDT.

Maximum defect size

The maximum defect size determined from systematic sectioning shall be compared to allowable defect sizes obtained from ECA.

The extent of the systematic macro sectioning shall be sufficient to determine that the probability of defects exceeding the critical defect size established by the ECA is 90% at 95% confidence level for the established parameter range.

Possible NDT method intended to replace or reduce the amount of the macro sections shall be qualified to obtain an equivalent confidence level.

Repeatability

When acceptable parameter ranges are achieved in welding trials, a series of test welds shall be welded with the same parameters and mechanically tested to verify repeatability and consistency in test results. The number of test welds is governed by the variation in obtained results and the strategy to define safety margins.

Monitoring and control

The parameter variation used in the prequalification form the basis for specification of monitoring and control to be applied for the actual operation. Inaccuracy tolerances in monitoring and control shall form parts of the input to establish the “safe margins”, ref. Figure 6-2.

Preliminary welding procedure specification

A preliminary hyperbaric welding procedure specification (pHWPS) based on the results from the development work shall be prepared in accordance with DNV-OS-F101, Appendix C.

The pHWPS shall include tables for each weld operation with parameter window for the essential welding parameters as described above.

6.10 Welding Procedure Qualification

When a pHWPS has been defined, either based on the development scheme outlined in Sec.6.9 or on a previous HWPS, qualification shall proceed as outlined in Table 6-2.

Qualification welding of welding procedures

Qualification welding shall be performed in accordance with DNV-OS-F101, Appendix C, and the defined pHWPS. The tests shall be carried out at the upper and/or lower safe range of parameter variation determined during pre-qualification, see range limited by the vertical lines in Figure 6-2.

Test welding

Test welds, including relevant results from pHWPS development, shall confirm that acceptable results are obtained when the critical parameters are varied within the established safe range.

a.	Define final pHWPS including ranges for essential parameters that can affect the weld and margins between operational limits and test qualification limits
b.	Test welding in pressure chamber at/with relevant environmental conditions, equipment and specimen size/fixture, at parameter limits with margins.
c.	NDT of all test samples
d.	Mechanical testing
e.	Systematic sectioning (applicable for qualification route A3)
f.	Issue of HWPQR
g.	Issue of qualified HWPS

6.10.1 Acceptance criteria

As a minimum the tests given in Table 6.3 shall be performed. Welds shall meet the acceptance criteria for strength and toughness as required from the weld design and defect level as determined during the pHWPS development, with a safety

level consistent with the requirements in DNV-OS-F101 Sec.2. The maximum hardness shall be in accordance DNV-OS-F101 Appendix C for the relevant material type, unless otherwise qualified.

Table 6-3 Type and number of tests for qualification of welding procedures

Required tests	No. of tests for butt welds	No. of tests for fillet welds ¹⁾	Notes	
Transverse weld tensile	As per DNV-OS-F101 Appendix C	-		
Longitudinal all weld tensile		2	The specimens shall be taken from each test weld	
Bending		-		
Charpy V-notch impact testing sets		See note	Specimens shall be taken from each test. The number of specimens shall be determined based on the weld size and geometry. As a minimum the test shall include the weld metal and fusion lines (FL) and FL+2mm and FL+5mm in both base materials. Additional samples shall always be performed when sufficient weld cross-sectional area allows for such testing.	
Macro Sections and Hardness		3	The specimens shall be taken from the start, end and middle of each test weld. The macro sections shall be documented by photographs (magnification to give sufficient resolution).	
Microstructure		See note	Examination of corrosion resistant alloys only	
Fracture toughness test		See note	The specimens shall be taken from each test. As a minimum the test shall include the weld metal and fusion lines.	
Non destructive testing		See note	To be determined based on the weld size and geometry. If possible, volumetric testing shall be performed.	
Systematic sectioning		See note	See note	In case of no NDT in actual operation. The number is to be established based on the principles established above.
General note:				
1) For fillet welds where the size is too small for sampling of any of the tests given in this table, measures shall be taken to enable testing. Such measures may include welding of wide angle butt weld with the relevant welding parameters or increased size of the fillet weld (requires that any tempering effect is considered when specimens are sampled).				

6.10.2 Welding procedures validity

A qualified welding procedure remains valid as long as all variables are kept within the qualified range (e.g. a depth/pressure range). If one or more variations outside the qualified range occur, the welding procedure shall be considered invalid and the welding procedure shall be re-specified in a new pHWPS and qualified.

6.10.3 Welding Installation Procedure

A Welding Installation Procedure (WIP) shall be established and considered qualified when the below tests have been successfully completed and the specified requirements to the equipment are fulfilled.

The welding installation procedure *qualification* test can be divided into:

- Surface test
- Shallow water test
- Deep water test simulating site depth.

The selection of tests for these respective areas depends on the sensitivity to water and depth for the item tested. Further some parameters may be simulated by change of other parameters. Therefore the conservatism in conducting the test at other sites (e.g. surface) than the actual shall be documented.

This is most practically made by:

- Defining test procedures specifying the objective of each test, test method to be used and acceptance criteria for each test
- Documentation of the conservatism of each test when performed under conditions not simulating the site depth.

Thereby the WIP can be qualified by performing tests as follows:

WIP-surface:

Describe and perform tests confirming those capacities and tolerances that can be based on the surface test.

WIP- shallow water:

Describe and perform tests confirming those capacities and tolerances that can be based on based on the shallow water test

WIP-site:

Describe and perform tests confirming those capacities and tolerances that can be based on the deep water test only.

In addition to all tests in the Equipment qualification test given in Sec.6.7 the following shall be tested:

- Installation at maximum inclinations/misalignment
- Alignment/clamping system for the items to be joined by the weld
- Locking to the pipeline
- Cleaning within the “best” tolerance limit, and
- Cutting and grinding to the “best” tolerance limit.

6.11 Production welding requirements

6.11.1 General requirements

All production welding shall be performed according to a qualified hyperbaric welding procedure specification (HWPS) and accepted welding consumables handling procedure.

HWPS confirmation test

A test weld according to the qualified HWPS shall be performed onboard the support vessel at the site close in time prior to the production welding, using the actual equipment to be used for the work. The purpose of this test is to ensure that no changes in procedures and equipment have taken place. The test pieces for the confirmation test shall be of a practicable shape that challenges the welding system similarly as the actual intended. The test piece shall be subject to NDT after the test. The welding control and monitoring system shall show a performance as qualified, but as relevant for the topside pressure.

Welding equipment

The welding equipment used for the work shall be identical to the equipment used during welding procedure qualification and equipment qualification testing. Type, cross section area and length of electrical cables is defined as part of the welding equipment, as well as the power source, welding control system and software make and model, tungsten electrode and contact tube (as applicable).

Habitat environment

All gas supply lines with connections and cavities/chambers shall be leak tested and flushed by the shielding gas intended for the welding prior to use. The last part of the flushing shall include measurement of purity and moisture.

The gas environment shall be continuously monitored during the welding, with alarm for high moisture content and possible other fume gases of concern to the weld quality. These fume gases shall have been identified during the pre-qualification tests.

Material check

The following checks of the sleeve/pup piece shall as a minimum be carried out before deployed to the site depth:

- a) Dimensions (diameter by gauge), wall thickness and length) measured at four (4) equidistant points on the pipe circumference.
- b) Bevel details (if applicable). The root face thickness shall be accurately measured for each clock hour position around the pipe circumference.
- c) Laminations on the joint faces by ultrasonic testing for a minimum distance at 100 mm from the edges and magnetic particle/ dye penetrant testing of the pipe edges/bevels.

Filler wire

The filler wire used during production welding shall be from the same batch as used during qualification of the HWPS.

Filler wire which shows any sign of damage or deterioration, or can not be properly traced and identified, shall be discarded.

Pipe surface/bevel preparation, alignment, lamination check

The pipe surface shall be checked before welding, with respect to tears, scale, rust, paint, grease, moisture or other foreign matter of the fusion faces that may adversely affect the weld quality to the extent not included in the HWPS qualification.

The pipe dimensions, surface/end cut, bevel dimensions, root gap around the circumference and alignment shall meet dimensional tolerance and surface appearance specification (Ref. Sec.1.5, Sec.3, Sec.5.1, Sec.6.10.3- WIP-site) to be established as part of the qualification scheme.

The pipe end material properties can be affected by the cutting method. Acceptable properties would normally be obtained e.g. from cutting by mechanical means such as by diamond wire or water-jetting/grit and possible additional grinding.

A lamination check by ultrasonic testing in accordance with DNV-OS-F101 Appendix D shall cover at least 100% of the area to be welded and in addition 100 mm upstream and downstream of that area. Acceptance criteria for possible lamination shall be established as a part of the qualification scheme.

Compliance with the specifications shall be verified by mechanical and/or ultrasonic means prior to the relevant non reversible operations, e.g. the mobilisation, the cutting of the pipe and the welding operation.

Cleaning of weld

Upon completion of each welding pass, the weld shall be inspected (Camera) and cleaned if found necessary.

Inspection during Welding

Inspection during welding shall be executed from the surface weld control room and/or an inspection room. Inspection shall as a minimum include the following:

- a) Camera in the welding habitat. Inspection by welder or habitat welder technician and video recording, all continuously to the extent qualified.
- b) Monitoring, recording and display of habitat environmental parameters (temperature, humidity, pressure, atmosphere composition). Alarm for critical parameters to be included.
- c) Photo/video, recording and display of pass identifications used for welding.
- d) Monitoring, recording and display of welding current, arc voltage, filler wire speed, welding speed and shielding gas flow. Alarm for critical parameters to be included.

Weld starts and stops shall be performed in compliance with the weld qualification tests.

Guidance note:

A normal procedure is to start and stop the weld at places so that these locations do not coincide in adjacent passes. At least 4 passes should be made before the same start or stop position is used. The passes should be deposited in a balanced sequence around the pipe circumference in order to minimise residual strain and distortion.

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

Inspection and Testing after Welding

After completion of the weld it shall be subject to NDT, to the extent forming a part of the qualification. This shall include visual examination.

The visual examination shall include:

- 100% visual camera inspection by welder or habitat welder technician.

Out of specification weld passes

Welds passes that, based on the inspection during welding or the inspection and testing after welding are to be considered as out of specification, shall be removed.

Hydrostatic testing

System pressure testing (hydrostatic testing) and leakage test of the repaired/modified pipeline section shall comply with the requirements in DNV-OS-F101.

Interruption of welding

In case welding is interrupted, e.g. due to equipment failure or weather limitations, the appropriate course of action for all foreseeable extents of welding completion and equipment status shall be described in a contingency procedure such that the integrity of the pipeline is ensured. Consequently shall this contingency be a part of the qualification.

Repair welding

Repair welding shall be qualified. Local grinding due to local excessive spatter or poor bead shape may be performed of the current/last welding pass.

6.12 Mobilisation

Due to the complexity in the use of the remote hyperbaric welding system, the likely sporadic use of the system and possible large consequences of welding interruption or failure, separate training should be performed not earlier than four weeks ahead of the planned repair welding.

State of readiness

In order to maintain its qualified status the equipment, systems and welding consumables shall be:

- stored under conditions according to a qualified procedure
- tested at intervals according to a qualified procedure including calibration and recording.

Personnel qualifications may be maintained by regular training including use of the equipment.

6.13 Documentation

General requirements to documentation are given in Sec.9. This is further detailed in the DNV-OS-F101 Sec.3 F. The as-built material documentation shall include the following:

- Weld procedures (WPS) and weld procedure qualification records (WPQR)

- Welding and NDE personnel qualification records
- NDE and visual inspection reports for pup-piece/sleeve/lamination control and hyperbaric weld (If applicable)
- Material certificates for base materials and welding consumables
- Records of all essential welding parameters. Ref. Sec.6.11.1, subsection “Inspection during welding”. Where no NDE is applied on the hyperbaric weld (Case A3), 100% documentation of all relevant welding parameters and weld pass positioning shall be included in the as-built documentation
- Records of habitat/chamber atmosphere and shield gas purity.

7. Design

7.1 General

The design of the fitting shall demonstrate safety against possible failure modes. A Failure Mode and Effect overview shall be established for each fitting type.

The method used to demonstrate safety against possible failure modes shall be qualified.

7.1.1 Failure modes

The general failure modes for fittings are:

- 1) Fail to install on the pipe,
- 2) Activation causes damage to the pipe,
- 3) Fail to seal (leak),
- 4) Fail to lock.

Conditions for prevention of failure modes type 1 and 2 are considered in Sec.5.

As an example, general failure modes type 3 and 4 are identified for fittings in the following:

- 3 Fail to seal (leak)
 - 3.1 Loss of seal compression loads due to lack of sufficient seal-elasticity to compensate for relaxation caused in some operational conditions by:
 - 3.1.1 Local plastic yield of pipe.
 - 3.1.2 Local plastic yield of seal support structure, back up rings or metal seal.
 - 3.1.3 Elasticity of the connection between the two halves of clamps possibly reducing the load on the longitudinal seals.
 - 3.2 Load case not considered e.g.:
 - 3.2.1 Compressive/expansion load effect from temperature and the additional expansion of polymer seals.
 - 3.2.2 Effects transferred from the locking mechanism.
 - 3.2.3 Effect from swelling (chemical reactions to polymer seals).
 - 3.2.4 Local distribution from unsymmetrical conditions.
 - 3.2.5 Seal axial loads/displacement/wear:
 - 3.2.5.1 Changing axial loads/displacement.
 - 3.2.5.2 Temperature effects.
 - 3.3 Seal micro performance fails.
 - 3.3.1 Seals ability to fill/seal discontinuities in pipe.
 - 3.3.2 Seal/back-up ageing/corrosion.
 - 3.3.3 Extrusion of polymer seals.
 - 3.3.4 Explosive decompression of polymer seals.
 - 3.3.5 Seal welds cracks or pores.
 - 3.4 Seal protection fails
 - 3.4.1 Deflections/damage caused by installation.
 - 3.4.2 Dirt on the sealing surfaces.
 - 3.5 Lack of sufficient seal test pressure.
- 4 Fail to lock.
 - 4.1 Axial capacity insufficient due to:
 - 4.1.1 Lack of friction.

- 4.1.2 Mechanical locking fails.
- 4.1.3 Pretension insufficient.
- 4.1.4 Secondary effects from internal pressure.
- 4.1.5 Poisson's effects not considered in design.
- 4.1.6 Eccentricity
- 4.1.7 Relaxation
- 4.1.8 Corrosion
- 4.1.9 Cracking/rupture of structural weld attachment of sleeve.
- 4.2 Micro motions caused by:
 - 4.2.1 Uneven axial load transfer distribution between pipe and sleeve. Loads exceeding the limits in parts of the coupling.
 - 4.2.2 Accumulation of local axial displacements between coupling and pipe caused by forces/temperature changes.
- 4.3 Fatigue (seldom design case).
- 4.4 Torque (could occur during the last phase of the installation).

Welds failure modes are further detailed in Sec.6.

7.2 Material properties

The following parameters shall be specified, when relevant:

- 1) Material strength: For steel see: "DNV-OS-F101", and for polymer materials see: API Bul 63 and NORSOK M710;
- 2) Thermal expansion coefficient and elasticity modulus. For soft seal materials both the linear and bulk modulus shall be specified;
- 3) Friction coefficient;
- 4) Galling limit;
- 5) Thermal effects on the mechanical properties of soft seal materials;
- 6) Swelling of soft seal materials in the specified environment;
- 7) Chemical resistance for the specified environment;
- 8) Corrosion resistance, particularly for seals and seal supports, for the specified environment.

7.3 Strength capacity

7.3.1 General

A fitting installation shall have sufficient strength capacity (resistance) to carry the loads with a safe margin to failure. The loads on couplings and Ts are transferred from the pipelines. Further all fittings are exposed to pressure and installation loads. The margin to failure is defined in Sec.4.6 by partial safety factors both for loads and strength (resistance).

7.3.2 Loads

The fitting design loads shall at least be:

- equivalent to the load capacity of the pipeline; or,
- for pressure, axial-, bending, torsion- and fatigue loads, equivalent to the maximum loads in operation, during installation and testing as relevant for the fitting.

(The methods to establish the maximum axial pipeline operational forces are given in Sec.4.)

An overview of loads and load combinations shall be established. The main load conditions to be included for couplings and Ts are:

<i>Load Type</i>	<i>Conditions, Parameters</i>
Internal and external pressure	Pipeline design and test conditions. Seal test pressure. Maximum seal diameters.
Bending moment	Pipeline capacity specified or limiting loads.
Tension, Compression	Pipeline capacity specified or limiting loads
Torque	Pipeline capacity specified or limiting loads
Bending fatigue	Pipeline capacity at the butt weld specified or specified number of bending cycles related to bending moment.
Temperature	Maximum and minimum related to the above capacities and limits.
Installation	Maximum forces limitations for interaction with the pipe and on coupling internals.

Load conditions relevant for other fittings installed on the pipeline shall be established as relevant.

7.3.3 Load responses

Fittings installed on the pipeline respond to loads by stresses and deflections. The principles used to predict stresses and related acceptance criteria are presented in Sec.2. General methods for stress calculations and related acceptance criteria are established in the standards referred to in “DNV-OS-F101” or other recognised standards.

7.3.4 Fitting grip-attachment to the pipe wall

Gripping by penetration of balls or teeth into the pipeline surface requires grips with significant higher hardness than the pipeline.

The possible failure modes causing lack of teeth/ball penetration to consider in design are:

- teeth/balls lack of hardness
- teeth lack of sharpness
- teeth lack of ductility causing brittle fracture. (Fragile teeth)
- teeth/balls braking due to cracks caused by stress corrosion/hydrogen embrittlement
- pipe coating thickness preventing teeth penetration into the pipe material.

7.3.5 Pipe wall - activation response

General

The pipe wall can be subject to significant radial forces caused by the activation of the fitting. Such high radial forces are beneficial in order to obtain the highest gripping capacity and best sealing performances. This is of particular concern to thin walled pipelines. For some types of fittings and applications this can cause plastic yield of the surface only and/ or the total pipe wall thickness. Possible failure modes to consider are:

- uncontrolled extent of yielding
- fracture caused by excessive tension yield or fatigue loading
- work hardening of possible concern to HISC and H₂S exposure.

The concerns and acceptance criteria depend on the following:

- pipe surface effects
- pipeline surface subject to gripping by teeth will normally

get indentation from the teeth of magnitude less than the pipeline surface roughness as limited by the pipeline standard specification and is therefore normally not of concern even for fatigue loads. Gripping by balls makes smoother indentation normally not of concern to fatigue except in rare cases.

Through thickness effects from radial *compression* would normally be related to control of the magnitude of yield and in some cases the work hardening. Radial compressive plastic permanent yield of 2% for the pipe wall membrane would normally be acceptable provided:

- This condition is caused by the make-up and therefore is considered as pretension. Further shall pipe forces in operation and testing not cause further plastic diameter reduction of the pipe.
- The consequences from pipeline axial forces and bending do not cause additional unacceptable accumulation of plastic strain in the area. The acceptance criteria shall be based on the possible degree of pretension loss caused by this additional plastic strain and possible reduced material characteristics (ref. DNV-OS-F101).

Through thickness effects from radial pipe *expansion* has a possible additional failure mode to those caused by compression due to risk for cracking by excessive plastic tension yield. Therefore the ultimate capacity for such a connection utilising the pipe in the plastic range must be based on a combination of plastic FEA, recognised acceptance criteria and testing. The pressure containment (bursting) capacity for the pipe with the fitting made up on/in it can be based on the “burst limit state” criterion given in DNV-OS-F101, provided possible plastic deformations are within functional criteria for the pipeline.

Plug loads

A pipeline with materials in compliance with DNV-OS-F101 subject to loads form a plug with relatively narrow loading lengths relative to the diameter has an ultimate limit state (ULS) defined by the following equivalent stresses.

$$\sigma_{eq,nom} \leq f_{cb} \quad (9)$$

$$f_{cb} = \left(f_y \text{ or } \frac{f_u}{1.15} \right) \quad (10)$$

This is provided:

- the maximum load, pressure and differential pressure combination is used
- conservative small friction factors are used for the slips.

The application in the nonlinear plastic material range is provided:

- certified true material behaviour is applied in analysis
- the limiting stress is derated by the material strength factor $\alpha_U = 0.96$ (Normal) if the material has not been subject to “supplementary requirements”
- effects on the load from changed geometry (larger diameter) is applied when establishing the ULS condition.

The allowable pipeline pressure conditions shall be based on the conditions for the ULS reduced by factors. These factors and their background in the partial safety factors are given in Table 7-2.

Table 7-2 Safety factors for pipes subject to plug loads

Property	Descriptions & abbreviations	Factors		
Safety class		Low	Normal	High
Safety class resistance factor	γ_{SC}	1.046 ²⁾	1.138	1.308
Material resistance factor	γ_m	1.15		
Material strength factor ¹⁾	α_U (Supplementary requirement U is specified)	1.00		
Linear analysis				
Implicit allowed hoop stress	Design pressure based on the incidental and maximum differential pressure	0.93 ³⁾	0.88	0.77
Maximum acceptable stress relative to f_y for setting and use of the plug at maximum incidental diff. pressure	Membrane (mid wall) stress	0.83 ³⁾	0.76	0.66
	Equivalent (von Mises) stress combining hoop and longitudinal stress			
	Surface linearized stress	0.96	0.96	0.96
Non linear analysis based on true material stress strain curve⁴⁾				
Maximum acceptable stress relative to $f_u/1.15$ for setting and use of the plug at maximum incidental diff. pressure	Membrane (mid wall) and surface stress Equivalent (von Mises) stress combining hoop and longitudinal stress	0.83	0.76	0.66
a) Total strain acceptance criteria	Provided ECA.	0.02		
b) Total strain acceptance criteria	No ECA required	0.004		
¹⁾ For material where supplementary requirement U has not been specified, 0.96 shall be used, giving a usage factor 4% lower than the numbers given in the table. ²⁾ Effectively 3% higher due to the system test requirements. ³⁾ Due to system pressure test requirements. ⁴⁾ α_A The anisotropy factor – removed in 2007. ⁵⁾ For areas based on FEM and linearized stress. Local strain exceeding this level can also be accepted based on further documentation, e.g. tests that show no tendencies of cracks with a safety margin.				

The principle of applying higher utilisation based on plastic analysis compared to that from elastic analysis shall be verified by strain gauge measurements on the pipe.

External sleeves

External sleeves or clamps are being used to reinforce pipes subject to internal plugging loads when the wall is too thin for plugging at the required pressure. There are two methods that are used for this either separately or in combination. They are based on either:

- 1) precompress the pipe radially
- 2) increase the stiffness (strengthen) the pipe radially.

In both cases the acceptance criteria for the pipe shall be met prior to and after setting of the plug.

The challenge for item 2 (increasing the stiffness) is to transfer the stiffness to the pipe wall by bridging possible initial clearances between the sleeve/ clamp and the pipe.

It is recommended to perform an FE analysis which includes the sequences of operation: a) installation of the sleeve/ clamp and its activation b) installation and activation of the plug. Further it is recommended to perform strain gauge measurements on the external surface of the pipe to verify the calculation.

7.4 Seal capacity

7.4.1 General

The sealing principles and seal installation sensitivities are discussed in Sec.1 and Sec.5.

A coupling shall have sufficient seal capacity to isolate the specified fluid at specified differential pressure, temperature and time, with a margin as defined in Sec.2. This applies to operation, pressure testing, and after depressurising the pipe-

line.

Each seal in a series shall be designed for the full differential pressure. The seal system shall be designed to enable a seal test without requiring pressurisation of the pipeline.

7.4.2 Design capacity

Calculations or tests of the seal system response to the load conditions shall be carried out. This shall include:

Table 7-3 Seal load conditions

Item of concern:	Calculations/Tests:
Soft seals clearance to seal	Circumferential clearance distribution as function of load conditions including unsymmetrical loads (bending), pipes geometry and manufacturing tolerances. Stresses in back up rings or strengthening devices and safety against their failure modes (e.g. warping, material plastic yield)
Hard seal loads	Circumferential seal contact load distribution as function of the load conditions including: unsymmetrical loads (bending) pipe geometry and pipe surface discontinuities.
Annulus seal test pressure limit	If there is an annulus seal test feature, calculate the maximum annulus test pressure limit both with respect to pipe failure and seal failure.
Soft seal volume changes	Calculate the volume changes caused by the fluid in contact and the temperature changes.
Soft seal fluid migration	Calculate the migration rate of the fluids to seal based on the material specification, at maximum differential pressure and temperature.

Discussion of seals aspects and application are presented in Appendix A.

8. Testing

8.1 Test philosophy

The test philosophy is briefly mentioned in Sec.2.

The extent of the required tests depends on the design type, confidence in analyses, and the extent of documented experience.

Sec.6 describes tests related to hyperbaric welds.

A qualification program shall be established based on the above aspects. This program shall determine:

- the tests to be carried out,
- the purpose of the test,
- the parameters to be measured and recorded,
- the accuracy of these measurements and
- type of analysis of the test results to enable correlation with the design analysis and limiting design conditions.

The typical tests are:

- 1) *Basic tests*, such as testing of material strength, seal capacity, extrusion gap limits etc.
- 2) *Type tests* (Qualification tests), which verify the functional requirements of a new type design with a recognised safety margin. This type test can be combined with the FAT (see below) for the fitting tested.
- 3) *Factory Acceptance Tests (FAT)*, which verify the manufacturing and assembly of a fitting which is already type tested. FAT for fittings that are not designed for reuse could be limited to dimensional measurements and check for material compliance with the design criteria.
- 4) *Final tests* which verify the completed installation.

Examples of typical tests are described in Appendix B.

9. Documentation

9.1 Documentation

9.1.1 General

General documentation principles are presented in DNV-OS-F101 and this publication. The documentation should be available and submitted for assessment as agreed. Requirements for such documentation are detailed further in the following. Sec.6 describes details related to hyperbaric welds.

9.1.2 General documentation:

- 1) Description
- 2) Installation principles including hyperbaric welding when relevant
- 3) Main specifications and limitations
- 4) Arrangement drawing with position numbers.

9.1.3 Qualification

Documentation of:

- 1) Calculations and related dimensional drawings and materials, and tests related to the design and installation principles.
- 2) Identification of possible failure modes and documentation of a reasonable safety margin against these failures.
- 3) Interpolation/extrapolation methods to be applied for the actual designs.
- 4) Material specifications.
- 5) Principles of manufacturing and quality control including main principles of factory acceptance test procedures.
- 6) Limitations, assumptions and requirements to installation tools and installation procedures.

9.1.4 Design

Documentation of:

- 1) Specifications and limitations.
- 2) Detailed dimensional drawings.
- 3) Identification of materials.
- 4) Design analysis.
- 5) Outline procedures intended for tests with the objective to document design features.

9.1.5 Manufacturing

Documentation of:

- 1) Material certificates.
- 2) Manufacturing records on bolt pretension, welding procedures, including qualification records, welder qualifications and NDE personnel qualification.
- 3) Dimensional measurement report on key dimensions.
- 4) Test reports.
- 5) Unique identification (for traceability of fittings and its

main components).

- 6) Manufacturers "Design and Fabrication Resume" (DFI) The DFI resume shall identify possible requirements to inspection and maintenance and give guidance for possible repair/retrieval.
- 7) Manufacturers Certificate of Conformity with specified criteria.

9.1.6 Installation

Documentation of:

- 1) Lay out drawing of the installation.
- 2) Dimensions including tolerances and material identification of the pipes to be connected.
- 3) Pipe and fitting manipulation documentation for compliance with both pipeline- and fitting design requirements.
- 4) Inspection records of pipe end cut geometry, pipe surface roughness and cleanliness, alignments of pipe ends.
- 5) Documentation confirming fitting make-up within prescribed limitations and the quality of possible hyperbaric welds.
- 6) Leak test report with P&ID (Process & Instrument diagram) of leak test system.
- 7) Final inspection documentation.
- 8) Installation contractors "Design, Manufacturing and Installation Resume".
- 9) For hyperbaric welded items, see supplements in Sec. 6.13.

9.2 Qualification check list

Methods used for qualification depend on the type of fitting. Appendix C presents a checklist for use in the qualification. The list is split into 3 main chapters: "A" for input parameters, "B" for parameters to qualify, and "C" for documentation.

The qualification part, the "B" list, is furthermore split into two main columns, one for analysis and theory and another for tests.

9.3 Quality assurance

The manufacturer and installation contractor shall:

- perform design, manufacturing and installation according to generally recognised quality assurance procedures; and
- follow recognised standards/acceptance criteria.

Guidance note:

A method to document the quality of the coupling is described in: DNV-OS-301 Certification and verification of submarine pipeline systems

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

9.4 Traceability

Each installation shall be traceable to the installation records (documentation), manufacturing records and qualification documentation.

APPENDIX A FITTING CAPACITY

A.1 Mechanical Coupling Strength Capacity

A.1.1 General

The locking capacity depends on the attachment method to the pipe:

- the attachment is nearly uniform along and around the pipe employing many balls or teeth, similar to a friction based coupling
- it depends on local attachments such as edges, few teeth or few balls penetrating into the pipe surface.

The structural strength of the coupling parts and the locking capacity of a coupling shall be sufficient to convey the pipeline forces. Parameters of concern are discussed as relevant for the various coupling groups as follows:

Bending

The bending strength of the sleeve is governing together with the pipe ability to convey the bending moment and transverse shear forces. A sleeve will, however, increase the pipeline stiffness locally.

Contact forces

The radial contact forces between the pipe and the sleeve govern the capacity to transfer axial and torque forces in combination with “locking coefficient” (the efficiency of the locking).

This radial contact force is generated by the pretension and the internal pipe pressure. This force is further increased by pipe tension for couplings with “wedging effect”.

The radial contact force is limited by either the collapse strength of the pipe, or the radial stiffness of the sleeve.

Pressure

Internal pressure will expand the pipe and hence may improve the locking capacity. This load type may therefore not be the dimensioning for the coupling.

Only relative small tension capacities are possible to verify by a pressure test alone.

An external differential pressure can occur in gas pipelines after depressurization. This load condition tends to contract the pipeline diameter and may therefore reduce the tension capacity of the coupling.

Tension/Compression

Pipe tension tends to contract the pipeline diameter due to the Poisson effect. Thereby the radial contact forces may be reduced for couplings which have no “wedging effects”, resulting in a slight reduced tension capacity.

Couplings with “wedging effects” may increase the radial contact forces by pipe tension. Increased radial contact forces cause pipe contraction and may cause an axial displacement of the pipe inside the coupling.

Axial pipe compression may reduce the contact forces and cause sliding of the pipe inside the coupling.

Likewise will this coupling’s capacity be reduced for axial compressive pipe loads unless the pipe ends meet a recess in the coupling or the other pipe end.

Torsion

A significant torsion capacity is seldom required. The torsion capacity is related to the contact forces multiplied by the friction coefficient and contact radius. Local gripping by balls etc., which prevents rotation of the pipe, improves the torsion capacity.

Temperature

Normally the pipe is warmer than the sleeve. This causes some increased contact force between the coupling and the pipe, dependant on the design. Different thermal expansion coefficients of sleeve and pipe will, however, also affect this contact force.

Fatigue

A significant fatigue capacity is seldom required. FEA/testing can be applied to demonstrate fatigue capacity.

Some aspects of the coupling types are discussed below.

A.1.2 Symbols

The following abbreviations are employed in the formulae that are derived in the below sections. Note that in the formulae subscripts of ‘s’ and ‘p’ are used for sleeve and pipe respectively. See also Sec.1.9.

- D = Outer diameter of the pipe. It may be assumed that the difference (e_p) between inside diameter of sleeve and outer diameter of the pipe is negligible compared to the diameter of the pipe. Therefore the outside diameter of pipe may be taken equal to inside diameter of the sleeve.
- L = Length of contact surface between sleeve and pipe
- e_f = Change in diameter due to tension force
- e_t = “Shrink fit”. Difference in inner diameter of the sleeve and outer diameter of pipe.
- e_{tm} = Shrink fit produces a contact pressure, which generate a fraction of yield stress of pipe.
- e_p = Change in outer diameter of pipe
- e_s = Change in internal diameter of sleeve
- t = Thickness
- T_m = Make up temperature
- T_o = Operational temperature for sleeve
- ΔT = Temperature difference between pipe and sleeve.

A.1.3 General compression fit

Most couplings, except for the wedging types, are dependent on initial high compressive forces between the pipe and the sleeve.

Figure A-1 illustrates a general compression fit between cylinders.

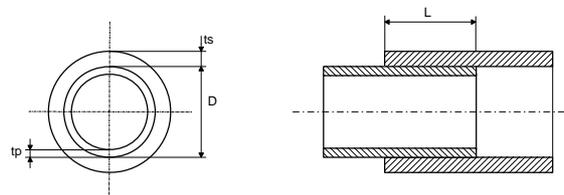


Figure A-1
Illustration of the compression fit (“Shrink fit”)

$$e_t = e_p + e_c$$

Where:

- e_t = “shrink fit”
- e_p = change in outer diameter of pipe
- e_c = change in internal diameter of sleeve respectively.

A.1.4 Expanded sleeves

One type of forging process expands the pipe to obtain a compressive radial load between an outer sleeve and the pipe. The forging sequences are:

- 1) Expanding the inner pipe until yield stress
- 2) Continue the expansion by yielding the inner pipe within the limit of:
 - an acceptable permanent deformation
 - an acceptable stress of the sleeve
 - relieve the internal forging force. this causes the sleeve to elastically shrink whilst pipe has experienced a permanent (plastic) deformation.

The remaining compressive force between the pipe and the sleeve must be sufficient to:

- assure a locking in the axial direction
- to seal.

The seal is best achieved by local surface yield occurring circumferentially between the two surfaces during the forging process. Internal ribs in the sleeve are beneficial for this purpose. Internal ribs also improve mechanical locking in the axial direction and thus improve the axial force capacity.

A.1.5 Pipe collapse

The contact forces during/after make-up are limited by:

- Type 1. The collapse strength of the pipe for uncontrollable radial deformations.
- Type 2. The yield strength of the pipe if the radial deformation is controlled and equal all around.

Some couplings can cause the above types of pipe collapse under the following conditions:

Friction	Type 1	During make-up
Grip, Balls (Wedged)	Type 2	During make-up and tension of the pipe
Flanged	Type 2	During make-up

A.1.6 Locking

Friction factors

Several types couplings partly depend on friction.

The friction coefficient depends on a range of factors:

- 1) static or dynamic
- 2) surface finish
- 3) material combinations
- 4) possible lubricants.

There are no distinct limits between mechanical locking and friction. Very rough surfaces tend to increase the locking capacity.

Common used static friction coefficients steel/steel surfaces range from 0.1 to 0.6. Sliding friction can be less. Note however, that NS (Euro code 3) specifies "slip factor" (friction coefficient) to be used in friction dependant connections from

0.2 to 0.5 dependant on the surface treatment:

Slip factor	Surface
0.5	Surfaces blasted with shot or grit, with any loose rust removed, no pitting. Surfaces blasted with shot or grit, and spray-metalled with aluminium Surfaces blasted with shot or grit, and spray-metalled with zinc-based coating certified to provide a slip factor of not less than 0.5
0.4	Surfaces blasted with shot or grit, and painted with a zinc silicate paint to produce a coating thickness of 50-80 micron.
0.3	Surface cleaned by wire brushing or flame cleaning, with any loose rust removed.
0.2	Surfaces not treated

A.1.7 Geometric locking

External local forge, where balls provide the lock

The point loads from the balls are to be distributed. The size of the balls is the key parameter for determining the number of balls used, and this is limited by geometrical conditions and local deformations. The minimum ball diameters will therefore be determined based on:

- 1) clearance to bridge between pipe and sleeve
- 2) deformation of pipe
- 3) deformation of sleeve
- 4) strength.

The locking is based on a local plastic yield of the pipe caused by the radial force from each ball. Local buckling of the pipe wall, instead of the required local plastic yield, is avoided by applying a sufficient amount of balls around the circumference. The diameter of the balls must then be optimised, to obtain sufficient indentation and number of ball rows for sufficient holding capacity.

External grip from teeth on wedge

Locking is obtained by an axial load generated by bolts which force the wedges into the pipe. During activation teeth on the wedges penetrate in the pipe surface and cause locking, shown in Figure A-2.

The contact pressure between pipe and wedge depends on the axial activation force, friction coefficient and the magnitude of the taper angle of the wedge.

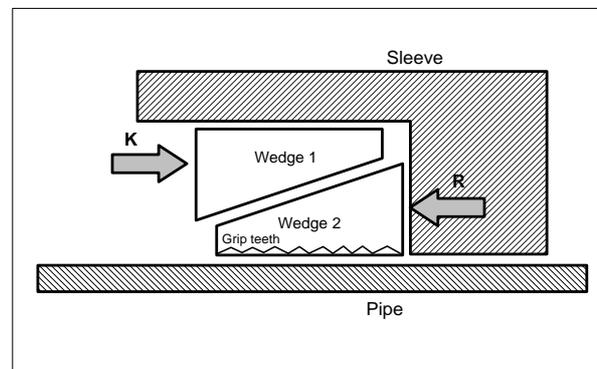


Figure A-2
Configuration of a simple connection providing locking by wedges

Pipe expansion into grooves in sleeve

Analysis and test of a typical coupling indicates for the following load conditions:

- 1) *Simple Tension*: The pipe waves in the grooves will be very slightly smoothed, but this Poisson effect will not affect the tensile capacity. The contact pressure at the edges due to tension will increase for the coupling because of the increase of the axial component.
- 2) *Axial Compression*: The pipe waves in the grooves will be slightly deeper but this will not affect the axial capacity.
- 3) *Tensile load capacity*: The few sharp edges on the sleeve penetrates into the pipe surface. Pipe tension causes high stresses around the pipe circumference thereby limiting the tension capacity when only few edges carry the load. The pressure will not improve the tension capacity.

A.1.8 Longitudinal force distribution

Connections will have a longitudinal shear force distribution. This depends on the thickness of pipe and sleeve, elasticity modulus, length and type of joint between pipe and sleeve.

Generally, the radial load is expected to be higher at the sleeve ends due to effects from the undisturbed pipe. Thus a friction shear capacity will be higher close to the sleeve ends. This is an effect which, to some extent, may compensate for the higher shear stress at coupling entrance caused by external forces.

There will be some shear stress due to a temperature gradient. The change in shear stress due to this temperature gradient will in most cases be small compared to that caused by tension. The impact of temperature to shear stress decreases for couplings with larger length. The effect of fluctuations of temperature will in most cases be small.

A.1.9 Micro motions

Each temperature cycle may cause an internal relative longitudinal displacement between the pipe and sleeve. When this motion is combined with tension, there may be a small resultant longitudinal sliding for each temperature and load cycle for a fully friction based junction.

For the majority of applications, however, the resultant effects are not considered to be of concern to the long term locking capacity.

A.2 Seal Capacity

A.2.1 Discussion

Soft seals

The seal manufacturers normally recommend limitations for use of the seal, including pretension for pressure activated seals as well as limits for extrusion gaps as function of pressure, temperature, time and load type. These recommendations shall be documented, however, as the application of soft seals for fittings is often outside normal use, further qualification may also be required.

Metal seals

The make up pressure for the gasket must significantly exceed the material yield strength of the seal material (or pipe material). Otherwise the seal material will not flow into the discontinuities and a seal cannot be obtained. These requirements can be relaxed if all discontinuities are removed completely, but this is seldom practical for pipe surfaces.

Consequently wide metal gaskets will be impractical as this would require unacceptable high radial loads against the pipeline. Such high loads could cause pipeline collapse due to the resultant high hoop stresses.

Therefore, radial metal seals for pipelines have thin sealing areas, often obtained by the local fitting geometry penetrating into the pipeline.

A.2.2 Compressive loads

Sealing action depends on a compressive load between the seal and its sealing surface. The contact pressure must exceed the

pressure of the fluid to seal. A safety factor must be applied to assure this condition.

A.2.3 Uniform loading

Circumferential seal loads

Some areas of concern are:

- 1) Loads closer than 0.2 diameters to the end cause significantly more inward deflections of the pipe wall than if they were further away. Elastic deflections at the end can exceed 4 times the deflections on a midsection of the pipe. High loads close to the ends are more likely to cause plastic deflections.
- 2) A distributed circumferential load on a pipe length less than 0.1 diameter gives equal pipe shell global responses similar to that from a line load of same force (The contact stress reduces proportional to length)
- 3) Plasticity of the pipe wall can be caused by high seal loads. This starts with yield related to plate bending (merodional bending) before hoop yield. Formulas for the plastic behaviour of the pipe wall can be developed based on the plastic capacity of the pipe wall and calibration.
- 4) Local plastic yield of the pipe surface is required for metal seals. Formulas for the penetration depth can be developed based on the theory related to Vickers hardness measurements and calibrations.

A.2.4 Thermal effects

Polymers

Thermal expansion of rubber in an enclosed space can be a matter of concern, as the thermal expansion coefficient of polymer materials can be more than 10 times that of steel.

Typical conditions for a polymer seal tightly enclosed within a steel boundary are indicated below, assuming:

- 1) equal temperature in the steel and the seal
- 2) a thermal expansion coefficient of 11 times that of steel
- 3) an incompressible seal.

$$\text{Steel stress magnitude: } \sigma = E \cdot \alpha \cdot \Delta t = 25 \cdot \Delta t$$

Thereby unstressed steel with yield strength of 350 MPa will yield at a temperature 14°C higher than at make-up.

The steel will, however, be pre-stressed, and hence will yield at a lower temperature.

The magnitude of the permanent relaxation will be as follows, by assuming:

- 1) Plastic yield in one direction
- 2) Typical polymer seal thickness "l" in this direction: 50 mm
- 3) Temperature increase from make-up: 50°C
- 4) Pre-stressed steel to yield.

$$\text{Relaxation magnitude: } \alpha \cdot \Delta t \cdot l = 0.3 \text{ mm.}$$

Consequently, the effect of different thermal expansion coefficients must be considered in design, i.e. there must be sufficient space for this expansion to avoid such effects.

Fluids

The expansion coefficients for trapped fluids in cavities must be considered in the design:

- 1) Hydrocarbon gases (mainly methane) initially at 205 bar and +4°C, then heated to 60°C typically gives an increase to approximately 2.1 times the initial pressure.
- 2) The thermal expansion coefficient of water depends on the temperature, pressure and salinity. Fresh water has a thermal

expansion coefficient of 0 at +4°C.

- 3) Typical oil has a thermal volume expansion coefficient of 0.001/°C.

A.2.5 Swelling

Polymer materials tend to expand due to absorption of fluids, and this is to be considered in the design.

A.2.6 Eccentricity

Flexibility in the systems design must compensate for the possible eccentricity between the seal and pipe.

This eccentricity may be caused by:

- 1) external forces acting on the pipe ends during activation
- 2) the function of the locking mechanism and positioning of the fitting
- 3) pipe deviations from straightness
- 4) pipe deviation from roundness.

A.2.7 Axial effects

Load effects

Elastic deflections of pipe and sleeve due to the axial pipe forces can, for some designs, cause a relative axial displacement between the pipe and the seal. This can be of concern for long term use, and should therefore be considered in the qualification

plans. The concern is:

- 1) seal displacements over local discontinuities of the pipe surface
- 2) wear.

Axial load effects are of most concern to thin metal seals.

Thermal effects

The seal is often located at some distance from the locking of the pipe. The pipe section between the locking and the seal will expand by temperature, whilst the sleeve external to the pipe will expand less due to the cooling effects from the water. Therefore, similar effects as above must be considered in the design.

A.2.8 Installation

Water block

Water trapped in cavities during make up prevents further action. This is of particular concern to the seals made by expansion of the pipe. The pipe is intended to expand into grooves of the sleeve, but this can be prevented by water located in the groove. Several designs therefore apply a resin filled with gas bubbles to reduce the water block effect. Such resins must, however, be qualified for the water depth they are installed. Deep water requires relatively compact resins to avoid collapse of the gas bubbles inside.

APPENDIX B TYPICAL TESTS

B.1 Basic tests

B.1.1 Introduction

Basic tests establish limiting parameters which are not established by analysis. Basic tests can be used to reduce the extent of "Type tests" (Qualification tests) required in combination with analysis. The following are examples of typical basic tests:

B.1.2 Materials

Typical tests are related to material properties and are well regulated by international and recognised standards.

Information can be obtained from literature and manufacturers as indicated below:

- 1) Properties of metallic alloys are easily obtained for commonly used metallic materials.
- 2) Relevant properties of non-metallic sealing compounds (rubbers, plastic, carbon, etc.) are difficult to obtain.

Tests related to resistance against the various types of corrosion are dealt with as for the pipeline itself.

Ageing tests of polymer seal materials are used to predict the lifetime of a seal in specified environments and are therefore time consuming. The test time can be reduced by an increase of the test temperature, but cannot normally be reduced to less than to 1/10 of the intended lifetime due to temperature limitations of the materials. Therefore ageing tests must be supplemented by detailed documentation for the materials.

B.1.3 Combined effects

Some combinations of design and material parameters require separate tests for establishing limiting parameters. Normally at least three tests and with separate specimens should be used to indicate the possible spreading of results.

Such tests are as follows:

Extrusion gap test of soft seals.

This test establishes the relationship between:

- 1) size of clearance gap to seal
- 2) pressure to seal
- 3) friction
- 4) temperature
- 5) time.

The seal manufacturers often give recommendations (limitations) based on documented testing. However, the intended seal applications can be outside such recommendations and therefore require separate tests.

Two types of gaps are of concern:

The first gap of concern is related to clearances to seal. The size of the tested clearance gap must be determined accurately, and can be affected both by the pressure and temperature. The gap is either pre-set fixed or measured during the test.

The second gap of concern is related to sealing against discontinuities on the pipe.

The pressure can be applied either via a test fluid, or, for larger compact soft seals, directly as a compressive force causing the intended internal pressure of the seal compound.

The term "extrusion" must be defined in relation to failure mode of the seal. For a soft seal as well as back-up rings, this could address:

- 1) The permanent deformation into the gap as a ratio of the gap size.
- 2) Plastic deformation of internal strengthening members such as metal springs in the seal.
- 3) The relative amount of reinforcement fibres fracture in the seal.
- 4) Loss of seal pressure.

Metal seals Tests

Metal seals must seal against the pipe surface including defined surface discontinuities. Therefore sufficient plastic yield of the pipe surface and/or the seal must be obtained. Important test parameters are:

- 1) material hardness of seal
- 2) material hardness of pipe
- 3) shape of seal
- 4) load applied to seal
- 5) defined discontinuity of pipe
- 6) for seals that can be marked during installation: defined discontinuity of seal.

The determining parameter could either be:

- leak test, or
- microscope investigations of the specimens being forced together, combined with later full-scale test including defined discontinuity.

Friction factor Tests

Most type couplings are affected by friction, either during installation, make-up or in operation. Friction coefficients, which are critical, are determined by tests. Important test parameters are:

- 1) material combinations
- 2) surface roughness
- 3) specific compression load
- 4) velocity (dynamic friction)
- 5) possible in-between fluids or contamination.

The monitoring of forces which are required to move and to compress is used to establish the friction coefficient.

B.1.4 Galling Test

Galling causes damaging of the surface finish as well as high friction coefficients. The galling limits are determined in the same way as friction coefficients but combined by a microscope survey of the surfaces.

B.1.5 Polymer decompression limits (explosive decompression)

Seals in gas systems can be damaged by high decompression rates. Gas which was dissolved in the material at high pressure can form bubbles when the pressure is reduced, and this can result in seal damage. Important test parameters are:

- 1) material type
- 2) size, shape of material and gas pressure exposed area
- 3) gas type, either the actual or a type, which exhibits similar effects
- 4) pressure

- 5) saturation time
- 6) decompression rate
- 7) temperature
- 8) detection method of blisters.

B.2 Type tests

B.2.1 Introduction

A Type test (Qualification tests of the type) verifies, in combination with analysis, the functional requirements and safe operational limits of the fitting type.

The number and extent of the type tests depends on:

- 1) the extent of documented experiences
- 2) the extent of the analysis performed
- 3) the accuracy and conservatism of the analytical approach
- 4) the extent of basic tests performed.

After a Type test, there follows a Factory Acceptance Test (FAT).

The Type test could be combined with the FAT. This combined testing is practical when only one fitting of the type is made.

The optimum qualification scenario should be analysis, basic test and type test combined in a practical manner.

The Type tests include the extreme tolerance combinations from dimensions, pressure, temperature, fluids, operation and installation; for which the analysis is either incomplete or indicates a particular risk of failure.

In addition, Type tests are used for verification of analysis. This involves measurement of sufficient parameters accurately to compare with those in the analysis.

Measurement and monitoring accuracy shall be documented.

The following describes typical Type tests.

B.2.2 Test specimens

Pipes

The pipes selected for type tests should represent the extreme dimensional tolerance combinations, surface discontinuities and material properties, unless the effect from these are sufficiently covered by the Basic Tests and analysis. Such pipes will, however, be difficult to obtain as the pipes will normally have only *some* adverse combinations. The effects from other combinations which are not available on the test specimens must be covered otherwise.

The manufacturing method of the pipe shall be specified.

The detailed pipe dimensions shall be measured and documented by a dimensional sketch, including information with respect to:

- 1) Straightness in two planes (90 degrees apart) within the attachment length of the fitting to the pipeline. The straightness shall be recorded as deviations from the straight line at intervals at maximum 1/10 the coupling length.
- 2) The accurate diameters shall be measured at sections:
 - at each end of the fitting's attachment to the pipeline
 - where seals interact
 - at the middle of the attachment to the pipeline
 - at maximum and minimum straightness deviation.
- 3) Each cross-section for diameter measurements shall be measured at 4 diameter positions equally spaced around the circumference.
- 4) Local imperfections (welds, undercut, artificial imperfec-

tions). The sketch shall show depth (height), length, shape and curvatures. Photographs and plastic replica can be used to supplement the sketch.

- 5) Wall thickness shall be measured 8 places equally spaced around the circumference at the attachment to the pipe.
- 6) End cut evenness or chamfer.

The pipes shall be marked for identification of the measurement-positions and for the intended axial and angular location of the coupling.

Test certificates valid for the particular pipe shall document actual material properties. Hardness (Brinell or Vickers) shall be measurements in weld areas.

Fitting

Drawings with dimensional tolerances shall be available.

The actual dimensions of the critical parts, such as minimum internal diameter, shall be recorded with an accuracy of at least ± 0.1 mm measured at, or transformed to, 20°C ambient temperature.

Material test certificates shall document the actual material properties for both metals and seals.

B.2.3 Installation

The installation test shall simulate exaggerated actual installation, i.e. design conditions with a margin.

This shall include e.g. the coupling maximum design limits with respect to pipe minimum end chamfer (if any), maximum misalignment (and pipe straightness deviation), and eccentricity between pipes and fitting including a margin.

Furthermore, the stiffness of the pipe supports, the support of the fitting, as well as effects from gravity/buoyancy, shall comply with the fitting limiting specifications. Thereby the limiting forces and critical seal interactions can be simulated during the installation test when the fitting position is adjusted while resting on the pipes.

The displacement shall be performed with actual maximum specified velocities.

The basis for the test procedure/test rig set-up is:

- 1) An overview of the critical tolerance combinations for installation.
- 2) Applied safety factors on tested tolerance combinations.
- 3) Stiffness of pipe ends including sub-sea fixation, if the installation causes pipe deflection that may have an adverse effect.
- 4) Stiffness of fitting support, if it may have any adverse effect.
- 5) Weights dry and submerged.
- 6) Displacement velocities.
- 7) Possible different effects from dry test versus submerged test.

The fitting shall be removed after installation from the correct position, and the internals shall be inspected for the interactions with the pipe. The seal area is of main importance.

The installation test shall be repeated to cover all critical tolerance combinations, and at least 3 tests shall be performed.

All parameters mentioned above, including the seal visual appearance, shall be recorded and compared with the acceptance criteria. Photographs shall also document interaction marks.

B.2.4 Activation

The activation test shall simulate the most adverse design conditions with a margin.

The most critical tolerance combination for activation should be selected. This will normally be the thinnest pipe wall-thickness, largest clearance between fitting and pipe, and largest misalignment (and pipe straightness deviation) combined with largest stiffness. Furthermore, the fitting shall be positioned at its maximum specified deviation from its intended position, e.g. one pipe end for a coupling. This deviation shall be in the most critical direction. For a coupling this will result in a shorter distance between the coupling seal and pipe end.

The basis for the test procedure/rig set-up is:

- 1) overview of critical tolerance combinations for activation
- 2) a margin applied to these tolerance combinations for determining tested combinations
- 3) stiffness of pipe at the fitting location, e.g. the ends including effects from sub-sea fixation to alignment frames, if the activation causes internal bending moments inside the fitting
- 4) weights dry and submerged
- 5) possible different effects from dry test versus submerged test
- 6) activation procedure
- 7) monitoring and measurement procedures.

Other tests normally follow on from activation tests.

Fittings which enable repeated activation shall be subject to at least 3 activation tests.

The deactivations shall be monitored as the activation.

B.2.5 Strength/leakage

Type test of the fitting strength/tightness shall normally be carried out to the design conditions (pipeline operation and/or pipeline pressure test conditions), with adjustment for actual material properties, dimensional tolerances, and with a safety factor in addition. Alternatively, the fitting can be tested to failure.

The basis for the test procedure is:

- 1) design capacity specification for separate loads and combined loads
- 2) a margin between design conditions and test conditions
- 3) actual dimensions and yield strength of the pipe for the test
- 4) the activation condition which gives the least strength capacity
- 5) measurements/monitoring of longitudinal (and rotational) displacements between fitting and pipe as function of the load
- 6) possible strain gauge measurements for verification of the analysis, supplement to the analysis and for determination of loads
- 7) leak detection measurements.

Leaks and unacceptable permanent deformation and displacements are rejection criteria.

Pressure test

The basis for the test procedure is:

- 1) test pipes with end caps
- 2) pressure causing a defined hoop stress utilisation depending on the application, e.g. 0.96 of the actual yield strength of the test pipe.

Coupling tensile test without pressure

For most pipelines, the tension capacity does not need to meet that of the pipeline.

The basis for the test procedure is:

- 1) A pipe tension, without significant internal pressure, as a fraction of the yield capacity of the actual test-pipe.
- 2) A small insignificant internal (or annulus) pressure as necessary to check the seal tightness.

Coupling compression test without pressure

A test can document the compression capacity in couplings where:

- the pipe ends do not meet each other
- the pipe ends do not meet a recess, and
- an axial pipe displacement inside the coupling can cause negative effects.

The basis for the test procedure is:

- 1) A pipe compressive force as a specified fraction of the yield capacity of the actual test-pipe.
- 2) A small insignificant internal (or annulus) pressure to check the seal tightness.

Torque test

A significant fitting torque capacity is needed for only a few pipelines applications.

The basis for the test procedure is:

- 1) A pipe torque as a specified fraction of the torque yields capacity of the actual test-pipe.
- 2) A small insignificant internal (or annulus) pressure to check the seal tightness.

Bending test

Bending moments can be introduced to couplings by the Activation test described above.

Bending moments introduced after activation will be of less concern to couplings. Normally the pipe, and in some cases the connection to the coupling, will represent the limit. A small insignificant internal (or annulus) pressure should be applied as necessary to check the seal tightness. Pipe bending moments from branch connections is of concern to T joints.

Pipe bending moments can also cause additional plastic deformation of the pipe wall when already subject to strain in the plastic region caused by high loads from e.g. seals in couplings, clamps and plugs.

Fatigue test

Only a few pipelines are subject to alternating bending loads of concern. The pipe itself, at its connection to the coupling, will in most cases represent the weakest point of the connection with respect to fatigue. The general limiting fatigue resistance of the pipeline is at pipeline butt welds. Pipe fatigue criteria are described in "DNV-OS-F101"

The basis for the test procedure is:

- 1) Specified maximum alternating bending moment as a fraction of the bending yield capacity of the pipe tested.
- 2) Number of cycles with this load.
- 3) Distribution of magnitude of bending moments and higher number of alternating loads.
- 4) A small insignificant internal (or annulus) pressure to check the seal tightness.

Temperature test

The analysis shall show whether the temperature reduces the strength/seal capacity more than that related to the material strength reduction. From this analysis, important combinations with any of the above tests, with part-loads, can be established

and will form the basis for test procedures to assure the strength capacity at elevated temperatures.

Temperatures of concern are:

- 1) maximum and minimum fluid temperature
- 2) water temperature
- 3) resulting temperatures of pipe and fitting
- 4) transient temperature distribution within the fitting during start-up and shutdown.

External pressure test

Deep subsea gas pipelines can have a particular load case if the pressure is relieved from the pipeline. The external pressure tends to reduce the interaction forces between the fitting and the pipe due to additional contraction of the pipe.

The basis for the test procedure is:

- The external differential pressure resulting from the water depth and the remaining internal pressure. The limit would be the collapse pressure of the pipe.

Combined loads

The analysis shall show whether any of the specified combined design load cases gives a smaller safety margin against failure than the separate cases described above. Such cases shall form the basis for testing of combined loads. Possible combined loads for couplings are:

Internal pressure causing a hoop stress of the pipe of 80% of actual yield strength combined; with

- tension (simulating a free span) and/or compression
- bending moments.

B.2.6 Seal Tests

B.2.6.1 General

Seal tests are partly included above.

In addition, the basis for seal test procedures includes:

- 1) facility used to confirm the integrity of the connection after make-up

In case of lacking Basic tests:

- 2) test of the relation between seal compressive load and the pressure leakage limit
- 3) test to confirm sealing at defined pipe surface irregularities
- 4) gas seal leak test
- 5) gas migration test. This includes detection by the use of Helium combined with circulation of gas, outside the seal, via a detector for Helium atoms in the gas stream.
- 6) test to confirm the seal function in case there is a defined eccentricity between the pipe and the coupling.
- 7) the seal test pressure confirming the integrity of the installation should in general be 1.5 times the design pressure to seal provided the maximum pipe stress is less than 0.96 of the specified minimum yield stress or that the resulting pipe strain is within acceptable limits. Strain causing local plasticity of the pipe needs to be qualified. For an annular seal test, the qualification test pressure may also be limited by the collapse pressure limit for the exposed short annulus pipe section.

An analysis shall show that the seal test pressure is conservative (large) compared to seal conditions at the pipe design pressures, where test pressures lower than 1.5 times the design pressure are applied. This can be demonstrated through analysis by showing that the specific seal pipe-contact pressure during seal test is larger than the

contact pressure at design pressure.

- 8) the seal test pressure to be applied sub-sea should be qualified with a higher pressure applied during the qualification tests.

Basic tests and type tests are described above. For the sealing function these test may be performed as full scale or small scale test as described in the following.

B.2.6.2 Full scale tests

A pressure test alone would be appropriate as a Factory Acceptance Test of a seal system which has been qualified. The pressure test will normally, however, not give sufficient assurance for seal without a qualification.

There are several methods to qualify that the sealing of a gap has sufficient strength at maximum adverse conditions. ISO 10423, Annex F.1.11 which applies to wellhead equipment as well as engineering judgement forms the background for the following tests and acceptance criteria. Two approaches appear feasible:

- 1) Cyclic test between the lowest and highest temperature and pressure for the number of maximum operating conditions.
- 2) Cyclic test between the lowest and the highest temperature and pressure for the number of cycles required to show seal pressure stabilisation.

The latter item 2) "seal pressure stabilisation" can be verified by stabilised extrusion, stabilised leak pressure (increased seal test pressure until leak occurs provided this does not harm the seal) or by direct measurement of the seal pressure. Thereby the cycle test time as well as number of cycles can be established. Conservatism can be included by:

- maximum temperature increase (say an increase of 10 deg. C) and
- maximum pressure (say by a factor of 1.1 of the maximum seal pressure)
- minimum pressure (say by a factor of 0.9 of the sealing pressure) and by
- cycles (say 1.5 times the actual numbers).

The first cycle with high temperature should preferably have a longer duration to assure the stability, say 3 times the time required to "indicate" stabilised conditions. The following cycles could then be limited to 1/3 of the first. Equal exposure times should be used for the following lower limit temperature exposure as for the higher temperature limit exposure.

The number of test cycles can be terminated when 3 following cycles do not show any changes, i.e. when stabilised conditions are confirmed.

The former approach 1) is more uncertain with respect to the holding time per cycle; say 3 hours for the first cycle followed by 1 hour for the following high as well as low temperature exposure. A total number of test cycles should be equal to the predicted number of pipeline depressurisations multiplied by 1.5

B.2.6.3 Small scale tests

It can be difficult and costly to perform the full scale test for the conservative limit of all the contributing parameters. In that case small scale tests establishing limiting parameters can replace parts of the full scale test. (Small scale tests are in principle part of the "basic" tests).

Small scale tests can be used to establish:

- correlation between extrusion gap, seal pressure, seal strength and elasticity, temperature and time
- possible swelling caused by fluid exposure
- chemicals or mixture of chemicals affecting aging
- seal material characteristics such as thermal expansion

- coefficient and volumetric (bulk) elastic modulus
- seal friction coefficient.

The setup for the small scale tests can differ from that for the full scale, but it must reflect the failure mechanism considered in a conservative manner, i.e. the failure must be allowed to develop similar to the actual in a conservative manner.

It is an advantage with an analytical numerical model for the seal pressure to make use of the results from the small scale tests. This analytical model should calculate the seal pressure changes caused by the parameter variations. An actual extrusion will most probably take place only in a limited part of this circumference reducing the pressure in this part. Ideally such an analytical model could include the effects from pressure variations around the seal circumference and possible seal mass redistribution due to this. It is, however, assumed that such an analytical model even being sophisticated will have a wide spread of the results when compared to test results. Consequently the conservative approach is advised: to calculate seal pressure reduction at the place of extrusion without including possible circumferential seal mass redistribution.

The use of small scale test results and an analytical model would require some higher safety factors compared to the full scale test for the worst parameter combinations

A simpler analytical model could be applied to “fully enclosed seals”, since there would be no seal extrusion. The main concern would be to estimate possible volume changes caused by the seal thermal expansion and check that the enclosing materials has sufficient elasticity, thereby avoiding plastic permanent deformations of the weaker parts of the seal support, and/or include this plastic deformation. This volume change would be caused by the elasticity/plasticity of the pipe itself and/or the anti extrusion rings.

In general a full scale test should be used to calibrate analytical tools.

B.2.7 Integration and Sub-sea

A sub-sea test shall be carried out. The test shall cover features with different effects (possible failure modes) from dry on land testing e.g. possible water block.

The tests shall, as a minimum, include:

- activation, and
- pressure test.

Materials and material combinations with possible failure modes related to the sub-sea use shall be qualified by Basic tests. Such features could be:

- 1) volume elasticity and water absorption properties of materials filling voids
- 2) swelling
- 3) electrical isolation
- 4) hydraulic systems pressure compensation systems.

B.2.8 Examinations

The fitting and the pipe shall be thoroughly examined after the tests. This examination shall include:

- 1) examination for marks and measurement for permanent deformation of the pipe
- 2) examination of the fitting internals, in particular the seals, before disassembly
- 3) measurement of critical dimensions of the fitting
- 4) disassembly of the fitting and measurement of critical dimensions.

The measures shall be carried out with the same accuracy as indicated above.

B.3 Factory acceptance tests

B.3.1 Introduction

The Factory Acceptance Test (FAT) checks the manufacturing of the fitting. It is, in principle, a spot check of only some aspects of the fitting. The aspects of concern are those related to possible errors in manufacturing.

Some types of fittings are designed for only one activation, i.e. only for the actual pipeline connection. Testing of such single activation fittings is therefore limited to the Basic tests, Type test and Testing after installation.

The following information regarding FAT applies in general for fittings designed for possible reuse.

B.3.2 Manufacturing

The manufacturer's quality control shall verify compliance of material, dimensional tolerances and make-up forces with the design documentation before assembly.

Critical dimensional tolerances and surface finish shall be measured with an accuracy of at least 1/10 of the prescribed tolerance band.

Where relevant, the magnitude of bolt pretension etc. shall be recorded.

B.3.3 FAT Testing

Fittings capable of activation, deactivation and reactivation shall be tested. The test shall follow a procedure with defined acceptance criteria. The acceptance criteria shall be documented by the qualification work. Factory acceptance tests can be carried out for nominal conditions with respect to dimensional tolerances, pressures and time. Typical tests for connection of pipes are as follows:

B.3.4 Activation test

The fitting shall be installed on pipes which are similar to the actual pipes with which the fitting is intended to mate. The key parameters shall be identified and recorded during activation and be within the prescribed limits.

B.3.5 Pressure test

The fitting installed on the test pipes with end closures shall be subject to a pressure test equal to the test pressure intended for the pipeline.

B.3.6 Seal test

The seals shall be subject to a seal leakage test via the annulus or the installation tool.

The test pressure shall be equal to that determined by the qualification.

B.3.7 Deactivation test

The fitting shall be deactivated after testing. The key parameters shall be identified and recorded during the deactivation and shall be within prescribed limits.

B.3.8 Examinations

The dismantled fitting and the test pipe shall be examined to check that the appearances/tolerances are within the acceptance criteria, including:

- seals
- grips (connection area to pipe)
- marks on the pipe surface from seals and grips
- dimensional measurements for possible plastic deformations of sensitive coupling internals
- dimensional measurements for possible plastic deformations of the pipes.

Any possible need for replacement with new parts (e.g. seals)

following activation / deactivation shall be recorded.

B.3.9 Insufficient Type tests

The FAT can be combined with Type tests, in case of incomplete separate Type tests. Where such combination is applied, the FAT must be extended to include the requirements relevant for the incomplete Type test(s).

B.4 Installation verification tests

B.4.1 Introduction

Final tests verify that the completed installation complies with prescribed criteria. In some cases, final testing consists only of a leak tightness test.

However, the verification of the completed installation, often comprises also monitoring and recording of parameters which are important for assurance of the prescribed criteria. TV or sensors are required as applicable to perform such a monitoring.

The following describes typical testing.

B.4.2 Measurements, Monitoring and Recording

Measurements or monitoring of the limiting parameters can assure that the fitting is installed within its limits. These limits are normally:

- 1) pipe conditions with respect to surface conditions and if applicable: the end-cut
- 2) pipe alignment and alignment of coupling relative to pipe ends prior to installation
- 3) pipe gap between ends for couplings

- 4) contamination monitoring and control to avoid seal and locking failure
- 5) displacement control of the fitting during installation and control to avoid excessive forces
- 6) the fitting position relative to its intended and to its possible limiting position on the pipe, e.g. pipe ends
- 7) activation displacements/forces monitoring/control to assure activation within limits.

B.4.3 Testing

Sealing shall be tested to qualified pressure and time, with testing either at annulus or via installation tool.

The time depends on the stabilisation period due to the size and length of the pipe work connected to the test. Normally, a much smaller time can be allowed compared to the pressure test of the pipeline itself, due to the small volume pressure tested; say 2 hours.

Seals which are not tested after installation shall be qualified for this purpose, i.e. to have a sufficient small risk for leakage. Further it shall be checked for leakage at a pipeline leak test.

B.4.4 Dismounting

- 1) Temporary connections for control and monitoring shall be sealed off after disconnection. The sealing off integrity shall be verified by appropriate means, dependent on the consequences of a leak through the seal-off. The verification method shall be a part of the qualification.
- 2) Forces applied to the connection after make-up and testing due to the final pipe manipulation shall be controlled within the connection limitations.

APPENDIX C CHECK LIST FOR QUALIFICATION

Det Norske Veritas
Pipeline mechanical fitting

Rev. Year
DNV Check list for Qualification

Revision record of list items:

Type:

The following tables are split in three:

Table A contains input parameters

Check list for qualification

Table B contains parameters to be verified. Table B is split in two main columns, one for analysis of parameter effects and the other for testing

Table B will be concluded by text in bold and reference to the design documents and test reports as the project progresses.

Table C list documentation and main technical correspondence

The last column will be filled in "OK" when all relevant information is received, and items to qualify found in order, or "NA" for not applicable.

Table A Input parameters								
	Item	Parameter/ Failure mode	Unit	Spec.	Comment	Testing	Data	Check
A	1.	Actual Pipeline:			Ref:	Test pipe applied in qualification and FAT:		
A	1.1	Pipe dimension and Tolerances						
A	1.1.1	External nominal diameter, D	mm					
A	1.1.2	Wall thickness nominal,	mm					
A	1.1.2.1	Wall thickness tolerance	mm					
A	1.1.3.1	External diameter tolerance. External diameter by tape	mm					
A	1.1.3.2	Out of roundness by gauge	mm		OD max - OD min. Flattening during installation might increase the out of roundness			
A	1.1.3.3	Local out of roundness	mm					
A	1.1.3.4	Straightness for one pipe length equal to fitting length	mm		Based on a fitting length on a typical line pipe section length with 0.1% (circular) deviation from total length.			
A	1.1.3.5	Total measured diameter tolerance (by gauge, not tape)	mm		,+/-tape m dia.tol +/- 0.5*out.o.r.m.dia.tol. Additions from local out of roundness, straightness and flattening during installation are to be considered based on the likelihood of a combination. Thereby a sum of all extremes could be avoided.			
A	1.1.4	Corrosion allowance, internal	mm					
A	1.1.5	Surface imperfections	mm		Common pipe spec: c) weld undercut: 0.8 mm for 10 mm length. J) equally for other imperfections			
A	1.1.6	End cut evenness	Degrees					
A	1.1.7	Chamfer on pipe ends to be defined						
A	1.2	Pipeline forces/temperatures						
A	1.2.1	Bending moment (operation and installation)	kNm		Max. expected			
A	1.2.2	Tension without pressure (operation and installation)	kN.		Max expected			
A	1.2.3	Torque without pressure (operation and installation)	kNm		Max expected			
A	1.2.4	Pipeline test pressure at fitting	MPa					

Table A Input parameters (Continued)								
	<i>Item</i>	<i>Parameter/ Failure mode</i>	<i>Unit</i>	<i>Spec.</i>	<i>Comment</i>	<i>Testing</i>	<i>Data</i>	<i>Check</i>
A	1.2.5	Internal pressure at fitting	MPa					
A	1.2.6	External pressure	MPa					
A	1.2.7	Max temp:	°C					
A	1.2.8	Min Temp:	°C					
A	1.2.9	Alternating loads, magnitude and number of cycles.			Start- ups including pressure and temperature			
A	1.3	Pipe material			Obtain typical material test data			
A	1.3.1	Material min spec yield strength	MPa					
A	1.3.2	Material min spec tensile strength	MPa					
A	1.4	Environment						
A	1.4.1	Cathodic protection exposure externally						
A	1.4.2	Internal fluid						
A	1.4.2.1.	During operation			Gas, oil (contaminants: H ₂ S, CO ₂ , sand, water)			
A	1.4.2.2	Possible internal water circulation before and during coupling installation,			List possible parameters of concern such as time and circulation rate.			
A	1.4.3	Max. fluid temperature change rate	°C/ min					
A	1.4.4	External fluid, salt water, possible leaking fluids						
A	1.4.5	Impacts from trawl boards						
A	2.	Fittings						
A	2.1	Dimensions						
A	2.1.1	Length, max	mm					
A	2.1.2	Diameter outer sleeve	mm					
A	2.1.3	Dry weight	kN.					
A	2.1.4	Wet weight	kN					
A	2.1.5	Internal min. diameter	mm					
A	2.1.6	Internal min. diameter of seals	mm					
A	2.2	Locking			Parameters important to the mechanical locking to the pipeline			
A	2.2.1	e.g. Radial make-up pressure between pipe and coupling			Average pressure load based on length of locking			
A	2.3	Metallic materials			Certify material properties			
A	2.4	Other materials			Certify material properties			
A	2.5	Max. gap between pipe ends and position accuracy in particular for couplings	mm		Possible limitation caused by fitting design			
A	2.6	Max misalignment and offset of pipe ends prior to and after final positioning	Degrees		The fittings ability to tolerate misalignment			
A	3.	Tool for installing the fitting and aligning pipes						
A	3.1	Pipe lifting capacity (H Frames)	kN, m					
A	3.2	Pipe transverse motion capacity (H frame)	kN, m		+/- capacity			
A	3.3	Pipe alignment capacity (CIF)	Degrees, kNm		Moment capacity for each claw			
A	3.4	Pipe joining force capacity (CIF)	kN, m		Push/Pull capacity			
A	3.5	Fitting axial displacement capacity	kN, m					
A	3.6	Total fitting handling stiffness vertical	N/mm					
A	3.7	Total fitting handling stiffness horizontal	N/mm					
A	3.8	Relative bending stiffness of pipe ends as fixed in the tool arrangement	Nm ²		Based on the combined stiffness of the pipe ends and the stiffness of the tool.			
A	3.9	Pipe diameter max. capacity	mm					
A	3.10	Coupling max. length capacity	mm					

	<i>Item</i>	<i>Parameter/ Failure mode</i>	<i>Unit</i>	<i>Spec.</i>	<i>Comment</i>	<i>Testing</i>	<i>Data</i>	<i>Check</i>
A	3.11	Accuracy tolerances:			Combination of control and monitoring accuracy:			
A	3.11.1	Fitting alignment relative to pipe	Degrees					
A	3.11.2	Fitting relative to pipe radial offset	mm					
A	3.11.3	Pipe ends relative alignment for couplings	Degrees					
A	3.11.4	Pipe ends relative transverse offset for couplings	mm					
A	3.11.5	Pipe ends axial gap for couplings	mm					
A	3.11.6	Coupling positioning axially	mm					

	<i>Item</i>		<i>Unit</i>	<i>Spec.</i>	<i>Items to be verified by</i> <i>Analysis, ref. to literature or doc.</i>	<i>Items possibly to be verified by</i> <i>Test</i>	<i>Data</i>	<i>Check</i>
B	1.	Interactions fitting/pipe:						
B	1.1	Make-up forces/geometry:						
B	1.1.1	Installation loads/alignments (seal protection)			Establish theoretical max based on 1) geometry, on stresses and seal safety 2) pipeline properties/tool limitations.	Verify by tests, measure geometry and forces, inspect for adverse effects.		
B	1.1.1.1	1)			Establish by calculations 1) the contact forces against sleeve, seals and pipe, 2) the following stresses, and utilisation against possible collapse/damage as function of bending moment on the pipe and extent of pipe insert.	Decide the limitations of the analysis, and the possible consequences for the extent of the above test. Galling between inner sleeve and pipe ends can cause local nipples on the pipe that can harm the seals.		
B	1.1.2	Pipe joining forces applied by tool			Establish consequence on moment and shear force and the resultant effects	Include in above test.		
B	1.1.3	Activation forces and tolerances			Calculate collapse pressure and safety against collapse.			
B	1.2	Relative effects between fitting/ pipe						
B	1.2.1	Clearance radial/diametrical			Establish whether the fitting or its internal parts' deformation/ displacements are within acceptable limits.			
B	1.2.2	Activation			Establish possible utilisation with respect to limiting effects e.g.: 1)Forces (See B1.1.3), 2)Stresses & Buckling 3)Displacements, 4)Galling 5)Risk for water block (See B4.1)	Conclude possible parameters to apply in test, Monitor e.g.: alignment forces & configuration/ activation forces/ displacements/ pressure/ stresses. Record.		
B	1.2.3	Relaxation of activation forces			Estimate based on previous test results. Possible causes: 1) Release of activation forces, 2) Uneven axial load distribution, 3) Load conditions causing local yield. 4) Thermal internal expansion forces caused by different thermal expansion coefficients.	Measure by strain gauges		
B	1.2.4	Temperature effects on locking			Calculate possible adverse effects from temperature or temperature changes. (Possible effects by micro-motions.) (See also B1.2.3)	Include in above test if found of concern from analysis.		

Table B Qualification parameters				For type				
					Items to be verified by	Items possibly to be verified by		
	Item		Unit	Spec.	Analysis, ref. to literature or doc.	Test	Data	Check
B	1.2.5	Friction coefficient (For couplings dependant on friction)				Establish by small sample test possible effects on the friction coefficient from: surface roughness, rust, water and oil. Include adverse effects in the above.		
B	1.2.5.1	Friction test fixture (Proposal):				Measure friction and forces between small plates forced against each other at realistic conditions.		
B	1.2.4	Coupling capacity			Calculate design capacity and safety factors against failure based on 1) symmetric, even and round pipe ends 2) max difference of pipe ends geometry tolerances.	Perform tests (to be agreed) and finally if relevant a tension test to brake without pressure. Verify by strain gauges.		
B	1.3	Sealing						
B	1.3.1	Overall seal capacity			Calculate theoretical seal load based on 1) symmetry, 2) maximum deviation from symmetry, Include seal reactions to test pressure and operational pressure and 3) temperature axial expansion of pipe versus that of the fitting at the seal. 4) effects from different thermal expansion of enclosed sealing materials.	Test annulus between seals to a pressure including safety factors for installation tests. Test conditions: most adverse. Test to leak should be considered as a final test.		
B	1.3.2	Local seal capacity			Correlate seal load between small sample test and the local load from the full scale test. (This requires that the radial seal load for the various load conditions is determined, Ref. B1.3.1)	Test by small sample test the effects from small and larger local pipe surface discontinuities and local seal damages. Include adverse effects in the above test.		
B	1.3.2.1	Test fixture (Proposal):			Establish realistic radial seal load conditions.	Simulate sealing condition for small scale test.		
B	2.	Relaxation						
B	2.1	Loss of locking and seal capacity during the life time			See B1.2.3, B1.3.1.4 and B3.1			
B	2.2	Design conditions			Establish the design conditions based on previous documented experiences and the results from the qualification.			
B	3.	Fitting Materials						
B	3.1	Deterioration of materials			Estimate the possible deterioration of materials over time to determine the effects on the above. (Corrosion of metallic materials, ageing etc. of polymer)			
B		Wear			For numerous operations, the maximum number should be established.			
B	4.	Fitting						
B	4.1	Utilisation of internal parts with respect to their limits. (Static and dynamic stress, Buckling, Galling)			Verify by calculations (See also B1.2.2)	Verify by strain gauges		
B		Risk for water block of internal parts?			Verify by assessment.			
B		Motion/Displacement			Verify that displacement of internal parts are within their limitations.	Verify by test.		

Table B Qualification parameters				For type				
					<i>Items to be verified by</i>	<i>Items possibly to be verified by</i>		
	<i>Item</i>		<i>Unit</i>	<i>Spec.</i>	<i>Analysis, ref. to literature or doc.</i>	<i>Test</i>	<i>Data</i>	<i>Check</i>
B	5	Tools						
B	5.1	Tool performance			Establish possible failure modes.	Verify by tests		
B	6	Inspections after test			Establish an overview of items to dismount, inspect and measure after test	Inspect and measure		
B	7	Test documentation			Establish an overview of recordings, data processing of records, inspections, and measurements. Document this.			

C Documentation/ Main Technical correspondence								
	Ref.	From: Manufacturer		Com-pany	From Company			
	No	Doc. No and name	Date	Date	Ref. No and name	Comments		