MECHANICAL PIPELINE COUPLINGS

1999
FOREWORD

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B) Materials Technology
C) Structures
D) Systems
E) Special Facilities
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1. General

1.1 Introduction
This Recommended Practice applies to couplings or sleeve type couplings for pipelines.

Couplings are mechanical connectors which join the pipes by direct attachment to the pipe wall. Couplings are different from flange connectors, which join pipes by aid of additional thick, machined pieces of material (the flange) welded or forged to the pipe ends prior to pipe installation.

Couplings require no welding of the pipe and the pipe ends can be:
1) Joined subsea or above sea;
2) Joined beyond diving depth where welding is not qualified;
3) Tied in to platforms or subsea installations.

The pipe itself represents the key internal component of a coupling and hence can also present limitations due to: e.g. pipe wall strength, surface irregularities and circular/straight shape deviations. Furthermore, the coupling must be installed with caution to reduce the likelihood for e.g. seal damage.

The pressure containing capacity and the bending strength of the coupling shall at least be equal to that of the pipe, but the tension and torque strength need not necessarily meet this criteria.

1.2 Application
This Recommended Practice is intended to provide criteria and guidelines for the qualification of mechanical pipeline couplings. This includes important aspects relating to coupling design, manufacture, safe installation and operation.

The Recommended Practice applies generally, but particularly to subsea installations, and is intended to be used as a supplement to the “DNV OS-F101”.

1.3 Structure of Recommended Practice
This document consists of the following main elements:

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

- **Basic philosophy (Sec. 2)** establishes the basic principles for qualification of couplings. 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 main input parameters for coupling design.

- **Design (Sec. 6)** deals with main principles in design. Further guidance/discussions are given in Appendix A.

- **Testing (Sec. 7)** deals with the test philosophy relevant for the various development phases. Typical tests are described in Appendix B.

- **Documentation (Sec. 8)** 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 categories

1.4.1 Strength
The axial and torsion strength capacity of the coupling can either be:
- equal or greater than that of the pipeline, or
- reduced compared to that of the pipeline

1.4.2 Installation Sensitivity
Two categories of installation sensitivity apply to couplings:
1. The *sensitive* type: No touch between pipe and seal is allowed prior to activation
2. The *less sensitive* type: Limited interaction forces with the seal are allowed.

1.5 Coupling grouping
Common locking principles showing a cross-section of the pipe wall and the coupling sleeve are illustrated in Figure 1-1.
The locking principles can be divided into two main groups:

1) Uniform attachment between the pipe-wall and sleeve, such as caused by a range of local attachments and or friction.
2) Spot attachment such as caused by one or a few circumferential attachments.

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

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

There are two main force responses of the locking principles. These are:

1) Based on initial pre-compression
2) Improved by pipe tension due to wedging effects

The main sealing principles are:

1) Metal ribs or corners of grooves in the sleeve
2) Pre-compressed Polymer seals or Flexibel Graphite seal enclosed by anti extrusion rings
3) Pre-compressed Polymer seals strengthened by metals or fibres.

1.6 Specifications

The specification for a pipeline coupling 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.

1.7 References

− API Bul 63 Testing of Oilfield Elastomers
− API spec GH Specification on End Closures, connectors and switches.

1.8 Definitions

**Locking** mechanical firm connection

**Locking capacity** mechanical strength of the coupling and pipe joint

**Safety factor** see Sec. 2.1 item 4

**Sleeve–type coupling** coupling enclosing the pipe as a sleeve. This applies to all current pipeline couplings.

Other definitions are given where relevant in the text.
2. Basic philosophy

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

This qualification should be based on the following principles:

1) Functional requirements shall be quantitative.
2) Possible failure modes shall be identified (See Sec. 6.1).
3) Theoretical analysis/calculations shall be used as the main tool to document fulfillment 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 fulfillment 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 fulfillment 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.

2.2 Analytical methods

2.2.1 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 yield, 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 or spreadsheets 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 behavior 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.
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 to coupling design are dealt with in the following.

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, $e_d$, 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, $e_s$, is normally measured by a taut string between the ends, and measures the greatest distance to the pipe surface. Straightness within the length of a coupling 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 coupling. The following formula applies to a possible “S” shaped pipe:

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

- $l$ = Length of coupling for $l/L<0.5$
- $L$ = Length of line pipe section (normally 12m.) 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” coupling 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:

$$ e_{m} = \pm e_d + \pm 0.5 \cdot e_o + e_l + e_s $$

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).

3.2.5 Statistical Maximum & Minimum diameter
Guidance note:
The extreme tolerance combination is unlikely to occur for most pipeline types.

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

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 forces

4.1 Fundamental forces

Tension and torque forces in the pipeline are removed when by 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) Pressure forces acting on the pipe internal cross section, the “End cap” effect.

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:

It is expected that sleeve type couplings will at least have the same capacity for resistance of internal pressure and bending moments as that of the pipeline. Compressive loads will normally be supported in recesses inside the coupling or by the pipe ends meeting each other. Torque can be caused by the connecting operation when curved spool pieces are used. Normally of most concern will then be tension in operation.

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

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; or

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 Forces

4.2.1 Scenarios

The maximum tensile forces to which the coupling could be exposed during normal operation, 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 “end cap” force 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.

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:

\[
N' = \frac{p_A - p_x A_x}{f_Y A_e} \tag{1}
\]

This maximum axial tensile force will be established as:

- \(N'_{pt}\) during pressure test
- \(N'_{op}\) at design pressure.

Guidance note:

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

---e-n-d---o-f---G-u-i-d-a-n-c-e---n-o-t-e---
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:

\[
N_y = \frac{\Delta p_1 \cdot A_1}{f_y \cdot A_1} (1 - 2\nu) - \frac{E \cdot \Delta T \cdot \alpha}{f_y} + \frac{p_1 \cdot A_1 - p_2 \cdot A_2}{f_y \cdot A_1}
\]

(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 expansion the loop, restricting movement back to the original position; or
- the pipeline has been rockdumped whilst in operation.

Equation (2) also applies for the tension force provided that the following definitions are made:

\[\Delta p_i\]  Internal pressure after shut down (pressure at installation) minus internal pressure before.

\[\Delta T\]  Temperature after shut down minus temperature before.

Note that the signs will be changed for the two first terms of equation (2):

With pressure and cooled down

\[
N_{y4} = \frac{E \cdot |\Delta T| \cdot \alpha}{f_y} + |p_1 \cdot A_1 - p_2 \cdot A_2| \cdot \left(1 - 2\nu \right) \cdot \frac{E|\Delta T| \cdot \alpha}{2 \cdot f_y}
\]

After pressure relief & cooled down, assuming an internal pressure reduction until there are no “end cap” effect (scenario a)

\[
N_{y4} = \frac{\Delta p \cdot |A_1| + p_1 \cdot A_1 - p_2 \cdot A_2}{f_y \cdot A_1} \cdot (1 - 2\nu) + \frac{E|\Delta T| \cdot \alpha}{2 \cdot f_y}
\]

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.](image)

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 \(S_1\), \(S_2\) or \(S_3\).

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.

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

\[ N'_{s,t} = \frac{|\Delta p|}{2A_f} + \frac{E}{2f_s} \left( 1 - 2v \right) + \frac{E|\Delta T|}{f_s} \frac{\alpha}{A_f} + \frac{p_c A_f - p_e A_s}{f_s A_s} \]  

(3)

With pressure and cooled down

\[ N'_{s,t} = \frac{E|\Delta T|}{2f_s} \frac{\alpha}{A_f} + \frac{p_c A_f - p_e A_s}{f_s A_s} \]

After pressure relief and cool down assuming an internal pressure reduction until there are no “end cap” effect (scenario a):

\[ N'_{s,t} = \frac{|\Delta p|}{2A_f} + \frac{E}{2f_s} \left( 1 - 2v \right) \]

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

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

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Axial</th>
<th>Lateral</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>0.5 to 0.6</td>
<td>0.6 to 1.0</td>
</tr>
<tr>
<td>Clay</td>
<td>0.2 to 0.5</td>
<td>0.2 to 1.0</td>
</tr>
</tbody>
</table>

4.3 Force boundaries

The maximum residual tensile stress given by the previous three scenarios are plotted in Figure 4-3, and are for a pipeline with main design parameters:

- Material: Steel
- Usage factor for pressure containment: (Safety Class High) \( \eta_s = 0.8 \) and (Pressure test) \( \eta_s = 0.96 \) according to “DNV OS-F101”
- \( D/t = 27.9 \)
- \( p_e = \) installation pressure
- No “end cap” effects after depressurization

**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. \( S_0 \) is the maximum tension force and \( \mu_s \) is the axial “friction” coefficient between the pipe and the sea bottom (N/m):

\[ \Delta l = \frac{1}{E \pi (D \cdot t^2)} \cdot \frac{S_0^2}{\mu_s} \]  

(5)

The axial displacement “\( \Delta l \)” of the pipe end is:
5. Installation

5.1 General

The limiting installation conditions shall be specified and calculated.

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 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 coupling.
7) Deployment of coupling, its installation tool and the intermediate pipe section.
8) Installation and activation of the coupling.
9) Testing of seals.
10) Pressure testing of pipeline, if required.
11) Deployment of the joined pipe 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.

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

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.

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.

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.

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.
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 5-1) are represented by (Case 1):

\[ e/2 > x_1 + a y_1 \]

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):

\[ e > a y_1 \]

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

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

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:

\[ e (y_1 - n)/n + s \]

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.
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:

\[ e > \frac{(b \cdot y_2 + x_2)}{2} \quad \text{when} \quad b \cdot y_2 > x_2 \]

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 mean square 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 coupling 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.
5.10 Monitoring and control

5.10.1 General

Diverless installation of a subsea pipeline coupling requires:

1) A system to control the forces and displacements,
2) Forces to displace and manipulate the pipe ends and the coupling,
3) A monitoring system to verify that manipulations are made within the limits for the pipe and coupling,
4) A monitoring system to verify that the coupling is made up properly,
5) A test and monitoring system to verify that the coupling seals.

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.

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 coupling shall identify and list the functional criteria to be checked.
6. Design

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

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

6.1.1 Failure modes
The general failure modes for couplings are:

1) Fail to install on the pipe,
2) Activation of coupling 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 either for all coupling types, or for particular groups, in the following:

3 Fail to seal (leak)
   3.1 Loss of seal compression loads due to lack of sufficient 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
   3.2 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
   3.4 Seal protection fails

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 effects not considered in design.
       4.1.6 Eccentricity
       4.1.7 Relaxation
       4.1.8 Corrosion
   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)

6.2 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);
2) Thermal expansion coefficient;
3) Friction coefficient;
4) Galling limit;
5) Thermal effects on the mechanical properties of polymer materials;
6) Swelling of polymer 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.

6.3 Strength capacity

6.3.1 General
A coupling shall have sufficient strength capacity to convey the pipeline forces, forces generated in the coupling, and installation forces with a safe margin. This margin is defined in Sec. 2.1

Requirements to material usage factors for the pipeline and components on the pipeline are defined, either directly or by reference to other standards, in “DNV OS-F101”
6.3.2 Loads

The coupling design loads (according to Sec. 1.4.1) shall, at least, be:

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

(The maximum axial pipeline operational forces are established in Sec.4.)

An overview of loads and load combinations shall be established. Main load conditions to be included are:

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

6.4 Seal capacity

6.4.1 General

The sealing principles and seal installation sensitivities are defined in Sec.1.1 and 1.4.2.
7. Testing

7.1 Test philosophy
The test philosophy is briefly mentioned in Sec. 2.1 items 5, 6 and 8.

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

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 gaps etc.

2) **Type tests** (Qualification tests), which verify the functional requirements of a new type design. This type test can be combined with the FAT (see below) for the coupling tested.

3) **Factory Acceptance Tests (FAT)**, which verify the manufacturing and assembly of a coupling which is already type tested. FAT for couplings 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
8. Documentation

8.1 Documentation

8.1.1 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:

8.1.2 General documentation:
1. Description
2. Installation principles
3. Main specifications and limitations
4. Arrangement drawing with position numbers.

8.1.3 Qualification
Documentation of:
1. Analysis 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.
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.

8.1.4 Design
Documentation of:
1. Specifications and limitations
2. Detailed dimensional drawings
3. Identification of materials
4. Design analysis

8.1.5 Manufacturing
Documentation of:
1. Material test certificates
2. Manufacturing records on bolt pretension, welding procedures, welding qualification and NDE personnel qualification.
3. Dimensional measurement report on key dimensions
4. Test reports
5. Unique identification (for traceability of coupling and 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.

8.1.6 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 coupling manipulation documentation for compliance with both pipeline- and coupling design requirements.
4. Inspection records of pipe end cut geometry, pipe surface roughness and cleanliness, pipe ends alignments
5. Documentation confirming coupling make-up within prescribed limitations.
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”

8.2 Qualification check list
Methods used for qualification depend on the type of coupling. The Appendix C to this Recommended Practice 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.

8.3 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 SS-301 Certification and verification of submarine pipeline systems

8.4 Traceability
Each installation shall be traceable to the installation records (documentation), manufacturing records and qualification documentation.
Appendix A Coupling Capacity

A.1 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 governs this 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”. (Sec 9.1.7)

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 occure in gas pipelines after depressurization. This load condition tends to contract the pipeline diameter and may therefore reduce the tension capacity of the coupling.

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 \( e_t \) 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.

\[ e_{im} \] = 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

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.
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")](image)

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.1.4 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 and
   - 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, and
- to seal.

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:
### 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.

---

<table>
<thead>
<tr>
<th>Slip factor</th>
<th>Surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>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</td>
</tr>
<tr>
<td>0.4</td>
<td>Surfaces blasted with shot or grit, and painted with a zinc silicate paint to produce a coating thickness of 50-80 micron.</td>
</tr>
<tr>
<td>0.3</td>
<td>Surface cleaned by wire brushing or flame cleaning, with any loose rust removed.</td>
</tr>
<tr>
<td>0.2</td>
<td>Surfaces not treated</td>
</tr>
</tbody>
</table>

**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 carries 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 couplings 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 sharp edges 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 (merodonial 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.

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.

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 coupling;
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 a number of 3 tests and specimens should be used to indicate the possible spreading of results.

Such tests are as follows:

Extrusion gap test of polymer 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 polymer 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 plastic and rubber 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,  
3) % fracture of reinforcement fibres.

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.

**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;

**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 coupling 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 coupling 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 one coupling length from the end. 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 the ends
   - Where seals interact
   - One coupling length from the end
   - Half a coupling length from the end
   - 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 imperfections). 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 each end.
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.

**Coupling**

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 (See Sec. 2.1).

This shall include 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 coupling including a margin.

Furthermore, the stiffness of the pipe supports, the support of the coupling, as well as effects from gravity/buoyancy, shall comply with the coupling limiting specifications. Thereby the limiting forces and critical seal interactions can be simulated during the installation test when the coupling is displaced 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 coupling 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 coupling 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 coupling and pipe, and largest misalignment (and pipe straightness deviation) combined with largest stiffness. Furthermore, the coupling shall be positioned at its maximum specified deviation from one pipe end. This deviation shall be in the most critical direction. 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 ends including effects from sub-sea fixation to alignment frames, if the activation causes internal bending moments inside the coupling;
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.

Couplings 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 documentation of the coupling strength/tightness shall normally be carried out to the design conditions, with adjustment for actual material properties, dimensional tolerances, and with a safety factor in addition. Alternatively, the coupling 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 coupling 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.

**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.

**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 torque capacity is needed for only a few pipelines.

The basis for the test procedure is:

1) A pipe torque as a specified fraction of the torque yield 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 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.

**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 fracture 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 coupling,
4) Transient temperature distribution within the coupling during start-up and shutdown.

**External pressure test**

Deep gas pipelines connected sub-sea 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 coupling 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 are:

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

- Tension (simulating a free span)
B.2.6 Seal Tests

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. 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.

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 coupling 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 coupling internals, in particular the seals, before disassembly;
3) Measurement of critical dimensions of the coupling;
4) Disassembly of the coupling 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 coupling. It is, in principle, a spot check of only some aspects of the coupling. The aspects of concern are those related to possible errors in manufacturing.

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

The following information regarding FAT applies in general for couplings 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

Couplings 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 coupling shall be installed on pipes which are similar to the actual pipes which the coupling is intended to connect. The key parameters shall be identified and recorded during activation and be within the prescribed limits.
B.3.5 Pressure test
The coupling 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 coupling 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 dismounted coupling 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 coupling is installed within its limits. These limits are normally:

1) Pipe conditions with respect to surface conditions and the end-cut;
2) Pipe alignment and alignment of coupling relative to pipe ends prior to installation;
3) Pipe gap between ends;
4) Contamination monitoring and control to avoid seal and locking failure;
5) Displacement control of the coupling during installation and control to avoid excessive forces;
6) Coupling position relative to 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.

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

<table>
<thead>
<tr>
<th>Item</th>
<th>Parameter/ Failure mode</th>
<th>Unit</th>
<th>Spec.</th>
<th>Comment</th>
<th>Testing</th>
<th>Data</th>
<th>Check</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 1.</td>
<td>Actual Pipeline:</td>
<td></td>
<td>Ref:</td>
<td>Test pipe applied in qualification and FAT:</td>
<td></td>
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<tr>
<td>A 1.1</td>
<td>Pipe dimension and Tolerances</td>
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<tr>
<td>A 1.1.1</td>
<td>External nominal diameter, D</td>
<td>mm</td>
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<tr>
<td>A 1.1.2</td>
<td>Wall thickness nominal,</td>
<td>mm</td>
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<td>A 1.1.2.1</td>
<td>Wall thickness tolerance</td>
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<td>External diameter tolerance.</td>
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<tr>
<td>A 1.1.3.2</td>
<td>Out of roundness by gauge</td>
<td>mm</td>
<td></td>
<td>OD max - OD min. Flattening during installation might increase the out of roundness</td>
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<tr>
<td>A 1.1.3.3</td>
<td>Local out of roundness</td>
<td>mm</td>
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<tr>
<td>A 1.1.3.4</td>
<td>Straightness for one pipe length equal to coupling length</td>
<td>mm</td>
<td></td>
<td>Based on a coupling length on a typical line pipe section length with 0.1 % (circular) deviation from total length.</td>
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<tr>
<td>A 1.1.3.5</td>
<td>Total measured diameter tolerance (by gauge, not tape)</td>
<td>mm</td>
<td></td>
<td>+/-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.</td>
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<tr>
<td>A 1.1.4</td>
<td>Corrosion allowance, internal</td>
<td>mm</td>
<td></td>
<td>Common pipe spec: c) weld undercut: 0.8 mm for 10 mm length. J) equally for other imperfections</td>
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<tr>
<td>A 1.1.5</td>
<td>Surface imperfections</td>
<td>mm</td>
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<tr>
<td>Item</td>
<td>Parameter/ Failure mode</td>
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<td>A 1.1.6</td>
<td>End cut evenness</td>
<td>Degrees</td>
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<td>A 1.1.7</td>
<td>Chamfer on pipe ends to be defined</td>
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<tr>
<td>A 1.2</td>
<td>Pipeline forces/temperatures</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>A 1.2.1</td>
<td>Bending moment (operation and coupling installation)</td>
<td>kNm</td>
<td>Max. expected</td>
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<td></td>
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<tr>
<td>A 1.2.2</td>
<td>Tension without pressure (operation and coupling installation)</td>
<td>kN</td>
<td>Max expected</td>
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<td></td>
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<td>Torque without pressure (operation and coupling installation)</td>
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<td>A 1.2.4</td>
<td>Pipeline test pressure at coupling</td>
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<tr>
<td>A 1.2.5</td>
<td>Internal pressure at coupling</td>
<td>MPa</td>
<td></td>
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<td></td>
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<tr>
<td>A 1.2.6</td>
<td>External pressure</td>
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<td>A 1.2.8</td>
<td>Min Temp:</td>
<td>°C</td>
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</tr>
<tr>
<td>A 1.2.9</td>
<td>Alternating loads, magnitude and number of cycles.</td>
<td></td>
<td>Start-ups including pressure and temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A 1.3</td>
<td>Pipe material</td>
<td></td>
<td>Obtain typical material test data</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>Material min spec yield strength</td>
<td>MPa</td>
<td></td>
<td></td>
<td></td>
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<td>MPa</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>A 1.4</td>
<td>Environment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A 1.4.1</td>
<td>Cathodic protection exposure externally</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A 1.4.2</td>
<td>Internal fluid</td>
<td></td>
<td>Gas, oil (contaminants: H2S, CO2, sand, water)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A 1.4.2</td>
<td>During operation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A 1.4.2.2</td>
<td>Possible internal water circulation before and during coupling installation,</td>
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<td>List possible parameters of concern such as time and circulation rate.</td>
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<td>Max. fluid temperature change rate</td>
<td>°C/ min</td>
<td></td>
<td></td>
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<td></td>
</tr>
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<td>External fluid, salt water, possible leaking fluids</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>A 1.4.5</td>
<td>Impacts from trawl boards</td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>A 2.</td>
<td>Coupling</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>A 2.1</td>
<td>Dimensions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A 2.1.1</td>
<td>Length, max</td>
<td>mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A 2.1.2</td>
<td>Diameter outer sleeve</td>
<td>mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>A 2.1.3</td>
<td>Dry weight</td>
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<td>Wet weight</td>
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<td></td>
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<td></td>
<td></td>
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<td>mm</td>
<td></td>
<td></td>
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<td></td>
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<td>A 2.2</td>
<td>Locking</td>
<td></td>
<td>Parameters important to the mechanical locking to the pipeline</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A 2.2.1</td>
<td>e.g. Radial make-up pressure between pipe and coupling</td>
<td></td>
<td>Average pressure load based on length of locking</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>A 2.3</td>
<td>Metallic materials</td>
<td></td>
<td>Certify material properties</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A 2.4</td>
<td>Other materials</td>
<td></td>
<td>Certify material properties</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A 2.5</td>
<td>Max. gap between pipe ends and position accuracy</td>
<td>mm</td>
<td>Possible limitation caused by coupling design</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Item</td>
<td>Parameter/ Failure mode</td>
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<td>Spec.</td>
<td>Comment</td>
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<tr>
<td>A 2.6</td>
<td>Max misalignment and offset of pipe ends prior to and after final positioning</td>
<td>Degrees</td>
<td></td>
<td>The couplings ability to tolerate misalignment</td>
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<tr>
<td>A 3.</td>
<td>Tool for installing the coupling and aligning pipes</td>
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<tr>
<td>A 3.1</td>
<td>Pipe lifting capacity (H Frames)</td>
<td>kN, m</td>
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<td>A 3.2</td>
<td>Pipe transverse motion capacity (H frame)</td>
<td>kN, m</td>
<td>+/- capacity</td>
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<td>A 3.3</td>
<td>Pipe alignment capacity (CIF)</td>
<td>Degrees, kNm</td>
<td>Moment capacity for each claw</td>
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<td>A 3.4</td>
<td>Pipe joining force capacity (CIF)</td>
<td>kN, m</td>
<td>Push/Pull capacity</td>
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<td>A 3.5</td>
<td>Coupling axial displacement capacity</td>
<td>kN, m</td>
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<td>A 3.6</td>
<td>Total coupling handling stiffness vertical</td>
<td>N/mm</td>
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<td>A 3.7</td>
<td>Total coupling handling stiffness horizontal</td>
<td>N/mm</td>
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<td>A 3.8</td>
<td>Relative bending stiffness of pipe ends as fixed in the tool arrangement</td>
<td>Nm²</td>
<td>Based on the combined stiffness of the pipe ends and the stiffness of the tool.</td>
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<td>A 3.9</td>
<td>Pipe diameter max. capacity</td>
<td>mm</td>
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<td>A 3.10</td>
<td>Coupling max. length capacity</td>
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<td>A 3.11</td>
<td>Accuracy tolerances:</td>
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<td>Combination of control and monitoring accuracy:</td>
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<td>A 3.11.1</td>
<td>Coupling alignment relative to pipe ends</td>
<td>Degrees</td>
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<td>A 3.11.2</td>
<td>Coupling relative to pipe end radial offset</td>
<td>mm</td>
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<td>A 3.11.3</td>
<td>Pipe ends relative alignment</td>
<td>Degrees</td>
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<td>A 3.11.4</td>
<td>Pipe ends relative transverse offset</td>
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<td>A 3.11.5</td>
<td>Pipe ends axial gap</td>
<td>mm</td>
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<td>A 3.11.6</td>
<td>Coupling positioning axially</td>
<td>mm</td>
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<td>B</td>
<td>Interactions</td>
<td>Coupling pipe:</td>
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<tr>
<td>B 1.1</td>
<td>Coupling makeup forces/geometry:</td>
<td>Establish theoretical max based on 1) geometry, on stresses and seal safety 2) pipeline properties/tool limitations.</td>
<td>Verify by tests, measure geometry and forces, inspect for adverse effects.</td>
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<tr>
<td>B 1.1.1</td>
<td>Installation loads/alignments (seal protection)</td>
<td>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.</td>
<td>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.</td>
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<tr>
<td>B 1.1.2</td>
<td>Pipe joining forces applied by tool</td>
<td>Establish consequence on moment and shear force and the resultant effects</td>
<td>Include in above test.</td>
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<tr>
<td>B 1.1.3</td>
<td>Activation forces and tolerances</td>
<td>Calculate collapse pressure and safety against collapse.</td>
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<tr>
<td>B 1.2</td>
<td>Relative effects between coupling/pipe</td>
<td>Establish whether the coupling or its internal parts' deformation/ displacements are within acceptable limits.</td>
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<tr>
<td>B 1.2.1</td>
<td>Clearance radial/diametrical</td>
<td>Establish possible utilisation with respect to limiting effects e.g.: 1)Forces (See B1.1.3), 2)Stresses &amp; Buckling 3)Displacements, 4)Galling 5)Risk for water block (See B4.1)</td>
<td>Conclude possible parameters to apply in test, Monitor e.g.: alignment forces &amp; configuration/ activation forces/ displacements/ pressure/ stresses. Record.</td>
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<tr>
<td>B 1.2.2</td>
<td>Activation</td>
<td>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.</td>
<td>Measure by strain gauges</td>
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<tr>
<td>B 1.2.3</td>
<td>Relaxation of activation forces</td>
<td>Calculate possible adverse effects from temperature or temperature changes. (Possible effects by micro-motions.) (See also B1.2.3)</td>
<td>Include in above test if found of concern from analysis.</td>
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<tr>
<td>B 1.2.4</td>
<td>Temperature effects on locking</td>
<td>Establish by small sample test possible effects on the friction coefficient from: surface roughness, rust, water and oil. Include adverse effects in the above.</td>
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<td>B 1.2.5</td>
<td>Friction coefficient (For couplings dependant on friction)</td>
<td>Establish by small sample test possible effects on the friction coefficient from: surface roughness, rust, water and oil. Include adverse effects in the above.</td>
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<td>Section</td>
<td>Description</td>
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<td>B 1.2.5.1</td>
<td>Friction test fixture (Proposal): Measure friction and forces between small plates forced against each other at realistic conditions.</td>
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<td>B 1.2.4</td>
<td>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 a tension test to brake without pressure. Verify by strain gauges.</td>
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<td>B 1.3</td>
<td>Sealing</td>
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<tr>
<td>B 1.3.1</td>
<td>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 coupling 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.</td>
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<td>B 1.3.2</td>
<td>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.</td>
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<td>B 1.3.2.1</td>
<td>Test fixture (Proposal): Establish realistic radial seal load conditions. Simulate sealing condition for small scale test.</td>
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<td>B 2.</td>
<td>Relaxation</td>
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<tr>
<td>B 2.1</td>
<td>Loss of locking and seal capacity during the life time See B1.2.3, B1.3.1.4 and B3.1</td>
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<td>B 2.2</td>
<td>Design conditions Establish the design conditions based on previous documented experiences and the results from the qualification.</td>
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<td>B 3.</td>
<td>Coupling Materials</td>
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<tr>
<td>B 3.1</td>
<td>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)</td>
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<td>B</td>
<td>Wear For numerous operations, the maximum number should be established.</td>
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<td>B 4.</td>
<td>Coupling</td>
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<tr>
<td>B 4.1</td>
<td>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</td>
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<td>B</td>
<td>Risk for water block of internal parts? Verify by assessment.</td>
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<td>B</td>
<td>Motion/Displacement Verify that displacement of internal parts are within their limitations. Verify by test.</td>
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<td>B</td>
<td>5</td>
<td>Tools</td>
<td>Establish possible failure modes</td>
<td>Verify by tests</td>
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<td>B</td>
<td>5.1</td>
<td>Tool performance</td>
<td>Establish possible failure modes</td>
<td>Verify by tests</td>
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<td>B</td>
<td>6</td>
<td>Inspections after test</td>
<td>Establish an overview of items to dismount, inspect and measure after test</td>
<td>Inspect and measure</td>
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<td>B</td>
<td>7</td>
<td>Test documentation</td>
<td>Establish an overview of recordings, data processing of records, inspections, and measurements. Document this.</td>
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### C Documentation/ Main Technical correspondence

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