
**Petroleum and natural gas industries —
Procedures for testing casing and tubing
connections**

*Industries du pétrole et du gaz naturel — Procédures de test des
connexions pour tubes de couvage et de production*

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 13679 was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 5, *Casing, tubing and drill pipe*.

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Introduction

This International Standard is part of a process to provide reliable tubing and casing connections for the oil and natural gas industry which are fit for purpose. It has been developed based on improvements to API Recommended Practice 5C5 and proprietary test procedures, with input from leading users, manufacturers and testing consultants from around the world. This International Standard represents the knowledge of many years of testing and qualification experiences.

The validation of connection test load envelope and failure limit loads is relevant to design of tubing and casing for the oil and natural gas industries. Tubing and casing are subject to loads which include internal pressure, external pressure, axial tension, axial compression, bending, torsion, transverse forces and temperature changes. The magnitude and combination of these loads result in various pipe body and connection failure modes. Although pipe body test and limit loads are well understood in general, the same cannot be stated for the connection. These failure modes and loads are generally different and often less than that of the pipe. Consequently experimental validation is required. Well design matches the test and limit loads of both the connection and pipe to the well conditions to provide load capacities with suitable reliability.

The validation of test and limit loads requires testing at the extremes of performance parameters to these defined loads. Testing at the extremes of the performance parameters assures that the production population, which falls within these limits, will meet or exceed the performance of the test population. Thread connection performance parameters include dimensional tolerances, mechanical properties, surface treatment, make-up torque and the type and amount of thread compound. For typical proprietary connections, worst-case tolerances are known and defined in this International Standard. For other connections design analysis is required to define worst-case tolerance combinations.

Users of this International Standard should be aware that further or differing requirements might be needed for individual applications. This International Standard is not intended to inhibit a vendor from offering, or a purchaser from accepting, alternate equipment or engineering solutions for the individual application. This may be particularly applicable when there is innovative or developing technology. Where an alternative is offered, the vendor should identify any variations from this International Standard and provide details.

This International Standard consists of the following major parts. Based on manufacturer's-supplied data specified in Annex A and/or calculations in Annex B, tests are conducted in accordance with Clauses 4 to 8 and reported on the data forms given in Annex C. Annex D lists all the information that is to be provided in the full report whereas Annex E lists the information that is to be provided in a summary test report. This summary test report lists the minimum information necessary to fully specify the connection tested and its preparation is intended for broader distribution. Annex F gives an example of a load frame calibration. Annex G gives considerations for possible connection product line qualification. Annex H provides guidelines for supplemental tests, which may be required for special applications. Annex I gives the design rationale for this International Standard. Annex J gives requirements for connections that contain both a metal-to-metal seal and a resilient seal which are tested separately.

Supplementary tests may be appropriate for specific applications that are not evaluated by the tests herein. The user and manufacturer should discuss well applications and limitations of the connection being considered.

Representatives of users and/or other third party personnel are encouraged to monitor the tests. ISO 13679 covers the testing of connections for the most commonly encountered well conditions. Not all possible service scenarios are included. For example, the presence of a corrosive fluid, which may influence the service performance of a connection, is not considered.

This International Standard includes provisions of various nature. These are identified by the use of certain verbal forms:

— SHALL is used to indicate that a provision is a REQUIREMENT, i.e. MANDATORY;

- SHOULD is used to indicate that a provision is a RECOMMENDATION to be used as good practice, but is not mandatory;
- MAY is used to indicate that a provision is OPTIONAL, i.e. indicates a course of action permissible within the limits of the document;
- CAN is used to indicate statements of POSSIBILITY and CAPABILITY.

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Petroleum and natural gas industries — Procedures for testing casing and tubing connections

1 Scope

This International Standard establishes minimum design verification testing procedures and acceptance criteria for casing and tubing connections for the oil and natural gas industries. These physical tests are part of a design verification process and provide objective evidence that the connection conforms to the manufacturer's claimed test load envelope and limit loads.

It categorizes test severity into four test classes.

It describes a system of identification codes for connections.

This International Standard does not provide the statistical basis for risk analysis.

This International Standard addresses only three of the five distinct types of primary loads to which casing and tubing strings are subjected in wells: fluid pressure (internal and/or external), axial force (tension or compression), bending (buckling and/or wellbore deviation), as well as make-up torsion. It does not address rotation torsion and non-axisymmetric (area, line or point contact) loads.

This International Standard specifies tests to be performed to determine the galling tendency, sealing performance and structural integrity of casing and tubing connections. The words casing and tubing apply to the service application and not to the diameter of the pipe.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 3183-1, *Petroleum and natural gas industries — Steel pipe for pipelines — Technical delivery conditions — Part 1: Pipes of requirement class A*

ISO 3183-2, *Petroleum and natural gas industries — Steel pipe for pipelines — Technical delivery conditions — Part 2: Pipes of requirements class B*

ISO 3183-3, *Petroleum and natural gas industries — Steel pipe for pipelines — Technical delivery conditions — Part 3: Pipes of requirement class C*

ISO 10400:1993, *Petroleum and natural gas industries — Formulae and calculation for casing, tubing, drill pipe, and line pipe properties*

ISO 10422, *Petroleum and natural gas industries — Threading, gauging and thread inspection of casing, tubing and line pipe threads*

ISO 11960, *Petroleum and natural gas industries — Steel pipes for use as casing or tubing for wells*

ISO 13680, *Petroleum and natural gas industries — Corrosion-resistant alloy seamless tubes for use as casing, tubing and coupling stock — Technical delivery conditions*

API Bul 5C3, *Bulletin on formulas and calculations for casing, tubing, drill pipe and line pipe properties*

API Spec 5B, *Specification for threading, gauging, and thread inspection of casing, tubing, and line threads (U.S. Customary Units)*

API Spec 5L, *Specification for line pipe*

3 Terms, definitions, symbols and abbreviated terms

For the purposes of this document, the following terms, definitions, symbols and abbreviated terms apply.

3.1 Terms and definitions

3.1.1

ambient temperature

actual room temperature in the test lab with no residual heat remaining in test specimens from previous thermal tests

3.1.2

axial-pressure load diagram

plot of pressure versus axial load showing pipe and/or connection test load envelope or limit load extremes

3.1.3

connection

assembly consisting of either two pins and a coupling or one pin and an integral box

3.1.4

failure load

load at which the pipe body or connection will fail catastrophically as in an axial separation, a rupture, large permanent deformation (e.g. buckling or collapse) or massive loss of sealing integrity

3.1.5

galling

cold welding of contacting material surfaces followed by tearing of the metal during further sliding/rotation

NOTE 1 Galling results from the sliding of metallic surfaces that are under high bearing forces. Galling can generally be attributed to insufficient lubrication between the mating surfaces. The purpose of the lubricating medium is to minimize metal-to-metal contact and allow efficient sliding of the surfaces. Other ways to prevent galling are to reduce the bearing forces or reduce the sliding distance.

NOTE 2 There are several degrees of galling used for repair and reporting purposes as defined in 3.1.5.1 to 3.1.5.3.

3.1.5.1

light galling

galling that can be repaired by the use of abrasive paper

3.1.5.2

moderate galling

galling that can be repaired by the use of fine files and abrasive paper

3.1.5.3

severe galling

galling that cannot be repaired by the use of fine files and abrasive paper

3.1.6

leak

any positive displacement of fluid in the measuring system during hold periods

3.1.7**limit load**

load combination extreme (axial load and/or pressure) which defines the failure conditions for the connection or maximum load resulting in large permanent deformation (such as buckling) prior to catastrophic failure

3.1.8**lot**

lengths of pipe with the same specified dimensions and grade from the same heat of steel which are heat-treated as part of a continuous operation (or batch)

3.1.9**metal-to-metal seal**

seal or sealing system that relies on intimate and usually high contact stress of mating metal surfaces to achieve a seal

NOTE The thread compound can affect, both beneficially and detrimentally, the performance of a metal seal.

3.1.10**mother joint**

length of pipe or coupling stock from which short lengths are cut for machining connection test specimens

3.1.11**multiple seals**

sealing system, which consists of more than one independent barrier, and of which each barrier forms a seal itself

3.1.12**pipe string**

pipe body and the connection

3.1.13**pup joint**

short pipe length usually with threaded ends

3.1.14**resilient seal**

seal or sealing system, which relies on entrapment of a seal ring within a section of the connection (e.g. in the thread-form, on a seal area, etc.) to achieve a seal

3.1.15**seal**

barrier to prevent the passage of fluids

3.1.16**seal ovality**

maximum seal diameter minus the minimum seal diameter divided by the average seal diameter multiplied by 100

NOTE Seal ovality is expressed as a percentage.

3.1.17**single seal**

one barrier or multiple barriers that cannot be physically differentiated in their function

3.1.18**specimen**

connection between two pieces of pipe

NOTE The specimen can be composed of one coupling and two pins for coupled connections, or one pin and one box for integral connections.

3.1.19

test load envelope

extremes of loads (axial load, pressure, bending) and temperature within which the connection will perform cyclically

NOTE The manufacturer has the primary responsibility for defining the test load envelope for their connection products (see 4.1).

3.1.20

thread lot

all products manufactured on a given machine during a continuous production cycle that is not interrupted by a catastrophic tool failure or injurious machine malfunction (excluding worn tools or minor tool breakage), tool holder change (except rough boring bar) or any other malfunction of either threading equipment or inspection gauges

3.1.21

thread seal

seal or sealing system, which relies on intimate fitting of the thread-form and usually entrapment of the thread compound within the thread-form to achieve a seal

3.2 Symbols and abbreviated terms

3.2.1 Symbols

A_i	Area calculated based on the pipe inside diameter
A_o	Area calculated based on the pipe outside diameter
A_p	Cross-section area of pipe body
C	Compressive axial force
D	Specified pipe outside diameter
D_i	Inside diameter
D_o	Outside diameter
D_{leg}	Effective dogleg severity expressed in degrees per thirty metres
E_r	Error in load frame calibration
E_{rp}	Error in load frame calibration expressed in percent
F	Failure
F_a	Axial force, tension or compression
F_b	Bending equivalent axial force
F_c	Published joint strength of the connection when the joint strength is the compressive rated load of the connection
F_f	Actual load frame axial force, tension or compression
F_i	Indicated load frame axial force, tension or compression

F_t	Published joint strength of the connection when the joint strength is the tensile parting or failure load of the connection
F_y	Published joint strength of the connection when the joint strength is the tensile yield load of the connection
I	Moment of inertia
K_c	Compression efficiency factor of the connection
K_{pi}	Internal pressure efficiency factor of the connection
K_{pe}	External pressure efficiency factor of the connection
K_t	Tension efficiency factor of the connection
k_i, k_o	Geometric variable
L_A	Length of pin A end from coupling face (or connection) to end cap or grip length
L_B	Length of pin B end from coupling face (or connection) to end cap or grip length
L_c	Length of coupling or connection if integral
L_{pj}	Minimum unsupported pup joint length
M	Bending moment
M_o	Super bending moment
p_c	ISO 10400 collapse rating for specified wall thickness and actual specimen yield strength
p_i	Internal pressure
p_{ib}	Internal pressure with bending
p_{ih}	High internal pressure
p_{in}	Normalized internal test pressure
p_{il}	Low internal pressure
p_{iyp}	ISO 10400:1993, Section 3, internal yield pressure for the pipe body
p_o	External pressure
p_{ob}	External pressure with bending
p_{on}	Normalized external test pressure
p_{tc}	Thermal cycle pressure at elevated temperature
p_y	Maximum pressure for an internal fibre stress S_{yt}

q_{ac}	Actual leak rate to be reported
q_o	Observed leak rate
R	Radius of curvature of the pipe body at the axis of the pipe
S_t	100 % of minimum of the specimen mother joint tensile strength (measured at room temperature or at elevated temperature as given in Table 1) for a pipe member or coupling in a T&C specimen (pin or box member for an integral connection)
S_y	100 % of minimum of the specimen mother joint yield strength (measured at room temperature or at elevated temperature as given in Table 1) for a pipe member or coupling in a T&C specimen (pin or box member for an integral connection)
S_{yt}	95 % S_y for Series A and B tests, and 80 %, 90 % and 95 % for Series C tests (see 5.12.4)
t	Specified pipe wall thickness
t_{ac}	Actual minimum wall thickness
T	Tension axial force
η_{lds}	Leak detection system efficiency
σ	Stress
σ_a	Axial stress without bending
σ_{ab}	Axial stress with bending
σ_{ao}	Axial stress with super critical bending
σ_b	Axial stress due to bending
σ_{bo}	Axial stress due to super critical bending
σ_c	Axial compressive yield strength if available or otherwise axial tensile yield strength
σ_h	Hoop (tangential) stress
σ_{ho}	Hoop (tangential) stress at outside diameter
σ_r	Radial (normal) stress
σ_{ro}	Radial (normal) stress at outside diameter
σ_t	Transverse tensile yield strength if available or otherwise axial tensile yield strength
σ_{tc}	Defined transverse compressive yield strength if available or otherwise axial tensile yield strength
σ_v	Von Mises equivalent stress
σ_y	Axial tensile yield strength, normally the ISO/API axial tensile yield strength

3.2.2 Abbreviations

CAL	Connection application level for which the successfully tested pipe [size, mass (label: weight), grade] and connections are intended to be used
CCS	Critical cross-section
CCW	Counter-clockwise direction
CW	Clockwise direction
CEPL	Capped end pressure load (tension)
CEYP	Capped end yield pressure
CRA	Corrosion-resistant alloy
EUE	External upset end
FMU	Final make-up specimen condition
kips	1 000 lbf (pound-force)
ksi	1 000 lbf (pound-force) per square inch
lb	Pound mass
LL	Limit load
LP	Load point
LP1	Limit load test path 1
LP2	Limit load test path 2
LP3	Limit load test path 3
LP4	Limit load test path 4
LP5	Limit load test path 5
LP6	Limit load test path 6
LP7	Limit load test path 7
LP8	Limit load test path 8
M/B	Make-up/break-out
MBG	Make/break galling test specimen condition
MC	Mechanical cycle
MT	Material test coupon
MTC	Metal seal threaded and coupled connection
MTM	Metal-to-metal seal

MU	Make-up
OCTG	Oil country tubular goods
PTFE	Polytetrafluoroethylene
r/min	Revolutions per minute
RRG	Round-robin galling test specimen condition
RS	Resilient seal
SRG	Seal ring groove
Std	Standard
TC	Thermal cycle
TLE	Test load envelope
TSC	Thread sealing connection
T&C	Threaded and coupled
VME	Von Mises equivalent stress

4 General requirements

4.1 Connection geometry, test load envelope and performance data sheet

The manufacturer shall provide connection geometry and a performance data sheet for the product stating its connection application level and its geometry and performance properties in terms of tension, compression, internal pressure, external pressure, bending, and torque compared to the pipe body. See Table A.1 for the connection geometry and performance data sheet. The manufacturer shall provide a drawing, which is representative of the cross-sectional area of the connection. The manufacturer shall also provide a test load envelope in graphical form (VME plot) and should quantify limit loads. The manufacturer's own method of calculation should be used to derive the connection test load envelope and to calculate the test loads. Performance data or the method described in Annex B may be used.

Annex B has been provided as a means by which a manufacturer or user may estimate the test load envelope using a connection performance model based on capacities of specific critical cross-sections in the connection.

The manufacturer should define as completely as possible the limit loads for each connection. A user may also make an independent estimate of the limit loads. Limit loads shall be greater than the test load envelope.

It is critical that the combined load capacity described by the test load envelope be defined near and throughout the conditions where the dominant load sensitivity of the connection may change from pressure to axial force and/or bending or vice versa. Connection equations, whether analytically or experimentally based, shall define the test load envelope for all combinations of pressure and axial force and for bending (as applicable). These equations shall also be suitable to calculate the test loads based on actual yield strength and geometry of the specimen and include any other structural or sealing performance requirements. The form of the equation shall facilitate the calculation of the pressure value given the axial load, with or without bending.

Since casing and tubing connection designs and the resultant performance can vary widely, no overall requirement for the minimum number of values in a tabular data format can be mandated. However, it is

expected that approximately 10 combined load values of pressure and axial force per quadrant should be sufficient to define the test and limit loads. If a connection design exhibits changes in load sensitivities, the loads at which the changes in load sensitivity occur shall be provided.

In the calculation of both pipe body and connection load capacities, it is the intent of this International Standard to test the specimens to as high a load or combination of loads as safely practical.

In the event that unanticipated events result in deviations to the detailed requirements and or procedures, such deviations shall be clearly identified in the documentation.

4.2 Quality control

All quality control procedures for the manufacturing of test specimens shall be documented and shall be consistent with procedures used for connections manufactured for well service. The connection manufacturer shall ensure that the connections manufactured for the purpose of these design verification tests are of the same design and manufactured to the same dimensions and extremes of tolerances (see Clause 6) as those supplied for well service. The connection manufacturer shall issue a declaration of conformity (see for example, ISO/IEC Guide 22). The manufacturer shall provide the process control plan. This process control plan shall include procedure number or drawing number as well as associated revision levels for all applicable sub-tier documents (manufacturing, gauge calibration, gauging procedure, surface treatment, etc.). These procedures and any others determined necessary to provide a consistent product for well service shall be used during manufacturing of all test specimens (see A.4).

5 General test requirements

5.1 Test classes

5.1.1 Principle

Connection performance data are generated by testing. Passing the tests demonstrates conformance of the connection to the specified connection application level. Failure of some or all tests may result in a revision of the connection design or a revision of the test or limit loads. In the first case, the testing shall be repeated. In the second case, the tests that failed shall be repeated unless they conform to the revised load envelope.

Four test classes, known as connection application levels, are defined. These relate to increasingly arduous mechanical service conditions in the application of casing and tubing connections. The test classes increase in severity by increasing the number of test parameters and test specimens.

The classes of tests do not include all possible service scenarios. For example, the presence of a corrosive fluid, which may influence the service performance of a connection is not considered and is beyond the scope of this International Standard.

The user of this International Standard shall specify the connection application level required based upon the needs for the particular service intended. Users of the connection should be familiar with the defined connection application levels, the test load envelope and the limit loads. The connection application levels (abbreviated CAL) are defined as follows.

a) Connection application level IV (8 specimens): most severe application

CAL IV is intended for production and injection tubing and casing for gas service. CAL IV test procedures expose the connection to cyclical test loads including internal pressure, external pressure, tension, compression and bending. CAL IV test procedures expose the connection to extensive thermal and thermal/pressure-tension cycling incurring a cumulative exposure of about 50 h to gas at an elevated temperature of 180 °C (356 °F) and pressure. Limit load tests to failure are conducted in all four quadrants of the axial-pressure load diagram.

b) Connection application level III (6 specimens): severe application

CAL III is intended for production and injection tubing and casing for gas and liquid service. CAL III test procedures expose the connection to cyclical test loads including internal pressure, external pressure, tension and compression. Bending is an optional load for CAL III testing. The CAL III test procedures for thermal and thermal/pressure-tension cycling are less severe than CAL IV and incurring a cumulative exposure of 5 h to gas at an elevated temperature of 135 °C (275 °F) and pressure. Limit load tests to failure are conducted in all four quadrants of the axial-pressure load diagram.

c) Connection application level II (4 specimens): less severe application

CAL II is intended for production and injection tubing and casing, protective casing and for gas and liquid service with limited exposure to significant external pressure. CAL II test procedures expose the connection to cyclical test loads including internal pressure, tension and compression. Bending is an optional load for CAL II testing and external pressure is not included. The CAL II test procedures for thermal and thermal/pressure-tension cycling are the same as CAL III. Limit load tests for CAL II to failure are conducted with internal pressure and axial load.

d) Connection application level I (3 specimens): least severe application

CAL I is intended for liquid service. CAL I test procedures expose the connection to cyclical test loads, including internal pressure, tension and compression, using a liquid test fluid. Bending is optional for CAL I testing and external pressure is not included. CAL I testing is conducted at ambient temperatures. Limit load tests are conducted in two quadrants of the axial-pressure load diagram.

5.1.2 Previous tests

Connection test data obtained from tests performed prior to the establishment of this International Standard may also be used as part of a design verification process or application test sequence, provided that parties to agreements based on this International Standard can agree such tests were substantially conducted to the technical and documentation requirements of this International Standard and that they give comparable results.

5.1.3 Abbreviated tests and deviations

Some of the tests herein, rather than the complete test programme, may be adequate to verify suitability for specific applications when experience and related test data, for example on other sizes, are available. Deviation to the tests specified herein are acceptable, provided:

- a) the planned deviations are clearly documented in advance,
- b) there is clear agreement between the parties involved, and
- c) the deviations are clearly identified in both the summary report and the full report of the tests.

A discussion of product line qualification and use of interpolation and extrapolation considerations is provided in Annex G. More stringent acceptance requirements, sensitivity requirements and/or more extended informative data may be agreed by the user and manufacturer.

5.2 Test matrix

Table 1 shows a matrix relating the connection application level to the relevant total number of test specimens, their identification numbers and the relevant tests. Figure 1 is a summary of the test programme. Specimens may be tested in series with multiple specimens in a single assembly. However, test loads shall be imposed to the highest levels as required by the highest strength specimen.

Table 1 — Test matrix — Test series and specimen identification numbers

Connection application level	Series A (see 7.3.3) 4 quadrants with mechanical cycles	Series B (see 7.3.4) 2 quadrants with mechanical cycles	Series C thermal cycling (see 7.3.5) Thermal/pressure and tension cycling	Bake and thermal cycle temperature	Internal test pressure medium (external is liquid)
IV Total number of specimens = 8	At ambient temperature Specimens 2,4,5,7	Bending required at ambient temperature Specimens 1,3,6,8	5 mechanical at ambient temperature 50 thermal with pressure/tension ^a 5 mechanical at elevated temperature 50 thermal with pressure/tension ^a 5 mechanical at ambient temperature Specimens 1,2,3,4	180 °C (356 °F)	Gas
III Total number of specimens = 6	At ambient temperature Specimens 2,4,5	Bending optional at ambient temperature Specimens 1,3,6	5 mechanical at ambient temperature 5 thermal with pressure/tension 5 mechanical at elevated temperature 5 thermal with pressure/tension 5 mechanical at ambient temperature Specimens 1,2,3,4	135 °C (275 °F)	Gas
II Total number of specimens = 4	CAL II does not require external pressure test	Bending optional at ambient temperature Specimens 1,2,3,4	5 mechanical at ambient temperature 5 thermal with pressure/tension 5 mechanical at elevated temperature 5 thermal with pressure/tension 5 mechanical at ambient temperature Specimens 1,2,3,4	135 °C (275 °F)	Gas
I Total number of specimens = 3	CAL I does not require external pressure test	Bending optional at ambient temperature Specimens 1,2,3	CAL I does not require thermal cycling test	CAL I does not require bake	Liquid

^a Only five thermal cycles are required for CAL IV casing. Five thermal cycles also apply to CAL IV tubing with redundant seals tested to Annex J.

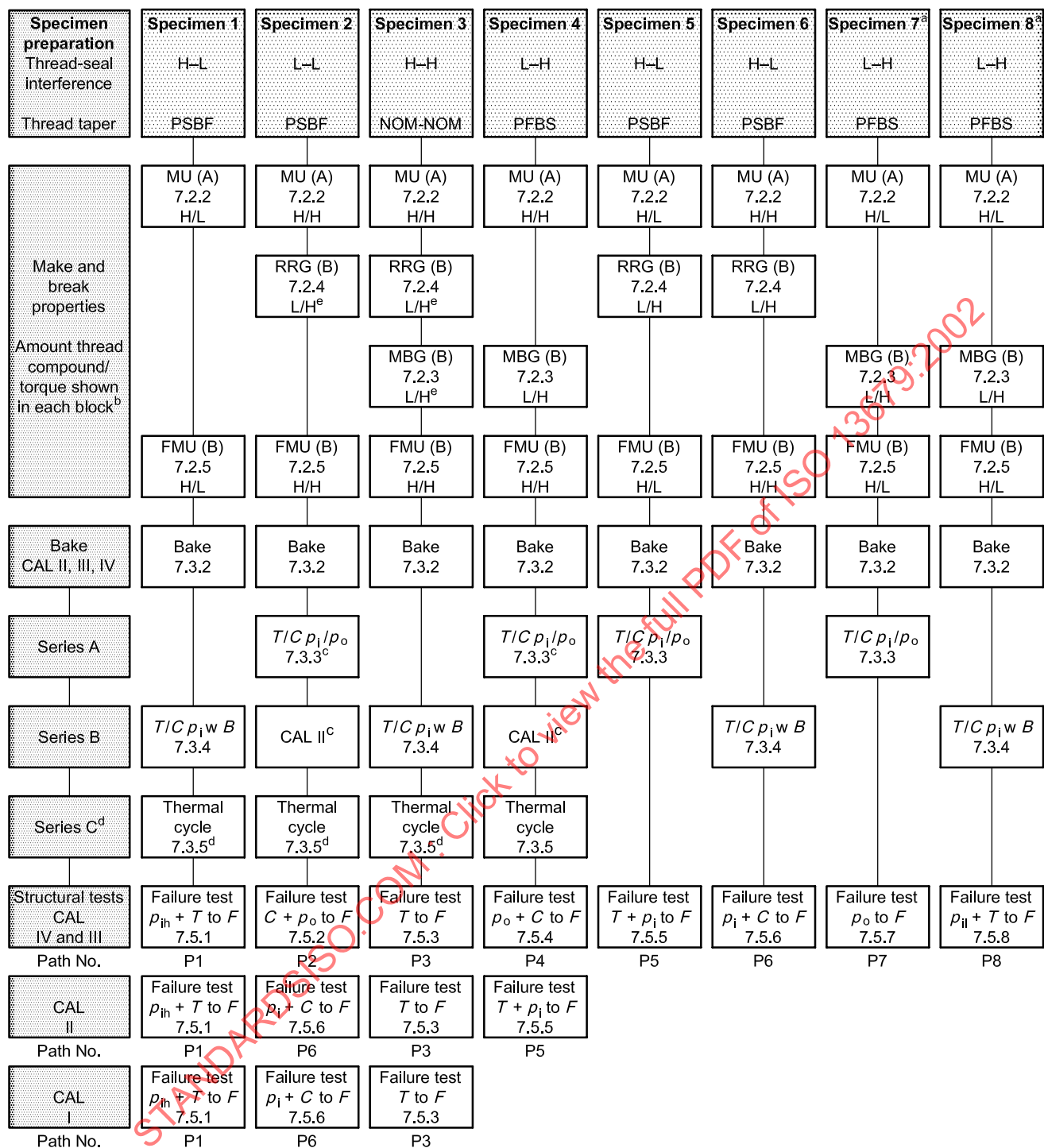


Figure 1 — Connection application level test programme

The abbreviations shown refer to the following test method titles:

- (A): Connection A end
 (B): Connection B end
 MU: 7.2.2 Make-up
 MBG: 7.2.3 Make-up/break-out test for galling resistance
 RRG: 7.2.4 Round-robin make-up/break-out for galling resistance
 FMU: 7.2.5 Final make-up
 Bake: 7.3.2
 $T/C\ p_i/p_o$: Tension, compression internal pressure and external pressure
 $T/C\ p_i/wB$: Tension, compression internal pressure and bending
 $p_{ih} + T$ to F : 7.5.1 High internal pressure with tension increasing to failure
 $C + p_o$ to F : 7.5.2 Compression with external pressure increasing to failure
 T to F : 7.5.3 Tension increasing to failure.
 $p_o + C$ to F : 7.5.4 External pressure with compression increasing to failure
 $T + p_i$ to F : 7.5.5 Tension with internal pressure increasing to failure
 $p_i + C$ to F : 7.5.6 Internal pressure with compression increasing to failure
 p_o to F : 7.5.7 External pressure increasing to failure
 $p_{il} + T$ to F : 7.5.8 Low internal pressure with tension increasing to failure

Thread-seal interference abbreviations:

- H-L: Thread high – seal low
 L-L: Thread low – seal low
 H-H: Thread high – seal high
 L-H: Thread low – seal high

Thread taper abbreviations:

- PSBF: Pin slow taper box fast taper
 PFBS: Pin fast taper box slow taper
 NOM-NOM: Pin nominal taper box nominal taper

Thread compound/torque abbreviations:

- H/L: High amount of compound/low torque
 H/H: High amount of compound/high torque
 L/H: Low amount of compound/low torque

- ^a For CAL III, do not use Specimens 7 and 8.
^b Applicable for CAL II, CAL III and CAL IV, only. For CAL I make/break conditions refer to Tables 5 and 6.
^c CAL II specimens receive only Series B and Series C testing (See Table 1).
^d CAL I does not require Series C testing (see Table 1).
^e For CAL I, RRG on specimens 2 and 3 is not required. Specimen 2 receives MU only. Specimen 3 receives MBG.

Figure 1 (continued)

5.3 Test programme

5.3.1 Physical testing

Conduct a physical test programme of make-up/break-out tests, test load envelope tests and limit load tests in accordance with the procedures stated in this International Standard.

Instructions in this International Standard shall be followed. If adverse conditions not specifically addressed in this International Standard are encountered, all deviations from this International Standard shall be documented in the test reports. In addition, a statement(s) should be provided to justify why the tests should be considered adequate.

5.3.2 Assessment of test results

5.3.2.1 General

Assess the results of the physical test programme, in accordance with Clause 8, following the procedure given in 5.3.2.2 to 5.3.2.4.

5.3.2.2 Test results that conform to the stated connection application level

By successfully conforming to the requirements for all the make/break tests, the test load envelope tests and the limit load tests, the connection in the size, mass (label: weight) and grade of material (i.e. same yield strength and chemistry) tested has demonstrated conformance to the connection rating at the stated connection application level.

Limit load tests have minimum acceptance criteria, which define passing the tests. The TLE may be adjusted, as described below, after the tests in order to achieve passing.

5.3.2.3 Test results that do not conform to the stated connection application level

When the test results do not conform to the requirements of the test load envelope tests, the results may be evaluated for:

- a) a connection design revision followed by a full re-test; or
- b) a revision of the test load envelope followed by re-test of all test specimen(s) which did not meet the requirements of the revised test load envelope for that specimen.

For a premature limit load test failure

- a design revision and full retest of all specimens shall be performed, or
- a revision of the TLE shall be made.

If the test results comply with the revised TLE and limit loads, no further testing or action is required. All limit loads shall exceed the test load envelope.

In case of the malfunctioning of testing facilities or test execution, which is not related to product design, neither a connection design revision, test load envelope revision nor limit load revision is required, but the specimen(s) or replacement specimen(s) shall be re-tested in full. Any event not conforming to acceptance criteria shall be reported. The number of retests and the need for the retests shall be included on the summary and detailed test reports.

5.3.2.4 Reporting of test results

Report the assessment of test results in the first section of full and summary test reports. All connection leaks, regardless of volume or rate, shall be reported on the data sheets and identified on the pressure plots. All equipment leaks, regardless of volume or rate, shall also be identified on the pressure plots.

5.4 Calibration and accreditation requirements

5.4.1 Accreditation

The laboratory conducting these tests shall be either

- a) accredited by a recognized national or international accreditation body, or
- b) at a minimum, comply in full with 5.4.2 to 5.4.5.

5.4.2 Equipment calibration

Before testing begins, ensure that all load frames to be used for the tests have a valid calibration. In addition, based on the connection manufacturer's or test laboratory's experience, measuring and recording instruments, such as pressure gauges and thermocouples, shall be calibrated periodically. The test laboratory standards for calibration and all of the calibrations shall be documented. Copies of current calibration test reports for the load frame, temperature, pressure and torque measuring devices shall be included in the detailed test report.

Equipment calibration during a test programme may be appropriate based on the required test loads and past equipment usage.

5.4.3 Annual load frame calibration

Each load frame used in an axial load or combined load test shall be calibrated in both tension and compression modes at least annually with device(s) (i.e. load cells) traceable to national standards bodies.

The calibration should consist of two passes of a minimum of 10 equal increments ranging from the minimum calibration load to the maximum calibration load (defined as the "loading range"). The calibration range of the load frame shall cover the range of loads that will be applied in the test programme. The maximum frame calibration load shall be greater than the maximum anticipated failure load of the connection/pipe being evaluated.

The error, E_r , and the percent error, E_{rp} are calculated as follows:

$$E_r = F_i - F_f \quad (1)$$

$$E_{rp} = 100 \frac{E_r}{F_f} \quad (2)$$

where

F_i is the indicated load;

F_f is the actual load.

The percent error for all loads within the loading range of the frame shall not exceed $\pm 1,0$ % (see Annex F for an example).

5.4.4 Load frame verification

In the event that the load frame is subjected to unusual loads, such as applying a load beyond the calibration range or if a failure occurs at an unexpected load that could indicate a calibration problem, a calibration bar shall be used to verify the load frame calibration. This calibration bar shall be traceable to national standards bodies and certified annually. In lieu of using the calibration bar, a full annual calibration may be performed.

5.4.5 Pressure transducer calibrations

Each pressure transducer shall be calibrated at least annually. The percent error for pressures within the loading range shall not exceed $\pm 1,0\%$.

5.5 Rehearsal tests

Rehearsal tests are recommended. The purpose of a rehearsal test is to give the opportunity to, in an abbreviated format, softly validate the connection design and testing procedures prior to beginning the official testing. Test specimens for the official test should be threaded after the rehearsal tests are complete and especially if material availability is a concern. For rehearsal testing, the specimen(s) with low metal seal interference shall be tested for pressure sealing. Specimens with high metal seal interference shall be used to validate the galling sensitivity of the connection.

5.6 Material property tests

Test the pipe material mechanically to determine the yield strength for calculation of the connection testing loads and acceptance criteria.

The mechanical properties of the material shall be characterized by a documented procedure consistent with the specification for the material. Typically this is ISO 11960 for low alloy steel or ISO 13680 for corrosion-resistant alloys. For connections machined on line pipe the procedure shall be in accordance with ISO 3183-1, ISO 3183-2, or ISO 3183-3 or API Spec 5L.

NOTE 1 For the purposes of this provision, ISO 11960 is equivalent to API Spec 5CT.

Tensile test specimens shall be cut from both ends of all lengths of pipe and coupling stock. In addition, tensile test specimens shall be cut from the middle of all lengths of pipe and from the middle of lengths of coupling stock longer than 3 m (9.8 ft). Tensile test specimens and the results of the tests shall be traceable to the mother tubes and the location within the tube.

An alternative layout for pipe pups and tensile test specimens is given in Figure C.1. This layout provides the material strength directly adjacent to the threaded connection. If specimens are cut as specified in Figure C.1, the manufacturer shall modify the material property data sheet, as shown in Form C.1, to show the correct coupon location and shall include a sketch similar to Figure C.1 showing the actual location of the specimen pups and material coupons. If this alternate method is used, an elevated tensile test coupon should be taken at each location where mechanical properties are measured. The measured yield strengths adjacent to the thread to be used during the connection evaluation on each pup shall be the values used to calculate the test loads.

Either a strip specimen (preferred) or the largest practical ASTM round specimen (see ASTM A370) shall be used. The yield strength determined shall be the yield strength used for calculations. Additionally, the 0,2 % offset proof stress shall be reported for information. A sketch of the test coupon shall be shown in the material property data sheet, Form C.1. For one coupling and one pipe, plot the stress-strain or load-strain behaviour from zero strain to 2 % strain minimum or to coupon failure (whichever occurs first) for one Series A or Series B specimen and at elevated temperature for one Series C specimen.

Perform one ambient temperature tensile test on each material coupon.

Perform one elevated temperature tensile test at 135 °C (275 °F) for CAL II and CAL III and at 180 °C (356 °F) for CAL IV on each middle coupon or on one of the end coupons of coupling stock shorter than 3 m (9.8 ft).

For each elevated temperature test, report the actual coupon temperature by monitoring with a thermocouple attached to the coupon.

Perform a chemical analysis on each middle material coupon or one of the end coupons of coupling stock less than or equal to 3 m long (9.8 ft).

Report the material property data required on the material property data sheet, Form C.1.

NOTE 2 Consideration needs to be given to the limits of qualification of a connection if, within a specific strength grade, high strength pipe is tested. Consideration needs to be given to the possible effects of anisotropy of mechanical properties and of residual stress in cold worked CRA pipe (see ISO 13680 for information). Axial tensile testing may not be sufficient to adequately characterize the pipe.

5.7 Make-up and break-out procedures

5.7.1 Principle

Make-up and break-out procedures and the thread compound used during testing should be consistent with normal industry practice used in the field.

5.7.2 Make-up thread compound

The connection manufacturer shall specify the type and amount, with tolerances, of thread compound that shall be applied to the connection, as well as the areas to which the thread compound shall be applied. These thread compound criteria shall be the same as those used for field applications. The same thread compound shall be used for all test specimens. Preferably, the maximum and minimum quantities should be specified as mass. In addition, the manufacturer shall provide photographs and descriptions of how the thread compound is to be applied. This includes photographs of connections with minimum and maximum thread compound.

5.7.3 Make-up torques

The make-up torques specified in Clause 7 are either the maximum or minimum torque recommended by the manufacturer. For a high specified torque, 95 % of the maximum or a greater torque is acceptable. For a low specified torque, 105 % of the minimum or a lower torque is acceptable. If the actual make-up torque lies outside the required values, the connection shall be broken out and re-torqued. The manufacturer shall specify the rotational frequency (r/min) range for make-up. All connections should be made up at no less than 90 % of the maximum recommended rotational frequency (r/min).

5.7.4 Make-up procedure

Make up each connection in the following manner. Record the results in the specimen make-up/break-out data sheet, Form C.2.

For each make-up, clean and dry the connection completely, then weigh and record the amount of lubricant applied to each connection member (pin and coupling or box). Monitor and record make-up and break-out torques on torque-versus-turn plots. The turn resolution shall be at least 1/1 000 th of a turn. Torque-versus-turn plots for all make-ups of Clause 7 and any additional make-ups considered relevant shall be included in the full test report (see Clause 8 and Annex D). At the time of make-up, annotate each plot to indicate the test specimen, pin-end and box-end, make-up number, date, time and any unusual observations.

Connections should be made up using tongs and tong dies typical of those used in the field. Vertical make-up should be used. For coupled connections, floating of the coupling is prohibited (i.e. each side shall be made up separately). Photograph all make-up equipment and at least one connection being made up. When gripping couplings (or boxes), clamping forces should be controlled to prevent adverse distortion of the internally threaded member.

When performing the make and break procedure, it is acceptable to have a “dummy pin” in the end that is not being made up to help avoid damage.

5.7.5 Break-out procedure

Break-out the connection test specimen with the same tongs and instrumentation as in 5.7.4 in accordance with the manufacturer's procedure. Record the results in the specimen make-up/break-out data sheet, Form C.2.

5.7.6 Break-out refurbishment

Following each break-out, pins and boxes may be refurbished using only techniques stipulated by the connection manufacturer for field use. All such repairs shall be fully documented including repair time. Any galling or other nonconformity shall be reported. A galling evaluation, including a clear description of the size and nature of the damage, shall be part of the final report. Photographs shall be made of the galled surface, repaired surface, repaired surface after the next break-out and the repaired surface after the final break-out and shall be included in the final report.

5.7.7 Connection test specimen inspection

Inspect the connection test specimens carefully following each break-out. Evaluate and document on the torque-versus-turn plots any correlation with observed connection galling. On the torque-versus-turn plots, document any observations or variances that contributed to other make-up concerns (coupling or pin spinning in tong dies, computer glitch/electrical spike which results in no torque-versus-plot printout, etc.). Record dimensional inspection results on the specimen geometry data sheet, Form C.3.

5.8 Internal pressure leak detection

5.8.1 Principle

Leak detection requirements are critical for those connections that need to be gas or liquid tight. Alternate methods of leak detection are shown below for use on different types of connections. The casing and tubing connections shall be subjected to internal pressure and monitored with a system capable of trapping and measuring all connection leakage.

5.8.2 Pressurization media

For CAL II, III, and IV, all tests with internal pressure to verify the test load envelope shall be conducted with dry nitrogen. At the option of any of the parties to the test, a 5 % helium tracer gas may be added. For CAL I, all tests with internal pressure to verify the test load envelope shall be conducted with solids-free liquid or dry nitrogen as agreed in the test plans. All limit load tests (i.e. planned failure tests) shall be conducted with liquid as the pressuring medium unless otherwise specified and agreed in the test plans.

5.8.3 Test safety

For safety considerations, specimens subjected to gas pressure testing should include an inserted filler bar. The filler bar material should either not be porous or should bleed off the test medium quickly to avoid problems with interpreting the test results. The bar should be dimensioned to reduce the internal specimen volume substantially but shall not result in any mechanical interference with the specimen when the specimen deforms during test execution (see Figure 8 in 5.10.2). Filler bars should be centralized to ensure no contact with the test specimen D_i within one pipe diameter of the connection.

5.9 Internal pressure leak trap device

5.9.1 Alternatives

The connection test specimen shall contain one, or more, of the following internal pressure leak trap devices. When the tests will be at elevated temperature, the materials shall be rated for temperature above the test temperature.

5.9.2 Collared leak trap device

A collared leak trap device consisting of an O-ring held against the face or OD of the box by a ported collar containing a flange with at least four bolt-holes. Four longitudinal bolts maintain the collar tight against the face for sealing. A second O-ring is used to seal the collar against the pipe body using a separate bolted ring as shown in Figure 2.

5.9.3 Flexible boot leak trap device

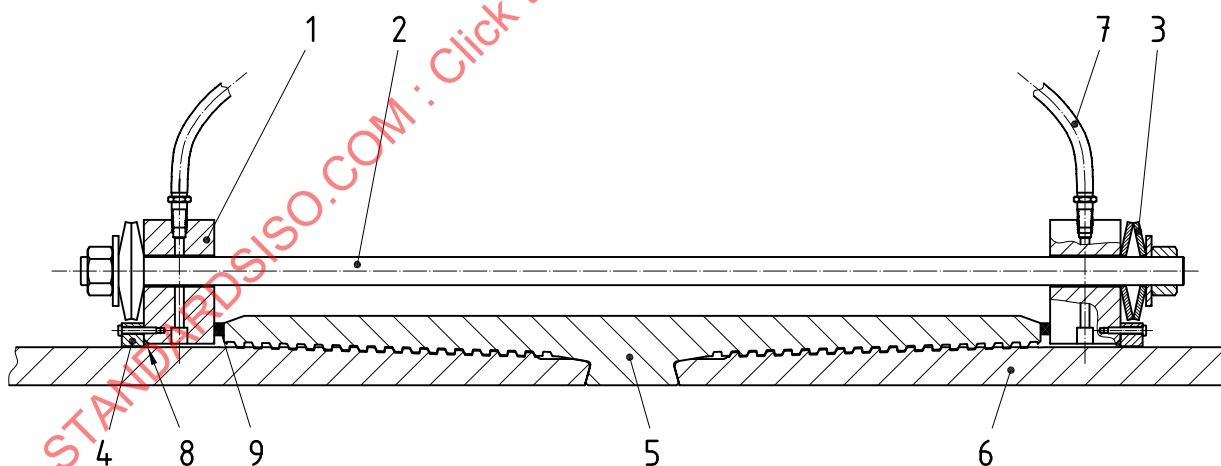
A flexible boot trap device consisting of a flexible material, such as silicone, that encapsulates the end of the box. A sealant is used between the pipe OD, box OD and the boot. Hose clamps are used to secure the boot to the pipe and the box OD. A tube is placed between the boot and pipe OD, using the sealant to ensure that escaping gas exits by the boot as shown in Figure 3.

5.9.4 Ported box leak trap device

A vent hole is drilled through the box over the pin run-out threads near the end of the box face to allow escaping gas to exit the connection. The hole is tapped and fitted with a threaded adapter to which a flexible hose is attached. The face of the box shall be sealed to prevent any gas from escaping out of the end of the box as shown in Figure 4.

Assemble the ported box (Figure 4) in the following manner:

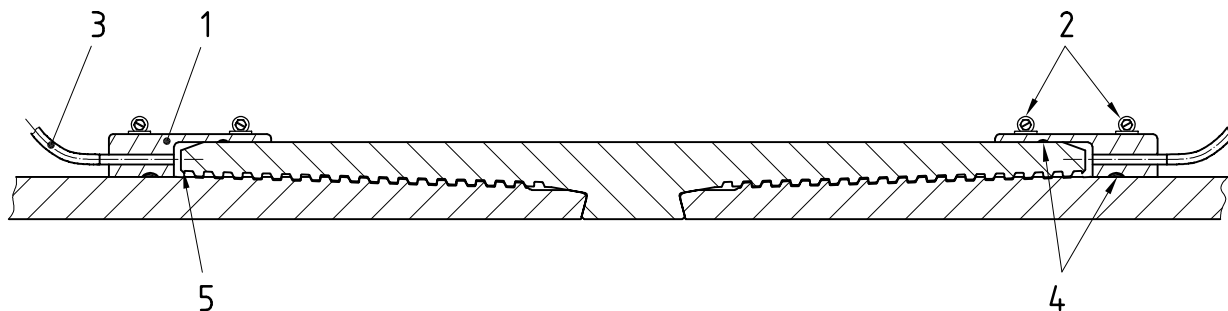
- drill, tap and de-burr holes before make-up;
- assemble connection;
- install threaded fittings into holes using thread sealer, such as PTFE;
- clean and seal the ends of the coupling with silicone sealant or equivalent;
- allow sealant to cure.



Key

- | | |
|-------------------|--------------------|
| 1 metallic flange | 6 pipe |
| 2 threaded rod | 7 flexible hose |
| 3 springs | 8 o-ring |
| 4 threaded nut | 9 flat face gasket |
| 5 coupling | |

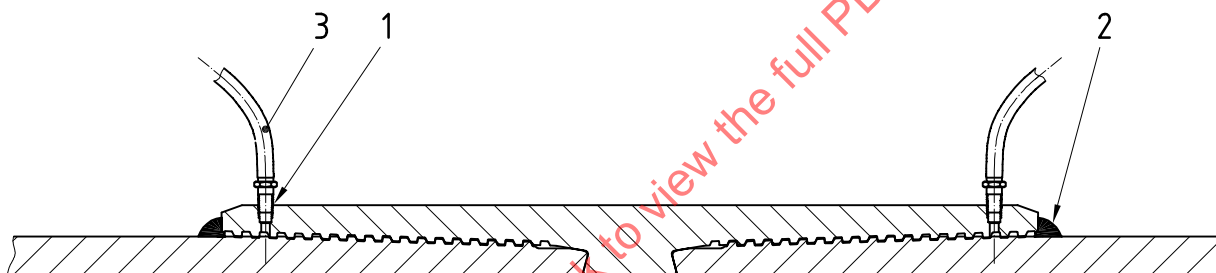
Figure 2 — Collared leak trap device for internal pressure leak detection



Key

- 1 flexible boot
- 2 hose clamps
- 3 metal tube or flexible hose (heat resistant for Test Series C)
- 4 sealant
- 5 small gap for good leak detection sensitivity

Figure 3 — Flexible boot leak trap device for internal pressure leak detection



Key

- 1 tapped hole in run out threads with threaded fitting
- 2 sealant
- 3 flexible hose

Figure 4 — Ported box leak trap device for internal pressure leak detection

5.9.5 Pressure test of leak trapping devices

Each trapping device shall be tested as follows:

- a) check sealant and fitting for leaks by attaching a hose to a pressure supply; apply a gas pressure of 0,007 mPa to 0,014 mPa (1 psi to 2 psi) air or nitrogen; close off from supply and observe pressure gauge for a decrease in pressure;
- b) tighten or repair trapping device as necessary;
- c) periodically remove fitting, clean hole as necessary and re-pressure test system as above;
- d) ports may be close to metal-to-metal seal by agreement.

5.9.6 Internal pressure leak detection sensitivity

The monitoring and measuring system for internal pressure leak detection shall meet a minimum leak indication sensitivity of $0,9 \text{ cm}^3/15 \text{ min}$ time period using a graduated cylinder of $0,1 \text{ cm}^3$ graduations or a sensitivity of $1 \times 10^{-4} \text{ cm}^3/\text{s}$ under standard conditions for gas chromatograph or spectrometer system. If helium tracer gas is used, the graduated cylinder based system shall have the capability of capturing the accumulated gas for the analysis of helium content to verify or discount leak events.

When using a graduated cylinder, take care to compensate for changes in barometric pressure because these changes may affect the leak detection sensitivity. It is recommended that prior to beginning any tests, a separate "dummy" graduated cylinder (see Figure 5) replicating the leak detection device be set-up. This separate "dummy" graduated cylinder would be used during analysis to determine if a connection is leaking or if the change is due to a change in barometric pressure. The separate "dummy" graduated cylinder should contain a gas bubble consistent with the size of the bubble in the inverted graduated cylinders of the connections being monitored.

Leak indicators may be evaluated regarding their source if there is reason to believe the leakage is not from the connection. A sensor calibrated to detect helium may be used to verify that any bubbles detected are coming from the pressure medium and not from the thread compound de-gassing or from thermal expansion of the connection or test equipment. Evaluation of the leakage source shall be based on conclusive analysis of the leakage gas. If leakage is generated from a source other than the connection (e.g. the end caps), the leakage source shall be repaired and testing continued. Report all leaks and their source (pressure fitting, valve, connection, etc.). All leak indicators shall be reported and the basis for discounting leakage clearly explained in the test report.

5.9.7 Internal pressure leak detection by bubble method

5.9.7.1 Principle

A leak detection system based on the bubble method is shown in Figure 5. The system is based on capturing any and all gas that passes through a connection and collecting the gas in a container for measuring the volume. The main components of the system are:

- a) a means of trapping the gas, such as the leak trap devices described above;
- b) a tube or flexible hose that connects the leak trap device to a bubble collection tube;
- c) a bubble collection tube that consists of a clear graduated cylinder with $0,1 \text{ cm}^3$ or smaller scale divisions. The cylinder is filled with water and a flexible hose is placed inside the open end of the cylinder. The cylinder and the end of the hose are submerged in a container of water and then inverted (see Figure 5). A leak is visually detected if bubbles rise in the cylinder. The gas from the bubbles is measured using the scale on the cylinder.

5.9.7.2 System verification for bubble method

Verify all internal pressure leak detection systems prior to a test programme by testing for leaks and assessing sensitivity.

- a) Test the system for leaks by applying $0,007 \text{ mPa}$ to $0,014 \text{ mPa}$ (1 psi to 2 psi) air or nitrogen gas pressure. When the pressure stabilizes, close off the gas supply. Observe the pressure gauge for 2 min for stability. Any drop in pressure indicates a system leak. Locate and repair any system leaks. Repeat this procedure until the gas pressure remains stable for a minimum 2-min hold period.
- b) Determine the sensitivity efficiency of the bubble leak detection system by introducing air and measuring the output air in each bubble tube. Inject the air in 1 cm^3 increments up to at least 10 cm^3 . Determine the average relationship of output volume to input volume by plotting the data as shown in Figure 6. The initial amount of input air required to start output air in the bubble tube (pre-charge) shall be recorded, but will not affect the calculated leak rate and is therefore not considered in this sensitivity efficiency. The sensitivity efficiency shall be at least 70 %. If it is less than 70 %, reconfigure the system to increase

sensitivity. This sensitivity efficiency shall be used to correct all observed leak rates and volumes during test execution according to Equation (3).

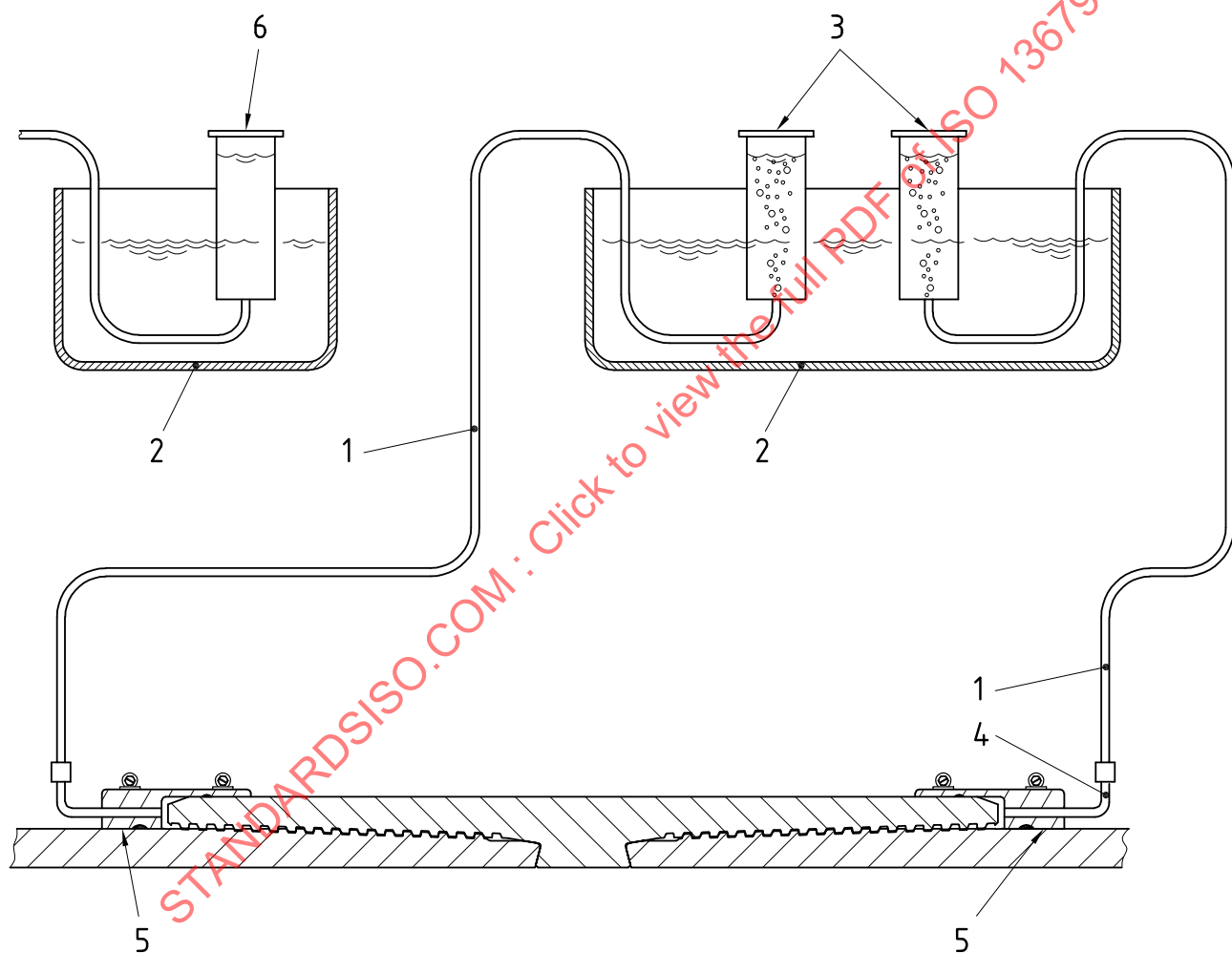
$$q_{ac} = \frac{q_o}{\eta_{lds}} \quad (3)$$

where

q_{ac} is the actual leak rate to be reported;

q_o is the observed leak rate;

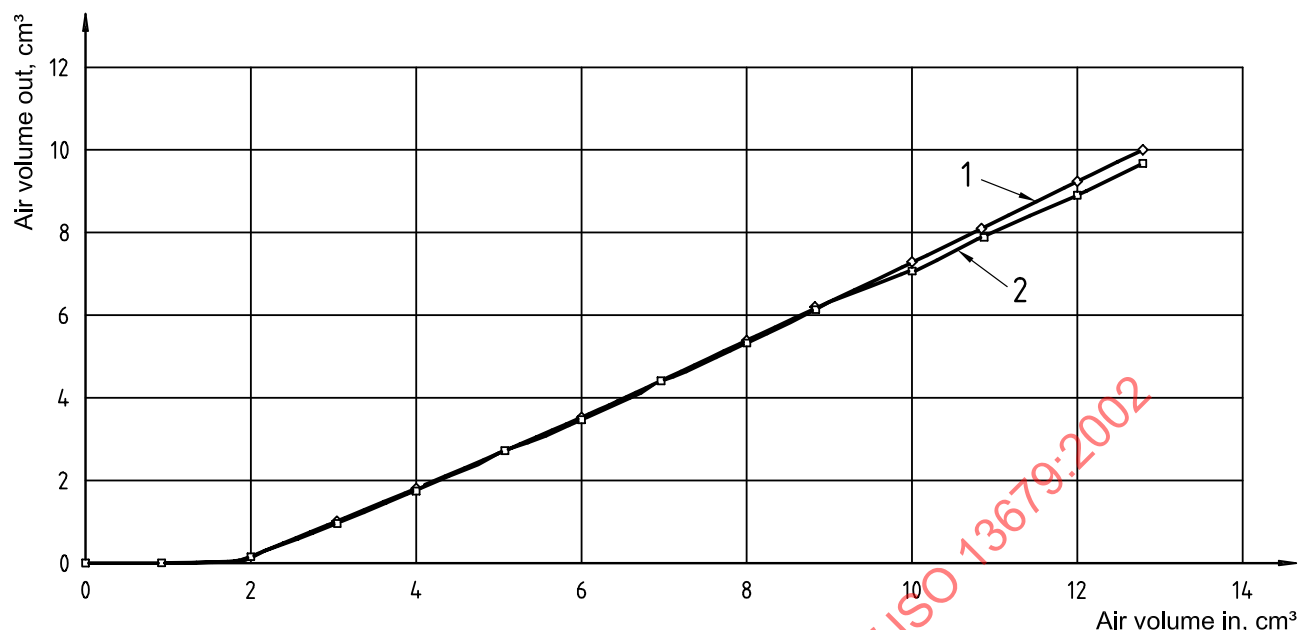
η_{lds} is the leak detection system efficiency.



Key

- 1 flexible hose
- 2 water tank
- 3 graduated cylinders
- 4 heat resistant tube
- 5 leak trap devices
- 6 dummy graduated cylinder (same size and height above top of water as cylinders, see 3)

Figure 5 — Internal pressure leak detection by bubble method



Key

- 1 specimen end A
- 2 specimen end B

Figure 6 — Example of a plot for determining leak detection sensitivity

5.9.7.3 Start of test

Before starting a test load envelope test, pre-charge each leak detection system by injecting air into the system near the box until a small amount of air collects in the bubble tube. Record this volume as the initial amount of gas to be subtracted from any additional gas collected in the tube. This pre-charge volume shall be sufficient to lower the water level to the scales on the graduated cylinder prior to the initiation of the test sequences.

5.9.8 Internal pressure leak detection by helium mass spectrometer method

5.9.8.1 Principle

A leak detection system using a helium mass spectrometer (see Figure 7) includes the following:

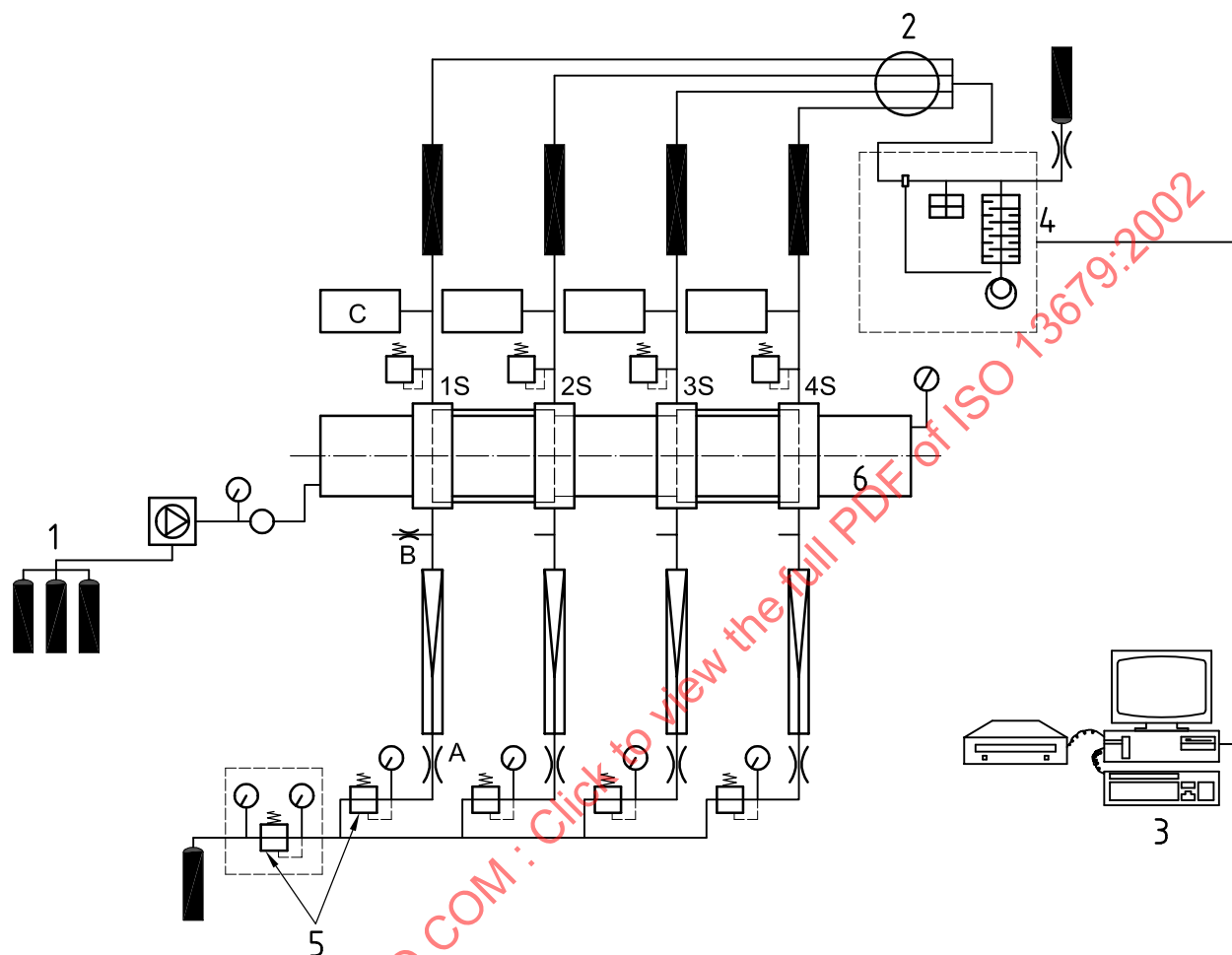
- a) a means of trapping the gas;
- b) a tube or flexible hose connecting the leak trap device to a carrier gas line;
- c) a pure nitrogen carrier gas line that connects to a mass spectrometer;
- d) a helium mass spectrometer (generally, the mass spectrometer uses a sniffing method of leak measurement, and consequently, much care shall be taken to ensure the sniffer is working properly at atmospheric pressure).

5.9.8.2 System accuracy

The helium leak measuring system shall be capable of measuring a total leak of $1 \times 10^{-4} \text{ cm}^3/\text{s}$ under standard conditions or lower leakage rate.

5.9.8.3 Calibration

The complete system shall be calibrated to the equipment supplier's recommendation and at least once annually using a certified calibrated leak source. The calibrated leak source shall be used in place of a test specimen with all other components of the leak detection system in place.



Key

- 1 internal pressure source
- 2 sampling valve
- 3 data logger
- 4 mass spectrometer detector
- 5 carrier gas regulators
- 6 test specimen (shown with two couplings and four connections: 1S, 2S, 3S and 4S)

Figure 7 — Leak detection by helium mass spectrometer method

5.9.8.4 Multiple specimen leak measurement

A manifold scanner can be used to test multiple connections or specimens. Minimum required sniffing time varies with equipment and shall be determined and demonstrated before starting the test. Each line shall be sniffed no less than once per minute.

5.9.8.5 System verification

Before each test, flush the system with nitrogen or nitrogen with helium and then test by sniffing the gas through the complete line and leak trap device. Check for proper helium content of the gas, demonstrating that the lines are not plugged.

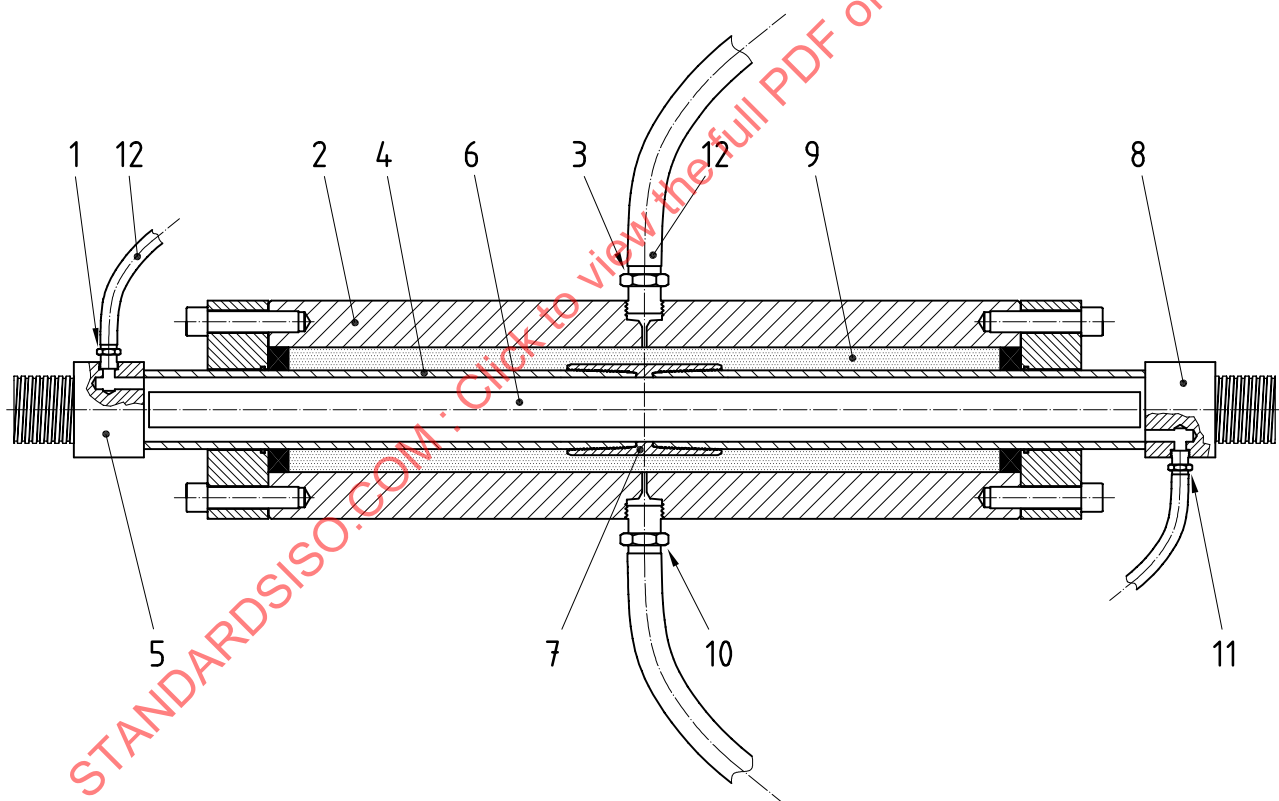
5.10 External pressure leak detection

5.10.1 Principle

The casing and tubing connections shall be subjected to external pressure within a system capable of detecting the external pressure leakage. External pressure leak detection is recognized as more difficult and less accurate than internal pressure leak detection. All external pressure tests shall be conducted with fresh water. All displacements shall be reported.

5.10.2 Test safety

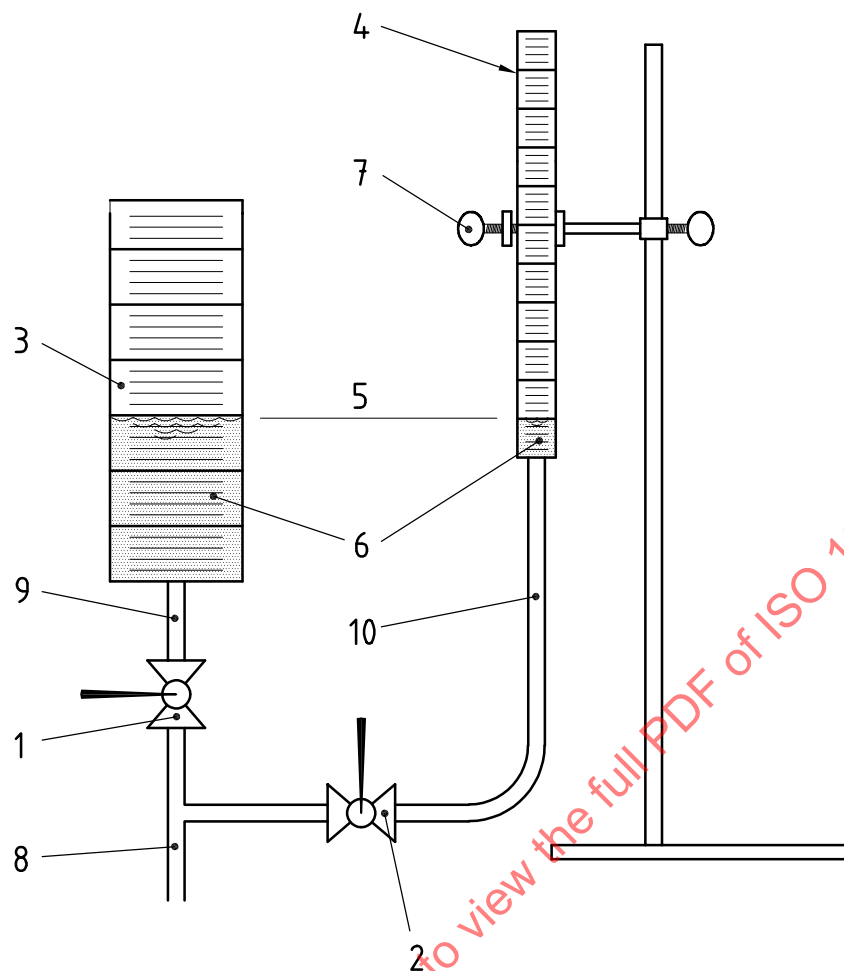
If external pressure testing is performed in conjunction with internal pressure testing, the specimens should have an internal filler bar as specified in 5.8.3 (see Figure 8).



Key

- | | |
|---|---|
| 1 port for pressure transducer for internal gas test, leak detection for external pressure test, shop air inlet to drain water after external pressure test | 6 internal filler bar, for safety |
| 2 external pressure chamber | 7 test connection |
| 3 hole, equipped with flexible hose to leak detection for internal pressure test or pressure transducer for external pressure test | 8 end cap containing bottom internal port, see 11 |
| 4 test pipe | 9 chamber, fully filled with water |
| 5 end cap, containing top internal port, see 1 | 10 hole, for water pressure inlet to chamber |
| | 11 port for gas pressure inlet, water fill for external pressure test, water drain after external pressure test |
| | 12 flexible hose that attaches to leak detection system (see 8 in Figure 9) |

Figure 8 — Example set-up for Test Series A



Key

- 1 valve to large graduated cylinder
- 2 valve to small graduated cylinder
- 3 large graduated cylinder with open top (approximately 100 cm³ to 200 cm³)
- 4 small graduated cylinder with 0,1 cm³ graduates with open top (approximately 25 cm³)
- 5 water level
- 6 coloured water
- 7 adjustable cylinder support to allow bottom of cylinder to be located at 100 cm³ to 200 cm³ water level at start of each hold period
- 8 flexible hose attached to top of chamber for internal gas tests and top port at one of end caps for external tests
- 9 flexible hose to large cylinder
- 10 flexible hose to small cylinder

Figure 9 — Example of leak detection system for Test Series A

5.10.3 Ported end caps

Connection test specimen end caps shall have holes that allow the inside of the specimen to be filled with water. These holes shall have high-pressure fittings able to contain internal pressure during internal pressure tests. Normally two holes are required, i.e. one for water inlet and one for air exit (air bleed). The air bleed hole shall be at the opposite end of the specimen from the water inlet hole. The bleed hole shall be located in the end cap so as to allow all of the air to be removed from the inside of the specimen. The ports shall also be

located in such a manner as to allow all the water to be removed from the specimen for subsequent internal gas tests.

5.10.4 Set-up for Test Series A

An example set-up for Test Series A is shown in Figure 8. During Test Series A, pressure loading changes from internal pressure to external pressure and back several times. To minimize test time, the tests may be conducted with an external pressure chamber in place for the entire series A. The external chamber may be used as part of the internal pressure leak detection system subject to the following requirements.

- a) Seek a leak detection sensitivity of $1 \times 10^{-3} \text{ cm}^3/\text{s}$; however absolute demonstration may not be possible.
- b) Fill the external chamber and flexible hose with water.
- c) To validate suspected leaks, perform additional tests to confirm the rate and source.

5.10.5 Leak detection and measurement by water level

For internal gas tests, fill the flexible hose at the top of the chamber (see 12 in Figure 8) with water and connect it to the leak detection system shown as 8 in Figure 9.

For external pressure tests, fill the inside of the specimen with water. Fill the flexible hose from the top of one of the end caps (see 1 in Figure 8) with water and connect it to the leak detection system shown as 8 in Figure 9.

During external pressure testing, a chamber encloses the test connection and some portion of the pipe on both sides of the connection. During the external pressure testing, it has been observed that immediately after reaching full pressure and axial load, there may be significant (greater than $0,9 \text{ cm}^3/15 \text{ min}$) water displacement. This displacement usually exhibits a decreasing trend and is a "stabilization period" that shall be performed before starting the required ISO hold period. In view of this test behaviour, the following criteria should be used for external pressure tests.

- a) Apply the full required external test pressure and close the pressure line valves from the pressurizing pump.
- b) Small pressure increases may be necessary immediately after closing the valves in order to maintain the required pressure.
- c) Begin recording the frame loads, pressures and bubble tube readings shortly after closing the valves (within approximately 2 min).
- d) Record the frame loads, pressures and bubble tube readings in 5-min increments.
- e) Note the trend of the bubble tube displacements. A decreasing trend in displacement is normal and indicates no connection leakage. A steady trend greater than $0,9 \text{ cm}^3/15 \text{ min}$ or an increasing trend indicates a possible connection leak.
- f) A hold period is considered to be leak free when the following are satisfied:
 - 1) for a 15-min hold:
 - i) four consecutive 5-min holds have been made;
 - ii) the sum of the first three 5-min holds and the sum of the last three 5-min holds (i.e. two consecutive rolling 15-min holds) do not exceed $0,9 \text{ cm}^3$ positive displacement;
 - iii) the 5-min hold period displacements do not show an increasing trend in displacement;

- 2) for a 60-min hold:
 - i) thirteen consecutive 5-min holds have been made;
 - ii) the sum of the first twelve 5-min holds and the sum of the last twelve 5-min holds (i.e. two consecutive rolling 60-min holds) do not exceed 0,9 cm³/15-min positive displacement;
 - iii) the 5-min hold period displacements do not show an increasing trend in displacement.

For both internal and external tests, at the start of the test, the large graduated cylinder shown in Figure 9 is approximately half filled with water. Before test loads are applied and adjusted, the large valve (see 1 in Figure 9) is opened and the small valve (see 2 in Figure 9) is closed. The water level inside the large cylinder will rise or fall with the applied test loads. At the start of a hold period, the small valve (see 2 in Figure 9) is opened and the position of the small graduated cylinder is adjusted up or down so that the water level in the small cylinder is near the bottom of the cylinder. The large valve (see 1 in Figure 9) is then closed. If a specimen leak occurs, the water level in the small cylinder will rise and can be observed and measured in time to give a leak rate. A colouring agent should be added to the water inside the cylinders for ease of viewing the water level.

The water level in the small cylinder shall be recorded at the start and end of each hold period and at the intervals stated in 7.3.2 when a leak occurs to determine the leak characteristic.

5.11 Data acquisition and test methods

5.11.1 General

The correct and adequate recording of data is fundamental to the qualification programme. Without adequate records, it will not be possible to provide the objective evidence of the qualification of a connection.

5.11.2 Principle

For Test Series A, the primary loading is pressure and axial force at ambient temperature. Bending loads are recognized as a secondary load accompanying axial load and shall be minimized as much as possible by careful alignment of end caps and load frame. For Series B CAL IV tests, test bending loads are deliberately added to the axial loads. For Series B CAL III, II and I tests, added bending loads are optional. Specimens tested in Series B with applied bending shall be instrumented to determine the bending load.

5.11.3 Procedure

5.11.3.1 General

Monitor and record the internal or external pressure, frame load, bending load and temperature that are applied to the specimen. For all tests record the pressures, axial load and temperature continuously versus time. Data may either be recorded continuously or digitally. For digital data acquisition systems, the data acquisition rate should be appropriate for the expected load and pressure changes but shall not be less than 1 scan of all channels every 15 s.

Draw a graph of the pressure in the sealing proof tests using a pressure scale from zero to a full scale greater than the maximum anticipated test load pressure. Draw a graph of the pressure applied in failure tests using a full-scale pressure range greater than two times the maximum anticipated test load pressure. Draw a graph of the machine tension load in sealing proof tests using a full-scale load range from zero to full scale greater than the maximum anticipated test load tension. Draw a graph of the machine load in failure tests using a full-scale load range of greater than 1,5 times the maximum anticipated test load tension. Temperature versus time shall also be plotted using an appropriate resolution scale. Annotate the graphs for ease of later interpretation.

5.11.3.2 Pressure and/or tension loads

Connect a pressure transducer to the internal or external pressure cavity of the specimen. Locate the pressure transducer at the air bleed hole and not at the pressure inlet hole.

Load each specimen at an axial stress rate of 105 MPa/min (15 000 psi/min) or less. Load each specimen with pressure at a rate of 105 MPa/min (15 000 psi/min) or less. Loading the specimens may be performed continuously or intermittently. However, in the case of intermittent loading the rates for axial load and pressure increments shall not exceed the maximum rates. There is no maximum or minimum rate for removing pressure or axial loads.

NOTE These rates are specified to ensure that accurate sealing and structural performance data are recorded in the tests.

5.11.3.3 Bending loads

When measuring bending using strain gauges, place the four biaxial strain gauge rosettes on at least one of the pipe bodies (and preferably on both pipe bodies) at a single cross-section plane and at a distance of at least $3\sqrt{Dt}$ from the connection and any end cap or gripping fixture. Equally space the strain gauges around the circumference at 90° spacing. The position/orientation of each gauge shall be documented. Other instrumentation may be used to monitor bending if its accuracy can be shown to be equivalent to four biaxial strain gauge rosettes.

Apply and control bending at the connection to at least the minimum bending moment for deliberate bending tests as determined by measured strains from the pipe body strain gauges and according to the moment distribution calculation below for three-point bending. Monitor the pipe body strain gauges, calculate the bending stress, moment and dogleg and continuously record the dogleg.

Three load methods for deliberate bending are recognized:

a) Four-point bending:

For a four-point bending fixture, locate both bending load cylinders at equal distances from the end reaction points and ensure they impose equal load.

b) Three-point bending:

For three-point bending (centre load applied on the coupling), apply a correction to the strain data bending results in proportion to the ratio of the distance from the outer load point to the centre of the coupling divided by the distance from the outer point to the centre of the strain gauges. This correction gives the bending values at the coupling.

c) Uniform bending from rotating end fixtures:

For rotating end fixtures, the applied bending moment shall be the same on both ends.

5.11.3.4 Tests to failure

Monitor and record the internal or external pressure and axial load that is applied to the specimen.

For each failure test, photograph the specimen after failure and show the location and mode of failure. Record major loads and dimensions on the limit load test data sheet Form C.4. Report and retain test data in the test reports (see Clause 9 and Annex D).

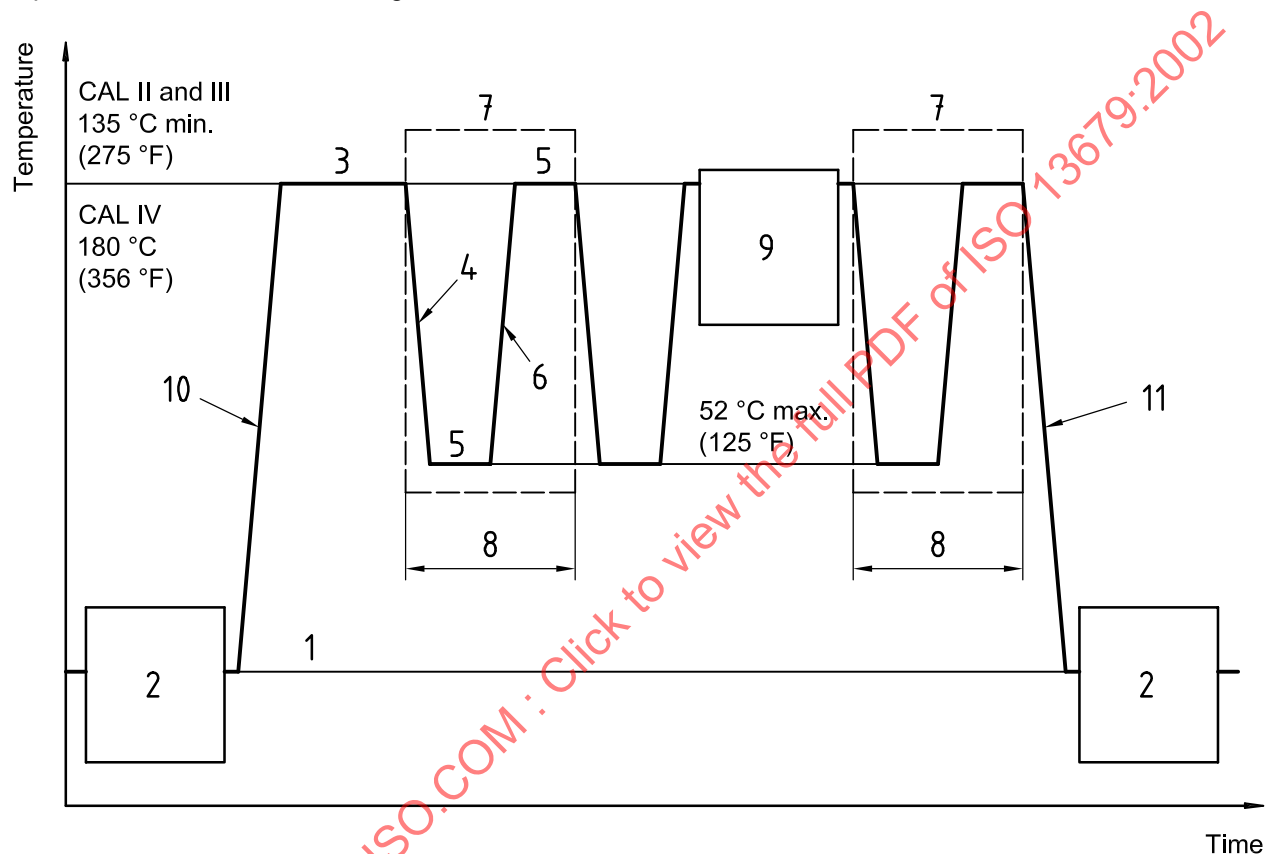
5.12 Thermal cycling tests

5.12.1 General

The purpose of thermal cycling is to approximate service conditions and accelerate potential leakage by applying thermal cycling while the connection is subject to axial tension and internal pressure loads.

5.12.2 Principle

A thermal cycle is a change from “maximum” temperature to “minimum” temperature and back to “maximum” temperature and is illustrated in Figure 10.



Key

- 1 ambient temperature
- 2 five pressure/tension cycles at ambient temperature
- 3 minimum 60-min hold at elevated temperature
- 4 cooldown
- 5 minimum 5-min hold
- 6 heat up
- 7 perform five thermal cycles for CAL II and III tubing and casing as well as CAL IV casing, and 50 thermal cycles for CAL IV tubing. Perform five thermal cycles for CAL IV tubing with redundant seal tested to Annex J.
- 8 typical thermal cycle (shall be at least 30 minutes)
- 9 five pressure/tension cycles at 135 °C (275 °F) for CAL II and III and at 180 °C (356 °F) for CAL IV
- 10 initial heatup
- 11 final cooldown

Figure 10 — Test Series C thermal/mechanical cycles for CAL II, III, and IV

5.12.3 Apparatus

The temperature changes for the thermal cycling tests may be produced by any means capable of producing sufficiently large temperature variations throughout the connections of the test specimens. The apparatus should avoid subjecting the test specimens to a substantially higher temperature than required by the test procedure.

The maximum temperature observed on the test specimen should be recorded at each load condition when the temperature observed is more than 16 °C (30 °F) higher than the intended test temperature.

5.12.4 Procedure

Refer to 7.3.5 and Figure 10 for thermal cycle load steps. A minimum time of 5 min shall elapse at or above the maximum temperature and 5 min at or below the minimum temperature. The maximum temperature shall be greater than or equal to 135 °C (275 °F) for CAL II and CAL III and greater than or equal to 180 °C (356 °F) for CAL IV. The minimum temperature for all application levels shall be less than or equal to 52 °C (125 °F). Minimum time per cycle is 30 min. Cycles may be continuous or interrupted as required for overnight shutdown or equipment repair. The five pressure/tension cycles performed at the beginning and end of Test Series C shall be performed at ambient temperature.

At ambient temperature the maximum mechanical loads are as specified in a) and b).

- a) Tension is the lesser of 80 % pipe body yield (or coupling yield) or 80 % connection test load envelope based on material yield at ambient temperature.
- b) Internal pressure is the lesser of 95 % VME pipe body yield (or coupling yield) or 95 % VME connection test load envelope, with both loads based on the above 80 % tension and material yield at ambient temperature.

At elevated temperature the maximum mechanical loads are as specified in c) and d).

- c) Internal pressure is the same as the ambient pressure above.
- d) Tension is the lesser of 90 % VME pipe body yield (or coupling yield) or 90 % VME connection test load envelope based on material yield at the specified elevated temperature.

Other methods to establish the pressure and tension for ambient and elevated temperature tests may be used provided the intent is consistent with having a high internal test pressure for both the ambient and elevated temperature tests and as high an axial load as practical. The basis for using the alternate method shall be documented in the test report.

Monitor the temperature during testing with thermocouples. Ensure that the temperature measured is not affected by local temperature variations in the vicinity of the thermocouple and that the temperature measured is representative of the connection's temperature. If heating or cooling is only being applied on one side of the connection, temperature measurements should be taken on the opposite side from where the temperature variations are being applied.

If the testing apparatus has been shown to apply uniform heating and cooling to the specimens, a single thermocouple may be used to monitor the thermal-cycling tests. If significant temperature variations are possible in the specimen, multiple thermocouples shall be used and an average temperature from all thermocouples shall be used to monitor the tests.

During the thermal cycling test, there may be small changes in the water level in the graduated cylinders. Variations of $\pm 0,1 \text{ cm}^3$ to $\pm 0,4 \text{ cm}^3$ and more occur randomly and may not be related to a connection leak. The rapid thermal changes and barometric pressure changes cause these water level variations. The 5-min hot and cold holds only have a $0,3 \text{ cm}^3$ allowable displacement ($0,9 \text{ cm}^3/15 \text{ min} = 0,3 \text{ cm}^3/5 \text{ min}$). Therefore, the leak evaluation criteria for this test are as follows.

- If during any of the 5-min hold periods, more than 0,3 cm³ is collected from a specimen, then the hold shall be extended another 10 min, for a total of 15 min.
- If the displacement is more than 0,9 cm³ for the 15 min-hold, then a 1-h hold shall be performed to characterize the leak, recording the displacement in 5-min intervals (as required in 7.3.2).

6 Connection test specimen preparation

6.1 General connection test objectives

Control and definition of test specimens is critical since this testing method is based on extreme-tolerance/worst-case connection configuration evaluation and not random sampling of a population. Extreme-tolerance evaluation addresses performance parameters of dimensions, mechanical properties, make-up torque and the type and amount of thread compound. Product tolerances are based on performance, manufacturing capabilities and cost of manufacture. It is significant to recognize that this test procedure does not provide the statistical basis for risk analysis.

Manufacture and test the connection specimens at the worst-case performance extremes that can be produced according to the drawings, quality plan, running (including doping) procedures and make-up torques described in the connection geometry and performance data test sheets and quality control procedures. Table 2 gives general connection test specimen objectives for each specimen. Table 3 gives guidance for selecting specimens for testing a metal-to-metal sealing, tapered thread connection with a torque shoulder. The test specimen extremes shall conform to these test objectives. For connections with attributes different than Table 3, worst-case extremes shall be determined and documented and used in the tests.

Table 2 — Connection test specimen objectives for all CAL

Specimen number	Make-up objective	Test load objective	Testing objective	Text reference	Limit load testing	
					Test path number ^a	
					CAL I and II	CAL III and IV
1	Thread galling	Minimum leak integrity ^b	High internal pressure with tension increasing to failure	7.5.1	LP1	LP1
2	Pin maximum axial stress	Leak resistance at maximum make-up tightness ^b	Compression with external pressure increasing to failure	7.5.2	LP6 (see 7.5.6)	LP2
3	Maximum box hoop stress	Leak resistance at maximum make-up tightness ^b	Tension to failure	7.5.3	LP3	LP3
4	Worst-seal galling tendency ^b	Minimum leak integrity	External pressure with compression increasing to failure	7.5.4	LP5 (see 7.5.5) (CAL II only)	LP4
5	Thread galling	Minimum leak integrity ^b	Tension with internal pressure increasing to failure	7.5.5		LP5
6	Worst-thread galling tendency ^b	Minimum leak integrity	Internal pressure with compression increasing to failure	7.5.6		LP6
7	Worst-seal galling tendency ^b	Maximum leak integrity	External pressure to failure	7.5.7		LP7 (CAL IV only)
8	Worst-seal galling tendency ^b	Maximum leak integrity	Low internal pressure with tension increasing to failure	7.5.8		LP8 (CAL IV only)

^a Test path numbers refer to failure tests shown in Figure 18 or Figure 19.

^b Primary test objective.

Table 3 — Guidelines for selecting connection test specimens for testing a metal-to-metal sealing, tapered thread connection with a torque shoulder

Specimen number	Summary of objectives	Made-up condition	Thread interference	Seal interference	Pin thread taper	Box thread taper	Final torque
1	Sealing	Minimum seal interference	High	Low	Slow	Fast	Minimum
2	Sealing	Maximum torque into shoulder	Low	Low	Slow	Fast	Maximum
3	Sealing	Maximum overall tightness	High	High	Nominal	Nominal	Maximum
4	Seal galling and sealing	Maximum seal interference	Low	High	Fast	Slow	Maximum
5	Sealing	Minimum seal interference	High	Low	Slow	Fast	Minimum
6	Thread galling and sealing	Minimum seal interference	High	Low	Slow	Fast	Maximum
7	Seal galling and sealing	Maximum seal interference	Low	High	Fast	Slow	Minimum
8	Seal galling and sealing	Maximum seal interference	Low	High	Fast	Slow	Minimum

6.2 Connection test specimen identification and marking

Identify each connection test specimen by marking with the following information (see Figure 11).

- The connection test specimen number (i.e. 1, 2, 3, 4, 5, 6, 7 or 8) shall be placed on both pups and the couplings (as applicable).
- The pup joint designation (A or B) shall be placed after the specimen number.
- The coupling side designation (A or B) shall be placed at the appropriate end of the coupling.
- Identify replacement and/or re-machined connections with an "R1" after the "A" or "B" identification the first time they are reworked, "R2" the second time they are reworked, etc.

6.3 Connection test specimen preparation

6.3.1 Additional and unsupported pipe lengths

Prepare connection test specimens such that for each specimen, each pipe length has:

- minimum unsupported pup joint length L_{pj} (see Figure 11) that is calculated from Equation (4):

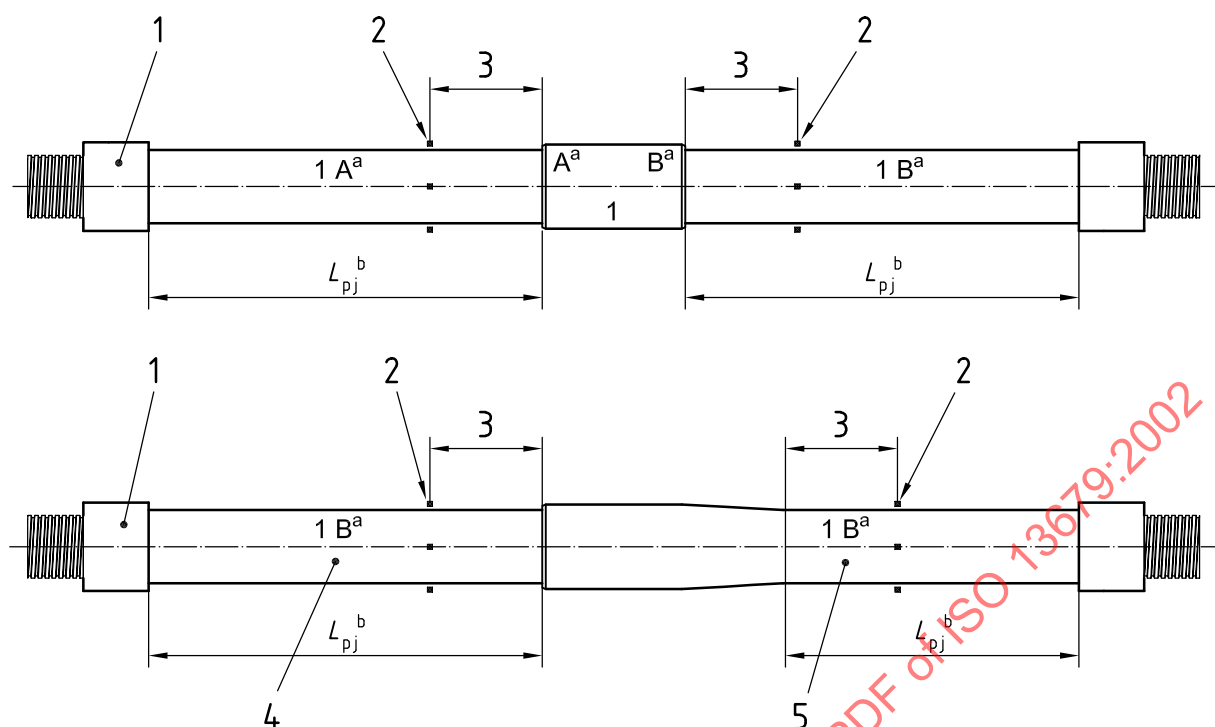
$$L_{pj} \geq D + 6\sqrt{Dt} \quad (4)$$

where

D is the specified pipe outside diameter;

t is the specified wall thickness;

- additional length for gripping and/or plugs shall be provided.
- scribe specimens to allow measurement of lengths L_A , L_B and L_C and record them on Form C.3.



Key

- 1 end fixture
- 2 strain gauge rosettes for measuring bending
- 3 minimum distance of $3\sqrt{Dt}$ between strain gauge rosettes and connection (leaving minimum distance of $D + 3\sqrt{Dt}$ between strain gauge rosettes and end fixture)
- 4 pin
- 5 box
- a Connection specimen number is designated by 1, 2, 3, etc. and A and B are pup joint and coupling side designations.
- b L_{pj} is the minimum unsupported pup joint length. ($D + 6\sqrt{Dt}$), see 6.3.1.

Figure 11 — Connection test specimen nomenclature and unsupported length

6.3.2 Pipe and coupling stock

Connection test specimens should be machined on pipe and coupling stock that is manufactured consistent with standard mill/thread practices as follows:

- a) machine connections for upset pipe on upset pipe;
- b) machine connections for swaged pipe on swaged pipe;
- c) machine flush connections for plain-end pipe on plain-end pipe.

It is acceptable, but less desirable, to manufacture connection specimens from material stock by machining external upsets to replicate the product configuration. If the upsets are machined, the configuration that is not normally machined, and the length shall be to the minimum allowed by the manufacturer. The test reports shall indicate that the test specimens were machined from thick wall cylinders, when applicable.

6.3.3 Material requirements

For each set of test specimens:

- a) the A-end and B-end pup joints shall come from one lot;
- b) coupling material shall come from one lot;
- c) for integral connections, material for both pin and box shall come from one lot;
- d) the material properties of each mother joint shall be determined in accordance with 5.6;
- e) all material should be in compliance with a specified material specification;
- f) the total range of measured yield strength at room temperature for each mother pipe shall be less than or equal to 70 MPa (10 ksi);
- g) the average yield strengths of all mother pipe shall be within a total range of 70 MPa (10 ksi);
- h) the average coupling mother pipe yield strength shall not exceed the minimum average pin mother pipe yield strength by more than 35 MPa (5 ksi);
- i) if the pipe and coupling are not from the same specified grade, the difference between yield strengths shall be by agreement between user and manufacturer;
- j) the actual minimum pipe body wall thickness shall not be greater than the specified wall thickness for the pipe being tested.

6.3.4 Recording of data

All appropriate data shall be recorded on material property data sheet Form C.1.

6.4 Connection test specimen machining

Manufacture connection test specimens as specified by the connection manufacturer's process control plan. The tolerances shall be as specified in 6.6.

The first article contour tracings, or equivalent such as impression moulds, (at minimum magnification of $\times 20$) shall meet the applicable machine drawing dimensions of the specimen being threaded. The piece representing the start of the thread lot shall be verified to meet the applicable machine drawing requirements prior to machining the test specimens. The contour tracings, or equivalent, shall be part of the connection manufacturer's detail test report.

In the sealing area measure the surface roughness in accordance with the surface roughness specifications of the product drawing and record in the test report. The measurement shall be taken after machining and before surface treatment and shall be within the surface roughness specifications of the product drawing.

The selected surface treatment of each pin and box shall be consistent with the surface treatment applied to production components. By agreement between manufacturer and user, especially on gall sensitive materials, surface treatment of pin and box shall be at minimum (or maximum) of the tolerance range, depending on which is deemed most severe for the connection.

If a connection test specimen is damaged before testing is completed, manufacture a replacement specimen. This replacement specimen shall be machined and assembled to the same tolerances as the damaged specimen, and all testing required for the original specimen shall be repeated. Identify replacement and/or re-machined connections with an "R1" after the "A" or "B" identification the first time they are reworked, "R2" the second time they are reworked, etc.

All proprietary data, which are to be reported on the specimen geometry data sheet, Form C.3, may be reported as a percent of tolerance range of the measured dimension, i.e. 0 % represents the minimum value of the tolerance range of the measured dimension and 100 % represents the maximum value of the tolerance range of the measured value. If using %, the measured value shall be retained in the thread manufacturer's files. Note that 50 % represents the middle of the tolerance range. Connection primary seal ovality shall be reported either as a real number or a percentage.

6.5 Machining tolerances

6.5.1 Worst-case performance objectives

The specific machining dimensions will depend on the type of connection. For connections with attributes other than covered by Table 3 or if different machining tolerances are recommended, then the manufacturer shall use analytical, computational (such as finite element analysis) and/or experimental techniques (such as strain gauge testing) to provide objective evidence that the extreme dimensional configurations of the product resulting in worst-case performance are tested. To select worst-case performance objectives, the manufacturer shall take into account the minimum and maximum extremes of local seal contact pressure, total seal contact load and total active seal contact length as influenced by machining parameters. For threaded and coupled connections, side A and side B shall be machined to identical dimensional objectives.

Machining tolerances, which may be relevant to worst-case performance, include, but may not be limited to the following:

- a) seal diameters;
- b) thread tapers;
- c) pin nose thickness;
- d) thread diameters;
- e) surface roughness.

6.5.2 Example machining tolerances

As an example, for metal-to-metal sealing, tapered thread, connections with pin-nose torque shoulders, Table 4 shows combinations of seal and thread diameters, thread tapers and final make-up torques which have been found to provide the worst-case performance extremes corresponding to the test objectives in Table 2. For this type of connection, the manufacturer should machine the specimens to the extremes in Table 4 unless the techniques described in 6.5.1 indicate other tolerances should be tested.

Table 4 — Tolerance limits on machining objectives

Item	Plus (+) tolerance	Minus (–) tolerance
Maximum thread diameters	No limit	0,025 mm (0.001 in)
Maximum seal diameters	No limit	0,025 mm (0.001 in)
Minimum thread diameters	0,025 mm (0.001 in)	No limit
Minimum seal diameters	0,025 mm (0.001 in)	No limit
Thread tapers: Maximum (fast) Minimum (slow)	No limit 0,025 mm/25,4 mm (0.001 in/1 in)	0,025 mm/25,4 mm (0.001 in/1 in) No limit
Taper tolerances shall apply to every incremental measurement of taper along the thread.		

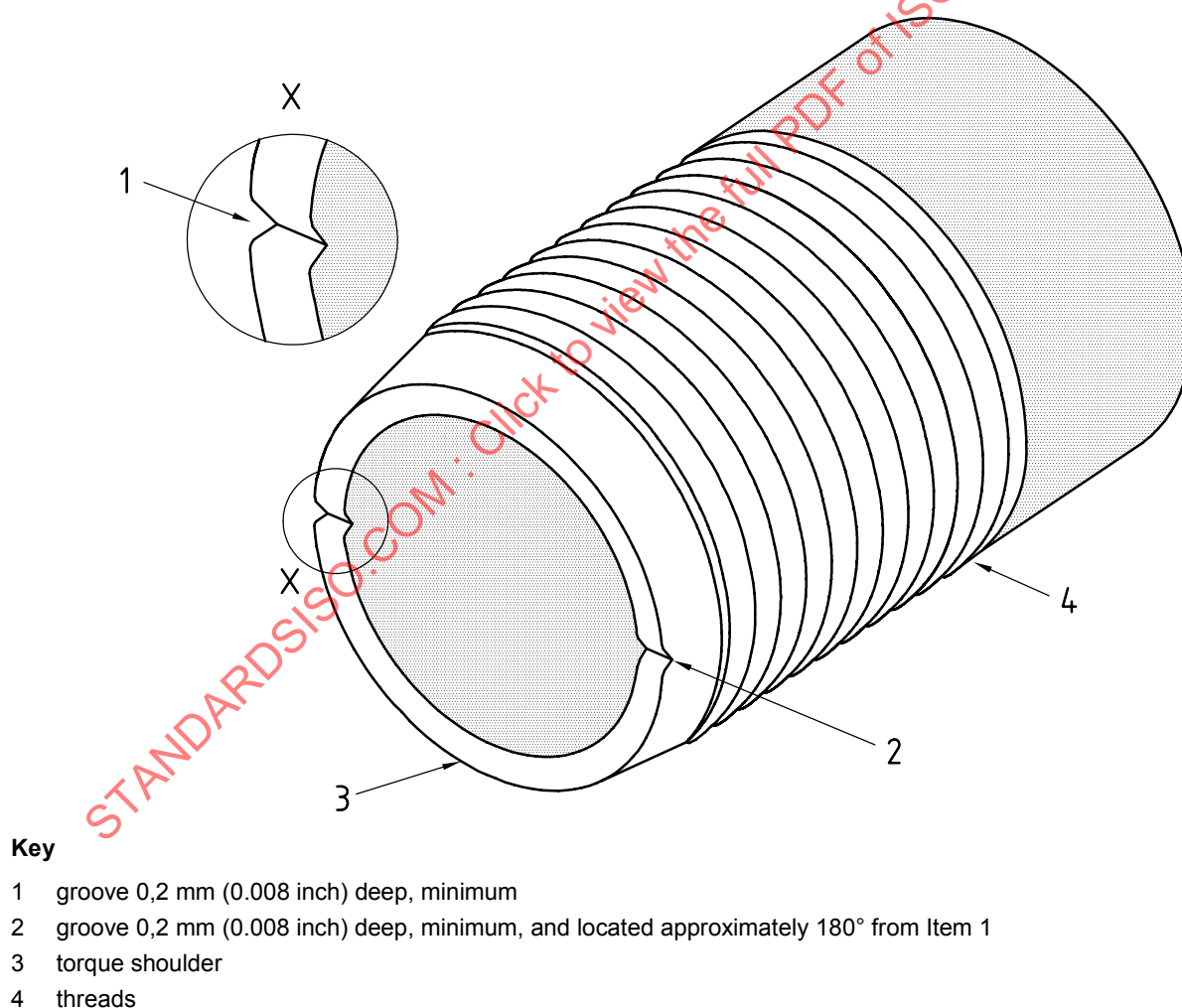
6.6 Tolerance limits on machining objectives

Specimen dimensions shall conform to Table 4.

6.7 Grooved torque shoulder

For connection types with a torque shoulder on the front of the pin, the A ends (B ends for integral connections) of specimens 1, 2, 3 and 4 (specimen 4 omitted for CAL I) shall have torque shoulders grooved as shown in Figure 12 in order to simulate possible handling damage which could be sustained by connections in the field. Grooves shall be applied before first make-up. Other specimen ends in the test may have the torque shoulder grooved by agreement between connection manufacturer and user.

Inclusion of the torque shoulder pressure by-passing groove is at the option of the user and manufacturer for other connection seal configuration types. Justification for omitting the pressure bypassing groove shall be included in the full test report specified in Annex D, as well as the shorter summary test report specified in Annex E. However, if any field dressing of the torque shoulder is allowed, the groove shall be included in the connection test configuration of specimens 1, 2, 3 and 4 (specimen 4 omitted for CAL I test procedures).



Corners at grooves 1 and 2 should be rounded to prevent possible galling. By-pass grooves shall not traverse into the pin nose metal seal.

Figure 12 — Torque shoulder pressure bypassing grooves

7 Test procedures

7.1 Principle

The procedures subject the worst-case connection configurations to test envelope loads and limit loads of the pipe body or connection (whichever is less).

In accordance with the connection test specimen objectives (see Table 2), Table 5 provides a summary of test procedures for each specimen according to seal interference condition, make/break condition and testing to Series A, B or C (thermal cycling) and LL (limit loads to failure). For an MTC (metal-seal threaded and coupled) connection, Table 5 provides further detail.

Table 5 — Specimen description and summary of test series for a metal-to-metal sealing, tapered thread connection with a torque shoulder

Specimen description				Thread compound			Torque			Make/break		CAL IV				CAL III				CAL II			CAL I				
Specimen No.	Interference		Condition							Condition B end		Test Series		Test Series		Test Series		Test Series									
	Thread	Seal		MU	M/B	FMU	MU	M/B	FMU	CAL II-IV	CAL I	A	B	C	LL	A	B	C	LL	B	C	LL	B	LL			
				A end	B end		A end	B end																			
1	H	L	Min. SL	H	—	H	L	—	L	FMU	FMU	—	B	C	LP1	—	B	C	LP1	B	C	LP1	B	LP1			
2	L	L	Low SL	H	L	H	H	H	H	RRG	FMU	A	—	C	LP2	A	—	C	LP2	B	C	LP6	B	LP6			
3	H	H	High SL	H	L	H	H	H	H	RRG	MBG	—	B	C	LP3	—	B	C	LP3	B	C	LP3	B	LP3			
4	L	H	Max. SL	H	L	H	H	H	H	MBG	—	A	—	C	LP4	A	—	C	LP4	B	C	LP5	—	—			
5	H	L	Min. SL	H	L	H	L	H	L	RRG	—	A	—	—	LP5	A	—	—	LP5	—	—	—	—	—			
6	H	L	Min. SL	H	L	H	H	H	H	RRG	—	—	B	—	LP6	—	B	—	LP6	—	—	—	—	—			
7	L	H	Max. SL	H	L	H	L	H	L	MBG	—	A	—	—	LP7	—	—	—	—	—	—	—	—	—			
8	L	H	Max. SL	H	L	H	L	H	L	MBG	—	—	B	—	LP8	—	—	—	—	—	—	—	—	—			
Sum of specimen A and B ends for each make/break condition				Make-up – A ends						MU (only)		8				6				4			3				
				Make/break galling – B ends						MBG		3				1				1			1				
				Round-robin galling – B ends						RRG		4				4				2			0				
				Final make-up – B ends						FMU		8				6				4			3				
Total number of specimens for each test class												8				6				4			3				
MU Make-up (see 7.2.2)												L		Manufacturer's recommended minimum value													
M/B Make-up/break-out												LL		Limit load (failure) tests (see Clause 7 and Table 2)													
MBG Make/break limit galling test (see 7.2.3)												SL		Seal interference condition determined by local seal contact pressure or total seal contact load, i.e. the integral of contact pressure													
FMU Final make-up (see 7.2.5)																											
H Manufacturer's recommended maximum value												RRG		Round-robin galling test (see 7.2.4).													
For threaded and coupled connections, all A ends shall be configured the same as the B ends described above and shall be made-up one time only as specified in 7.2.2.																											
NOTE All threads on integral joint connections are identified as B end threads.																											

7.2 Make-up/break-out tests

7.2.1 Principle

All initial and intermediate connection make-ups for MBG and RRG shall be to maximum make-up torque with the minimum amount of thread compound. The final make-up prior to test load envelope testing shall have the maximum amount of thread compound applied to all connections and torque shall be in accordance with

Table 5. For thread sealing connections (TSC), final make-up prior to test load envelope testing shall have the minimum amount of thread compound and minimum amount of torque.

A galling evaluation shall be part of the final report, including photographs of the galled surfaces before and after repair from the first galling event, the repaired surfaces after the next break-out and the final break-out.

For connection types not included in Table 5, the manufacturer shall provide thread compound and torque values to meet the objectives of Table 2. Thread sealing connection and large diameter connection types may follow Table 5 when the applicable columns are used.

All A ends receive only one make-up (MU) as specified in 7.2.2. All B ends receive a final make-up (FMU) as specified in 7.2.5, with some specimens also receiving make-up and break-out testing as specified in 7.2.3 (MBG) and in 7.2.4 (RRG).

7.2.2 Make-up (MU) — A ends

For all A ends, make-up connection test specimens in accordance with the following procedure.

- a) Refer to 5.7 for general make-up/break-out procedures. Record connection geometry data on the specimen geometry data sheet, Form C.3.
- b) The connections shall be clean and dry, and the mass of thread compound applied shall be recorded.
- c) Make-up all assemblies as shown in Table 5 with the indicated amount of thread compound and make-up torque (see Note).
- d) Report results on the specimen make-up/break-out data sheet, Form C.2, and on the specimen geometry data sheet, Form C.3.

NOTE All integral connections are “B” assemblies and do not have “A” ends.

7.2.3 Make-up/break-out test for galling resistance (MBG) — B ends

Make-up and break-out connection test specimen ends shall be in accordance with the following procedure.

- a) Refer to 5.7 for general make-up/break-out procedures. Record connection geometry data on specimen geometry data sheet, Form C.3.
- b) The connections shall be clean and dry, and the mass of thread compound applied shall be recorded.
- c) After each break-out, clean, examine and photograph the pin and box end in accordance with 5.7. On the first and last break-out, record connection geometry data on specimen geometry data sheet, Form C.3. Report results on the specimen make-up/break-out data sheet, Form C.2.
- d) Make-up and break-out specimen end 4B for CAL II and III and ends 4B, 7B and 8B, for CAL IV nine times for tubing and two times for casing. For CAL I make-up and break-out specimen 3B nine times for tubing and two times for casing. All make-ups shall use the amount of thread compound and make-up torque shall be as specified in Table 5. See 7.2.5 for final make-up.

7.2.4 “Round-robin” make-up/break-out test for galling resistance (RRG) — B ends

Make-up and break-out connection test specimen ends 2B, 3B, 5B and 6B shall be in accordance with the following procedure.

- a) Refer to 5.7 for general make-up/break-out procedures. Record connection geometry data on the specimen geometry data sheet, Form C.3.
- b) The connections shall be clean and dry, and the quantity of thread compound applied shall be recorded.

- c) After each break-out, clean, examine and photograph the pin and box end in accordance with 5.7. On the first and last break-out, record connection geometry data on the specimen geometry data sheet, Form C.3. Report results on the specimen make-up/break-out data sheet, Form C.2.
- d) For CAL III and IV tubing and casing make-up and break-out ends 2B, 3B, 5B and 6B. For tubing, make-up and break-out the ends four times, each time switching the pin members such that all four pins are made-up with all four boxes. For casing, make-up and break-out the ends two times, using ends 2B and 5B together and ends 3B and 6B together. For CAL II, make-up and break-out specimens 2B and 3B four times for tubing and two times for casing. The amount of thread compound and make-up torque shall be as specified in Table 5. See 7.2.5 for final make-up.

7.2.5 Final make-up (FMU) — B ends

Make-up connection test specimens in accordance with the following procedure.

- a) Refer to 5.7 for general make-up/break-out procedures. Record connection geometry data on Form C.3.
- b) The connections shall be clean and dry, and the quantity of thread compound applied shall be recorded.
- c) Make-up all assemblies as shown in Table 5 with the indicated amount of thread compound and make-up torque.
- d) Report results on the specimen make-up/break-out data sheet, Form C.2, and on the specimen geometry data sheet, Form C.3.

7.3 Test load envelope tests

7.3.1 Test load envelope calculation

In the calculation of both pipe body load capabilities and critical connection cross-section capacities, it is the intent of this International Standard to test the specimens to as high a load or combination of loads as safely practical. In view of this objective, the following variable definitions for load calculation and TLE and LL normalization to minimum service TLE and LL guidelines shall be applied to each specimen.

- a) Yield strengths:

Yield strengths selected shall be the minimum actual yield strength for the mother pipe of each specimen. However, by agreement between the user and manufacturer, higher values of yield strength may be used, such as the average for a mother joint rather than the minimum.

- b) Outside diameters and inside diameters:

The specified outside diameter shall be sufficient and may be used for calculation purposes or the actual average outside diameter may be used for calculation purposes. The D_i shall be calculated using minimum wall thickness (see below).

- c) Pipe wall thickness and thickness at critical connection cross-sections:

Minimum actual wall thickness shall be used for calculation purposes for both pipe-body and connection cross-sections.

For connections rated equal to the pipe body rating, the pipe body test load envelope shall be the minimum calculated using:

- the actual minimum yield strength, the minimum wall thickness (but not greater than 95 % of the specified wall thickness for the pipe) and the outside diameter of pup joint A;
- the actual minimum yield strength, the minimum wall thickness (but not greater than 95 % of the specified wall thickness for the pipe) and the outside diameter of pup joint B;

- the actual minimum yield strength of the coupling material, 95 % of the specified pipe wall thickness and the specified pipe outside diameter. The calculations are made using equations for pipe body ratings the same as if the pipe had the yield strength of the coupling material.

For connections that are rated less than pipe body load rating in any quadrant of the test load envelope, the manufacturer shall establish methods to determine the loads for the specified test in that quadrant. If a connection is rated less than the pipe body rating in compression, the tests shall include internal pressure (external pressure as applicable) to 95 % VME (or the established pressure limit) at the compression rating.

As a cautionary note, testing in quadrants II and III typically requires special fixturing to prevent buckling.

7.3.2 Principle

In combined load testing, the total axial load is the sum of the load frame axial load plus the pressure-induced axial load if any. In addition to the data required herein, the manufacturer shall record and report other data the manufacturer considers pertinent to these tests. Use Form C.5, the connection leak log sheet, to record any leakage during the tests.

The test hold time begins when load, pressure and temperature, as stated in Tables 6, 7 and 8, have been reached and stabilized. Any pressure load step where leakage is detected shall be held for a minimum of 1 h to determine the leak characteristic. Report the average leak rate over rolling 15-min intervals, every 5 min during the 1-h hold.

Before Series A and B tests, all specimens except CAL I are subjected to a 12-h bake at a minimum temperature as specified in Table 1. This procedure

- reduces thread compound degassing later which may appear to be a leak, and
- provides worst-case thread compound performance.

Testing may be occasionally interrupted at any point in the procedure by removing all loads, e.g. an overnight shutdown or equipment repair. Testing shall then resume at the same load step in the procedure. Multiple specimens may be tested simultaneously in series. However, the applied loads shall be the largest required for all specimens in series.

7.3.3 Test Series A — Tension/compression and internal/external pressure (tubing and casing)

Submit the connection test specimens (see Table 1) to the following procedure.

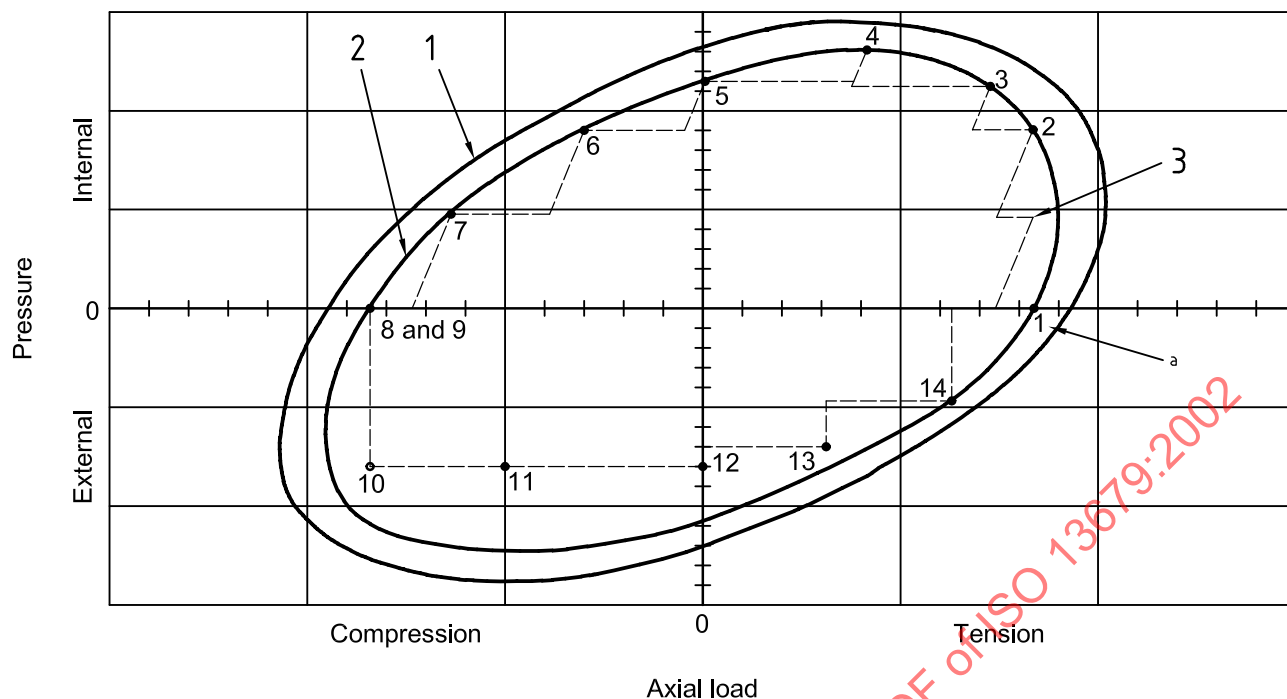
- Determine the axial loads for the hold points shown in Figure 13 and Figure 14 and in Table 6.
- Determine the internal pressure for the load points shown in Figure 13 and Figure 14 and in Table 6.
- Determine the external pressure for the load hold points shown in Figure 13 and Figure 14 and in Table 6.
- Perform the test according to instructions in 5.9, 5.10 and 5.11 as shown in Figure 13 and Figure 14 and in Table 6.
- Report results on Form C.6, summary of observed bubble tube water displacement and Form C.5, connection leak test log sheet.

Table 6 — Test Series A load steps (see Figures 13 or 14, as applicable) —
Testing in quadrants I, II, III, IV (no bending) at ambient temperature

Load step	Load point	Total axial force ^a	Internal pressure ^a	External pressure ^b	Hold time min
1 ^c	1	95	0	0	5
2 ^c	2	95	95	0	60
3 ^c	3	80	95	0	15
4 ^c	4	CEPL	95	0	15
5 ^c	5	0	95	0	15
6 ^c	6	– 33	95	0	15
7 ^c	7	– 67	95	0	15
8 ^c	8 and 9 ^{e f}	– 95	0	0	5
Switch from internal pressure to external pressure					
9 ^c	10 ^{g h}	– 95	0	95	15
10 ^c	11 ^{g h}	– 50	0	95	15
11 ^c	12 ^{g h}	0	0	95	15
12 ^c	13 ^g	33	0	95	15
13 ^c	14 ^g	67	0	95	15
14 ^c	1	95	0	0	5
15 ^d	14	67	0	95	15
16 ^d	13	33	0	95	15
17 ^d	12	0	0	95	15
18 ^d	11	– 50	0	95	15
19 ^d	10	– 95	0	95	15
Switch from external pressure to internal pressure					
20 ^c	2	95	95	0	15
21 ^c	3	80	95	0	15
22 ^d	8 and 9 ^{e f}	– 95	0	0	5
23 ^d	7	– 67	95	0	15
24 ^d	6	– 33	95	0	15
25 ^d	5	0	95	0	15
26 ^d	4	CEPL	95	0	15
27 ^d	3	80	95	0	15
28 ^d	2	95	95	0	15
29 ^d	1	95	0	0	5
30 ^c	2	95	95	0	15
31 ^c	3	80	95	0	15
32 ^c	4	CEPL	95	0	15

Table 6 (continued)

Load step	Load point	Total axial force ^a	Internal pressure ^a	External pressure ^b	Hold time min
33 ^c	5	0	95	0	15
34 ^c	6	– 33	95	0	60
35 ^c	7	– 67	95	0	15
36 ^c	8 and 9 ^{e f}	– 95	0	0	5
Switch from internal pressure to external pressure					
37 ^c	10 ^{g h}	– 95	0	95	15
38 ^c	11 ^{g h}	– 50	0	95	60
39 ^c	12 ^{g h}	0	0	95	15
40 ^c	13 ^g	33	0	95	60
41 ^c	14 ^g	67	0	95	15
Switch from external pressure to internal pressure					
42 ^c	1	95	0	0	5
43 ^c	2	95	95	0	60
CEPL = capped end pressure load ^a Percentage of connection test load envelope ^b Smaller of 95 % test load envelope or 100 % ISO/API collapse, if test load envelope is equal to 100 % ISO/API collapse then use 100 % ISO/API collapse. ^c Steps which are CCW. ^d Steps which are CW. ^e For connection rated equal to pipe body, load points 8 and 9 are the same and equivalent to only one load point. ^f For connection weaker than pipe body in compression, load points 8 and 9 are different (see Figure 14). ^g Load points 10 to 14 are typically governed by pipe body collapse and not pipe VME yield. ^h Load points 10 and 11 are not required to be a higher pressure than load point 12.					

**Key**

- 1 100 % VME pipe body yield envelope
- 2 95 % VME pipe body yield envelope
- 3 recommended intermediate load between steps 1 and 2

Load paths are repeated in CCW, CW, CCW directions for a total of 3 mechanical cycles.

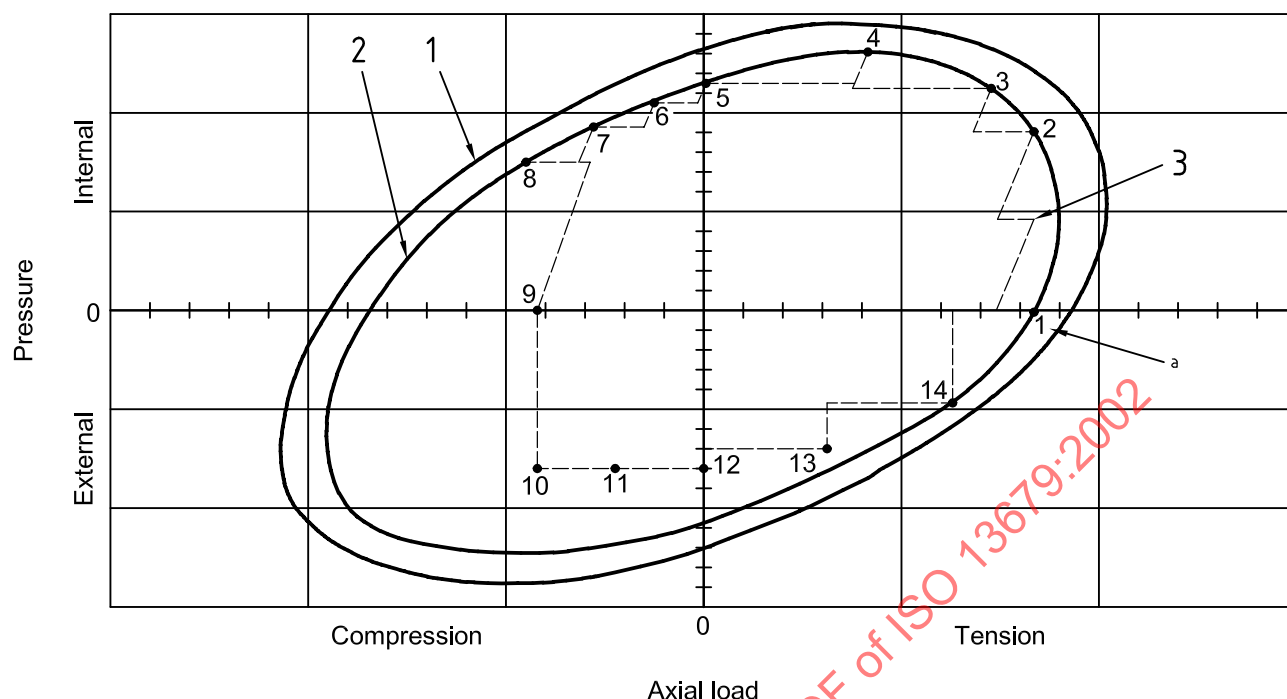
Load points 8 and 9 are the same for connection equal to the pipe body in compression.

Load points 10 and 11 are not required to be a higher pressure than load point 12.

Load points 10 through 14 are typically governed by pipe body collapse and not pipe VME yield.

^a Small-sized numbers are load points.

Figure 13 — Test Series A load path for connection rated greater than or equal to pipe body in compression



Key

- 1 100 % VME pipe body yield envelope
- 2 95 % VME pipe body yield envelope
- 3 recommended intermediate load step between steps 1 and 2

Load paths are repeated in CCW, CW, CCW directions for a total of 3 mechanical cycles.

Load points 10 and 11 are not required to be a higher pressure than load point 12.

Load points 10 through 14 are typically governed by pipe body collapse and not pipe VME yield.

^a Small-sized numbers are load points.

Figure 14 — Test Series A load path for connection rated less than pipe body in compression

7.3.4 Test Series B — Tension/compression and internal pressure (tubing and casing)

Submit the connection test specimens (see Table 1) to the following procedure. Note that for CAL I, II and III bending is optional, for CAL IV bending is normative.

- a) If bending is used, determine the equivalent axial tension and compression loads for bending equivalent to 40 % of the pipe body yield strength, 40 % of the connection yield strength (see Note) or dogleg of 19,7°m/30 m (20°/100 ft), whichever is less.
- b) Determine the axial loads and internal pressure for the hold points shown in Figure 15 and Table 7 without bending.
- c) Determine the axial loads and internal pressure for the load points shown in Figure 16 or Figure 17 and Table 8 with bending.
- d) Perform the test according to instructions in 5.8, 5.9 and 5.11 as shown in Figure 15, Figure 16 or Figure 17 and Table 7 or Table 8.
- e) Report results on Form C.7, summary of observed bubble tube water displacement, and Form C.5, connection leak test log sheet.

NOTE Typically pipe sizes greater than 244 mm (9 5/8 in) will be limited by the 40 % of connection yield strength criteria.

Table 7 — Test Series B load steps without bending for connection rated equal to pipe body
(see Figure 15) — Testing in quadrants I and II without bending at ambient temperature

Load step	Load point	Total axial force % service envelope ^a	Pressure % service envelope ^a	Hold time min
1 ^b	1	95	0	5
2 ^b	2	95	95	60
3 ^b	3	80	95	15
4 ^b	4	CEPL	95	15
5 ^b	5	0	95	15
6 ^b	6	– 33	95	15
7 ^b	7	– 67	95	15
8 ^b	8 and 9 ^{d e}	– 95	0	5
9 ^b	2	95	95	15
10 ^c	8 and 9 ^{d e}	– 95	0	5
11 ^c	7	– 67	95	15
12 ^c	6	– 33	95	15
13 ^c	5	0	95	15
14 ^c	4	CEPL	95	15
15 ^c	3	80	95	15
16 ^c	2	95	95	15
17 ^c	1	95	0	5
18 ^b	2	95	95	15
19 ^b	3	80	95	15
20 ^b	4	CEPL	95	60
21 ^b	5	0	95	15
22 ^b	6	– 33	95	60
23 ^b	7	– 67	95	15
24 ^b	8 and 9 ^{d e}	– 95	0	15
25 ^b	2	95	95	60

CEPL = Capped end pressure load.

^a Percentage of connection test load envelope.

^b Steps which are CCW.

^c Steps which are CW.

^d For connection rated equal to pipe body, load points 8 and 9 are the same and equivalent to only one load point.

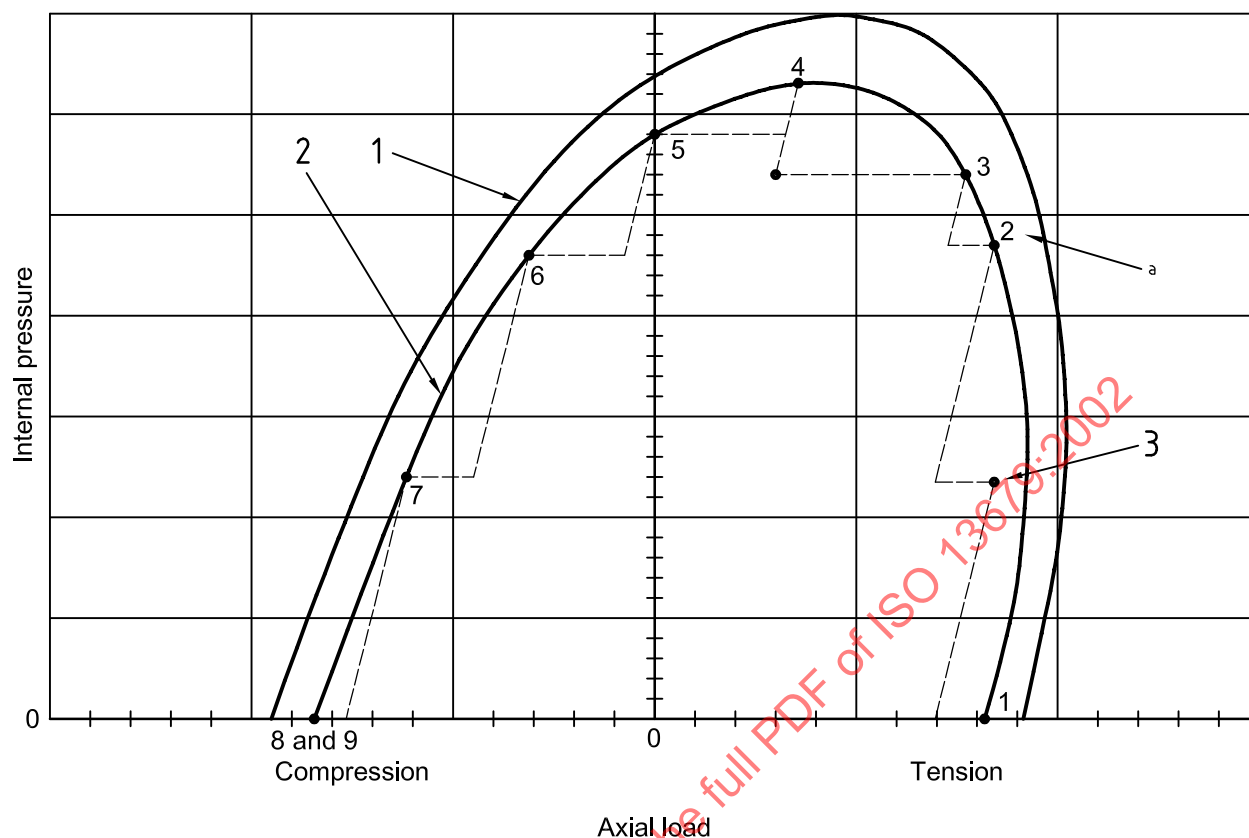
^e For connection weaker than pipe body in compression, load points 8 and 9 are different (see Figure 17).

Table 8 — Test Series B load steps with bending for connection rated equal to pipe body
(see Figure 16) — Testing in quadrants I and II with bending at ambient temperature

Load step	Load point	Bending in pipe °/30 m (°/100 ft) ^a	Total axial force % connection yield ^b	Pressure % service envelope ^b	Hold time min
1 ^c	1	—	95	0	5
2 ^c	2	—	95	95	15
3 ^c	2B	20° ^f	$F_b + T = 95$	95	60
4 ^c	3	—	80	95	15
5 ^c	3B	20° ^f	$F_b + T = 80$	95	15
6 ^c	4	—	CEPL	95	15
7 ^c	5	—	0	95	15
8 ^c	5B	20° ^f	0	95	15
9 ^c	6	—	– 33	95	15
10 ^c	6B	20° ^f	$F_b + T = -33$	95	15
11 ^c	7	—	– 67	95	15
12 ^c	7B	20° ^f	$F_b + C = 67$	95	15
13 ^c	8 and 9 ^e	—	95	0	5
14 ^c	2	—	95	95	15
15 ^c	2B	20° ^f	$F_b + T = 95$	95	15
16 ^d	8 and 9 ^e	—	– 95	0	5
17 ^d	7B	20° ^f	$F_b + C = -67$	95	15
18 ^d	7	—	– 67	95	15
19 ^d	6B	20° ^f	$F_b + T = -33$	95	15
20 ^d	6	—	– 33	95	15
21 ^d	5B	20° ^f	0	95	15
22 ^d	5	—	0	95	15
23 ^d	4	—	CEPL	95	15
24 ^d	3B	20° ^f	$F_b + T = 80$	95	15
25 ^d	3	—	80	95	15
26 ^d	2B	20° ^f	$F_b + T = 95$	95	15
27 ^d	2	—	95	95	15
28 ^d	1	—	95	0	5
29 ^c	2	—	95	95	15
30 ^c	2B	20° ^f	$F_b + T = 95$	95	15
31 ^c	3	—	80	95	15
32 ^c	3B	20° ^f	$F_b + T = 80$	95	15

Table 8 (continued)

Load step	Load point	Bending in pipe °/30 m (°/100 ft) ^a	Total axial force % connection yield ^b	Pressure % service envelope ^b	Hold time min
33 ^c	4	—	CEPL	95	60
34 ^c	5	—	0	95	15
35 ^c	5B	20° ^f	0	95	15
36 ^c	6	—	– 33	95	15
37 ^c	6B	20° ^f	$F_b + T = - 33$	95	60
38 ^c	7	—	– 67	95	15
39 ^c	7B	20° ^f	$F_b + C = 67$	95	15
40 ^c	8 and 9 ^e	—	– 95	0	5
41 ^c	2	—	95	95	15
42 ^c	2B	20° ^f	$F_b + T = 95$	95	60
T = Tension C = Compression CEPL = Capped end pressure load F_b = Equivalent bending force (Bending stress at pipe $D_o \times$ pipe area) ^a See 7.3.4 a). ^b Determined from 95 % test load envelope. ^c Steps which are CCW. ^d Steps which are CW. ^e For connection rated equal to pipe body, load points 8 and 9 are the same and equivalent to only one load point. For connection weaker than pipe body in compression, load points 8 and 9 are different (see Figure 17). ^f Bending load should be the lesser of 19,7°/30 m, 40 % of the pipe body bending yield load determined at the D_o, or 40 % of the connection bending yield load. Bending is optional for CAL III, II and I.					
NOTE 1°/30 m = 1.016°/100 ft.					



Key

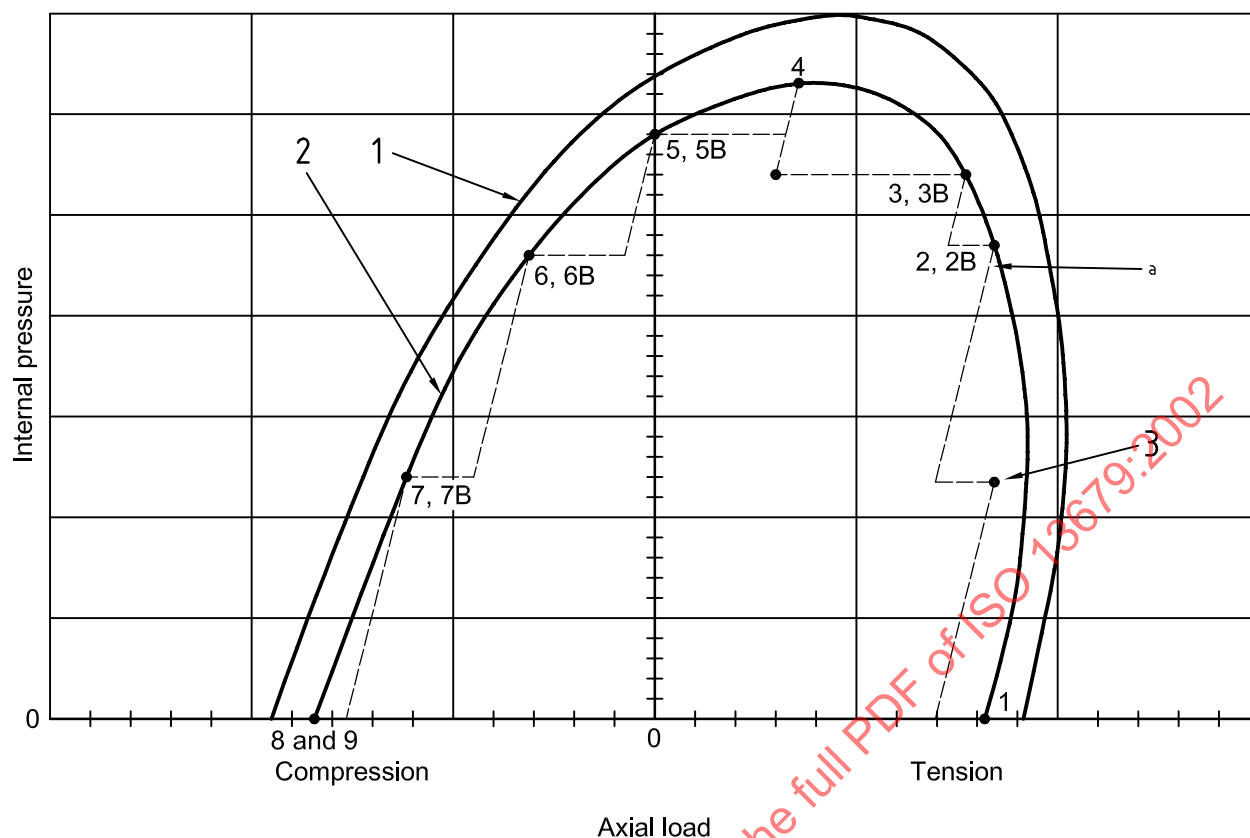
- 1 100 % VME pipe body yield envelope
- 2 95 % VME pipe body yield envelope
- 3 recommended intermediate load step between steps 1 and 2

Load paths are repeated in CCW, CW, CCW directions for a total of 3 mechanical cycles.

Load points 8 and 9 are the same for connection equal to the pipe body in compression.

^a Small-sized numbers are load points.

Figure 15 — Test Series B load paths without bending for connection rated equal to pipe body



Key

- 1 100 % VME pipe body yield envelope
- 2 95 % VME pipe body yield envelope
- 3 recommended intermediate load step between steps 1 and 2

Load paths are repeated in CCW, CW, CCW directions for a total of 3 mechanical cycles.

Load points 8 and 9 are the same for connection equal to the pipe body in compression.

^a Small-sized numbers are load points.

Figure 16 — Test Series B load paths with bending for connection rated equal to pipe body

- 1 100 % VME pipe body yield envelope
- 2 95 % VME pipe body yield envelope
- 3 recommended intermediate load step between steps 1 and 2

a Small-sized numbers are load points.

7.3.5 Test Series C — Thermal cycling tests with tension and internal pressure (tubing and casing)

- a) Determine the axial load, T , and internal pressure, p_i , as specified in 5.12.
- b) Perform the test according to instructions in 5.12 and as shown in Figure 10.
- c) Apply five pressure-tension cycles at ambient temperature, i.e. using the internal pressure and tension mechanical cycle procedure as follows which is then repeated four more times:
 - 1) first apply tension T , adjusted to allow for pressure-induced tension;
 - 2) then apply internal gas pressure p_i ;
 - 3) hold the loads for 5 min;

- 4) remove the frame tension to less than 5 % T ;
 - 5) then remove the pressure to less than 20 % p_i .
- d) Heat the specimens in accordance with 5.12.
- e) Anytime during the 60-min thermal hold, the tension and internal pressure specified in f) and g) can be applied.
- f) Apply the axial load T , adjusting the frame load to allow for pressure-induced tension when applicable.
- g) Apply the internal pressure p_i .
- h) Apply five thermal cycles for CAL II and III tubing and casing, as well as CAL IV casing, and 50 thermal cycles for CAL IV tubing in accordance with 5.12.4. For CAL IV tubing with redundant seals tested as specified in Annex J, apply five thermal cycles. For casing, allow the internal pressure and axial load to fluctuate with temperature. For tubing, maintain the tension and internal pressure near constant (within 0 % to – 10 % of T and p_i) during thermal cycling.
- i) Apply five pressure-tension cycles as specified in c) and d) at a temperature of at least 135 °C (275 °F) for CAL II and CAL III or 180 °C (356 °F) for CAL IV.
- j) Repeat thermal cycles as specified in h).
- k) Repeat five pressure-tension cycles as specified in c) at ambient temperature [less than 5 °C above the ambient temperature originally recorded in c)].
- l) Report results on Form C.8.1 or Form C.8.2, summary of observed bubble tube water displacement and Form C.5, connection leak test log sheet.

7.4 Limit load tests

7.4.1 Principle

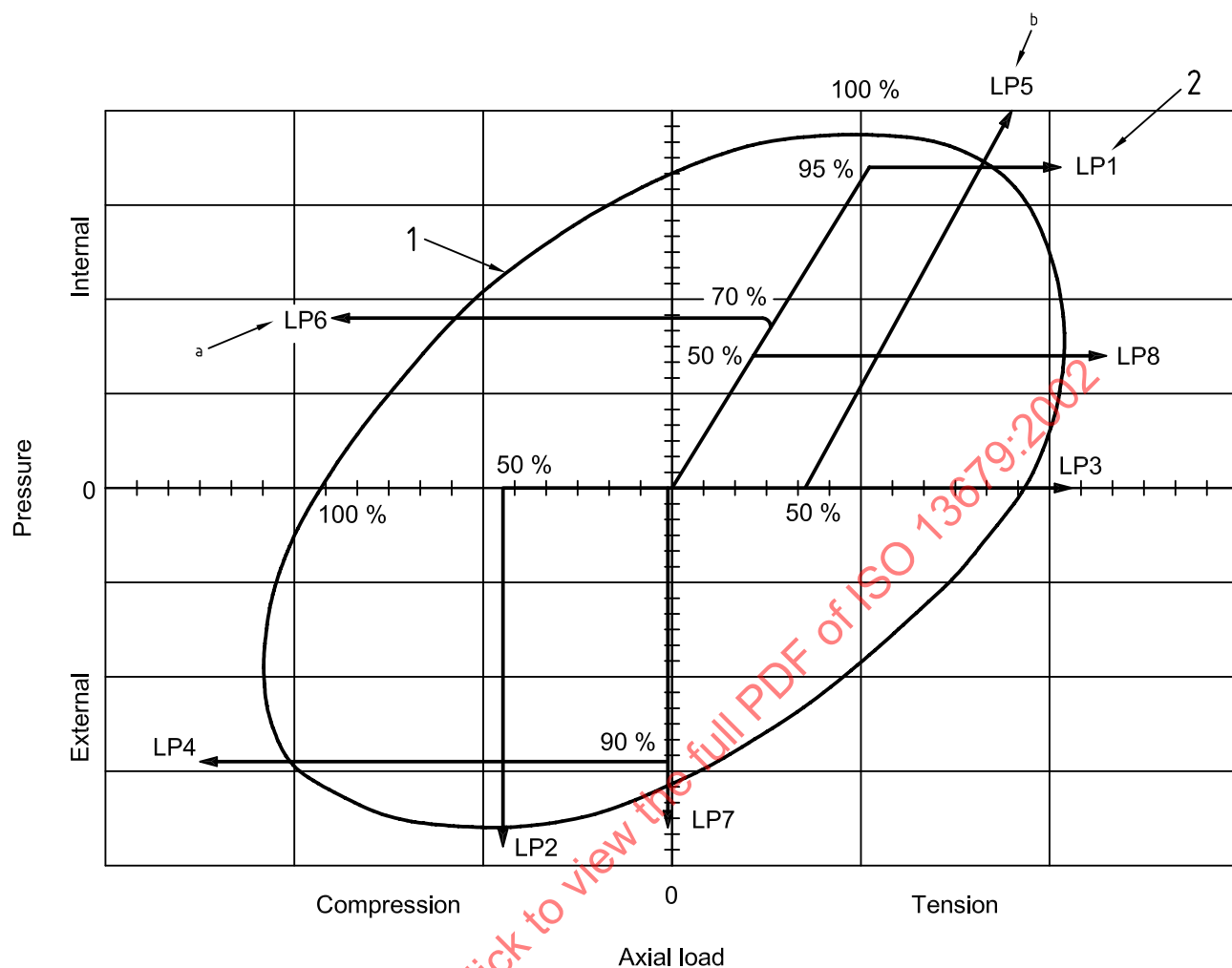
Limit load tests are conducted to establish the structural and sealing limits of the connection. Limit load tests are important for demonstrating connection performance beyond the test load envelope. Limit load tests may also be useful for correlating with finite element analysis data. The results of the limit load tests are used to interpret the connection conformance to the requirements of this International Standard, however the limit load results may necessitate a downward revision to the manufacturer's original limit loads. Specific test paths are specified in 7.5.1 to 7.5.8. Figure 18 shows limit load test paths for a connection rated equal to or stronger than the pipe body for all eight load paths. Figure 19 shows limit load test paths for a connection weaker than the pipe body for all eight load paths.

Limit load pressure tests shall be conducted with either water or oil. After termination of limit load test, measure and record lengths L_A , L_B and L_C on Form C.4. Where applicable, strain gauge data from the pipe-body gauges may also be recorded during limit load tests.

The manufacturer's performance properties data sheet, specified in A.7 and Table A.1, should contain nominal failure loads based on minimum strengths and nominal dimensions. Separate limit loads for each test should contain actual anticipated failure loads, based on actual material strength and actual connection dimensions (see A.9). For direct comparison to measured failure loads, the nominal failure loads may be considered as normalized to actual anticipated failure loads by multiplication with two factors:

- a) the ratio of actual test material strength to minimum material strength;
- b) the ratio of actual to nominal dimensional parameter for the connection under the specific load.

The dimensional parameter for tension and compression loads is the appropriate critical area. For pressure loads, the geometry-dependent portion of the connection pressure resistance is the dimensional parameter.

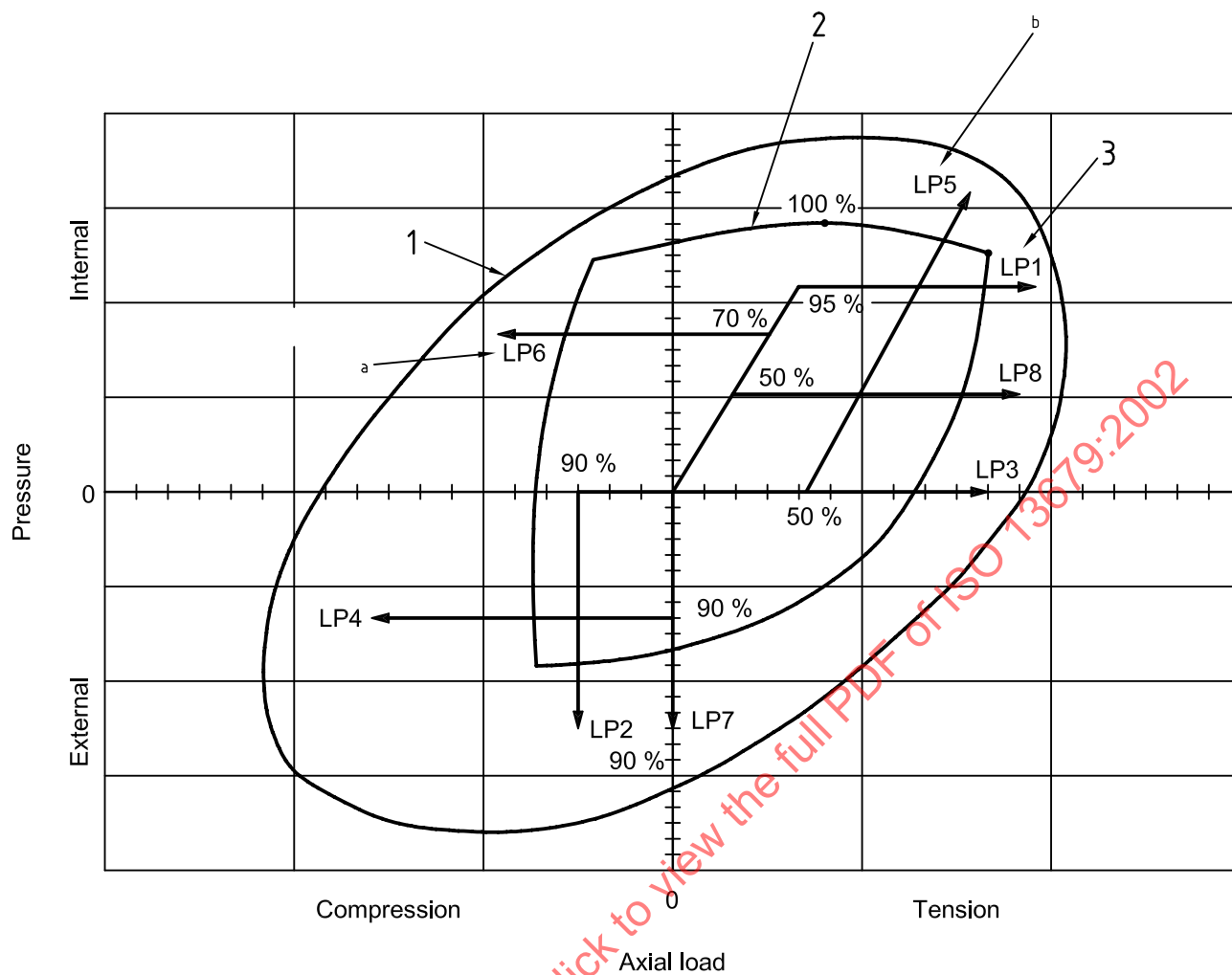
**Key**

- 1 100 % connection test load envelope
- 2 specimen number and load path number

The % in the graph represents % of the connection test load envelope.

- a For CAL II and CAL I, use specimen 2 for LP6.
- b For CAL II, use specimen 4 for LP5.

Figure 18 — Limit load test paths for connections rated equal to or stronger than pipe body



Key

- 1 100 % VME pipe body yield envelope
- 2 100 % connection test load envelope
- 3 specimen number and load path number

The % in the graph represents % of the connection test load envelope.

- a For CAL II and I, use specimen 2 for LP6.
- b For CAL II, use specimen 4 for LP5.

Figure 19 — Limit load test paths for connections weaker than pipe body

7.4.2 Termination of limit load test

The test may be terminated when either

- a) the change in specimen length ($L_A + L_B + L_C$ in Form C.3) exceeds 3 %, or
- b) the change in specimen volume under load exceeds 6 %, or
- c) the specimen leaks continuously.

By agreement between the user, manufacturer and test facility, the tests may be continued beyond a) or b) above to structural failure, which shall be reported as the limit load except when leakage has occurred first. If the specimen leaks continuously, report the load at the beginning of leak as the limit load.

In a test with pressure, if a continuous leak occurs before structural failure, record the pressure and frame load, establish the leak rate in terms of volume or pressure loss per unit time. Structural or leakage failure at the end fixtures gripping the specimen invalidates the test, and the test shall be repeated unless the specimen was at imminent failure indicated by 50 % of the above termination criteria or sufficient gross deformation as agreed between user and manufacturer. If the specimen is undamaged by failure of an end fixture, reuse the specimen and repeat the test. However, if the specimen is damaged by the failure of an end fixture, repeat the test with a new specimen. The new specimen shall be machined to the same conditions as specified in Clause 6. The replacement specimen should be assembled and tested through other sequences prior to failure, and these conditions should fulfil the original specimen objectives as fully as possible, and these conditions and their deviations from original conditions shall be fully documented. These provisions could be appropriate, for example, if a specimen that has undergone round-robin make/break testing did not achieve its limit load test objectives. A replacement specimen shall be baked as specified in Table 1.

7.5 Limit load test path (see Figures 18 and 19)

7.5.1 Test Path 1 — High internal pressure with tension increasing to failure tests

The limit load is determined by Test Path 1 using the following procedure.

- a) Use specimen number as specified in Table 5 (i.e. Specimen Number 1 for CAL IV).
- b) Monitor leakage in the same manner as test load envelope tests (5.8 to 5.11).
- c) Apply an internal pressure to the lesser of:
 - 1) 95 % of the pipe body capped end internal pressure test load; or
 - 2) 95 % of the connection highest internal pressure test load, while maintaining constant pressure and increasing tension to specimen failure.
- d) Report the results of each test on a separate limit loads test data sheet, Form C.4, and include representative photos of the failure in the connection test report.

7.5.2 Test Path 2 — Compression with external pressure increasing to failure tests

The limit load is determined by Test Path 2 using the following procedure.

- a) Use specimen number as specified in Table 5 (i.e. Specimen Number 2 for CAL IV).
- b) Monitor leakage in the same manner as test load envelope tests (5.8 to 5.11).
- c) Apply a compressive axial load to the lesser of:
 - 1) 50 % of the pipe body compression yield load at zero pressure load; or
 - 2) 90 % of the connection axial compression test load at zero pressure load and monitor the specimen displacement while maintaining a constant specimen axial load and applying increasing external pressure to specimen failure.
- d) Report the results of each test on a separate limit loads test data sheet, Form C.4, and include representative photos of the failure in the connection test report.

7.5.3 Test Path 3 — Tension increasing to failure tests

The limit load is determined by Test Path 3 using the following procedure.

- a) Use specimen number as specified in Table 5 (i.e. Specimen Number 3 for CAL IV).
- b) Hold pressure loads at zero, then apply increasing tension to failure.
- c) Report the results of each test on a separate limit loads test data sheet, Form C.4, and include representative photos of the failure in the connection test report.

7.5.4 Test Path 4 — External pressure with compression increasing to failure tests

The limit load is determined by Test Path 4 using the following procedure.

- a) Use specimen number as specified in Table 5 (i.e. Specimen Number 4 for CAL IV).
- b) Monitor leakage in the same manner as test load envelope tests (5.8 to 5.11).
- c) Apply external pressure to the lesser of:
 - 1) 90 % of the pipe body external pressure rating at zero axial load; or
 - 2) 90 % of the connection external pressure rating at zero axial load, while maintaining external pressure constant and applying increasing axial compression to specimen failure.
- d) Report the results of each test on a separate limit loads test data sheet, Form C.4, and include representative photos of the failure in the connection test report.

7.5.5 Test Path 5 — Tension with internal pressure increasing to failure tests

The limit load is determined by Test Path 5 using the following procedure.

- a) Use specimen number as specified in Table 5 (i.e. Specimen Number 5 for CAL IV).
- b) Monitor leakage in the same manner as test load envelope tests (5.8 to 5.11).
- c) Apply machine tension to the lesser of:
 - 1) 50 % of the pipe body yield tension with zero pressure load; or
 - 2) 50 % of the connection axial tension service load at zero pressure load while maintaining machine tension constant and increasing internal pressure to specimen failure.
- d) Report the results of each test on a separate limit loads test data sheet, Form C.4, and include representative photos of the failure in the connection test report.

7.5.6 Test Path 6 — Internal pressure with compression increasing to failure tests

The limit load is determined by Test Path 6 using the following procedure.

- a) Use specimen number as specified in Table 5 (i.e. Specimen Number 6 for CAL IV).
- b) Monitor leakage in the same manner as services load envelope tests (5.8 to 5.11).
- c) Apply internal pressure to the lesser of:
 - 1) 70 % of the pipe body capped end internal pressure test load; or

- 2) 70 % of the connection highest internal pressure test load while maintaining internal pressure constant and applying increasing axial compression to specimen failure.
- d) Report the results of each test on a separate limit loads test data sheet, Form C.4, and include representative photos of the failure in the connection test report.

7.5.7 Test Path 7 — External pressure increasing to failure tests

The limit load is determined by Test Path 7 using the following procedure.

- a) Use specimen number as specified in Table 5 (i.e. Specimen Number 7 for CAL IV.)
- b) Monitor leakage in the same manner as test load envelope tests (5.8 to 5.11)
- c) Hold axial load at zero and apply increasing external pressure to specimen failure.
- d) Report the results of each test on a separate limit loads test data sheet, Form C.4, and include representative photos of the failure in the connection test report.

7.5.8 Test Path 8 — Low internal pressure with tension increasing to failure tests

The limit load is determined by Test Path 8 using the following procedure.

- a) Use specimen number as specified in Table 5. (i.e. Specimen Number 8 for CAL IV).
- b) Monitor leakage in the same manner as test load envelope tests (5.8 to 5.11).
- c) Apply an internal pressure to the lesser of:
 - 1) 50 % of the pipe body capped end internal pressure test load; or
 - 2) 50 % of the connection highest internal pressure test load while maintaining constant pressure and increasing tension to specimen failure.
- d) Report the results of each test on a separate limit loads test data sheet, Form C.4, and include representative photos of the failure in the connection test report.

8 Acceptance criteria

8.1 Make-up and break-out tests

Make-up and break-out tests are considered acceptable if they comply with the following.

- a) Make-up and break-out tests are considered successful if no galling is observed or if repairable damage meeting the manufacturer's repair criteria is observed and repaired, and the connector performs without leakage.
- b) Any galling or other nonconformities shall be reported.
- c) Light and moderate galling on thread and/or seal within the scope of manufacturer's field repair recommendations may be repaired in accordance with such recommendations. After such repair, testing may be continued.
- d) Except for light and moderate galling as discussed above, galling is not acceptable. Any severe galling shall be evaluated for its cause. Galling evaluation has to demonstrate that the cause of galling was other than from the design. If it can be proven that the cause was other than design, a minimum of two replacement specimens of the previous type shall be re-tested through the make-break sequence to

confirm acceptance and a single specimen through sealing and limit load tests. If the galling problem cannot be resolved, testing shall be terminated.

8.2 Test load envelope tests

8.2.1 General

Test load envelope tests are considered successful if pressure sealing requirements stated herein are met and no structural failure occurs.

8.2.2 Internal pressure sealing

Sealing tests are considered successful:

- a) if loads remain stable during hold periods;
- b) if the leak rate of $1 \times 10^{-3} \text{ cm}^3/\text{s}$ (equivalent to $3,6 \text{ cm}^3/\text{h}$) is not exceeded, which can be measured in intervals of up to 15 min ($q_{\text{max}} = 0,9 \text{ cm}^3/15 \text{ min}$);
- c) if the leak rate does not have a tendency to increase.

The leak rate is determined by the measured leak volume collected over the testing hold time divided by the hold time and can be measured in intervals of up to 15 min. The leaked volume of $0,9 \text{ cm}^3/15 \text{ min}$ period corresponds to $1 \times 10^{-3} \text{ cm}^3/\text{s}$.

8.2.3 External pressure sealing

Sealing tests are considered successful:

- a) if loads remain stable during hold periods;
- b) if the leak rate of $1 \times 10^{-3} \text{ cm}^3/\text{s}$ (equivalent to $3,6 \text{ cm}^3/\text{h}$) is not exceeded, which can be measured in intervals of up to 15 min ($q_{\text{max}} = 0,9 \text{ cm}^3/15 \text{ min}$);
- c) if the leak rate does not have a tendency to increase over time.

The leak rate is determined by the measured leak volume collected over the testing hold time divided by the hold time and can be measured in intervals of up to 15 min. The leaked volume of $0,9 \text{ cm}^3/15 \text{ min}$ period corresponds to $1 \times 10^{-3} \text{ cm}^3/\text{s}$.

Leak detection in external pressure tests is recognized as more difficult and less exact than internal pressure tests. Indirect objective evidence equivalent to the required maximum leak rate is acceptable for external pressure tests.

8.3 Limit load tests

A limit load test further validates the connection test load envelope provided:

- a) the end of the test as defined in 7.4 is reached;
- b) the limit load established is a load greater than the manufacturer's test load envelope, based on actual material strength and actual connection dimensions.

9 Test reports

Two test reports shall be prepared documenting the connection tested and the test results. The full detailed test report is specified in Annex D. A shorter summary test report is specified in Annex E. The emphasis in the summary test report is on compact presentation of data for broader distribution so that a connection purchaser may

- a) fully specify in a purchasing document the connection tested,
- b) make up the connection properly, and
- c) have confidence in the connection's performance and be aware of its limitations.

The test data provide objective evidence of validation of the connection test load envelope and failure limit loads.

The connection manufacturer shall maintain copies of test results as long as the connection is offered to the industry by the manufacturer. The test results shall be assembled into a test report as follows. All photographs specified by this International Standard shall include identification of significant items shown in the photographs and be included in the test report. Test reports may be filed for public access with a national standards body.

Annex A (normative)

Connection geometry and performance data sheet

A.1 General considerations

The connection manufacturer shall provide the information on Table A.1 describing the connection geometry and performance data at the beginning of any testing.

A.2 Connection geometry

The connection manufacturer shall provide a detailed description listing the design features and benefits of the threads, seals, shoulders, and body configuration (see Table A.1).

A.3 Diagram

The connection manufacturer shall provide a representative cross-sectional diagram of the connection identifying the critical planes for tension, compression, internal pressure, external pressure and bending (see Table A.1).

A.4 Connection manufacturing specification

The connection manufacturer shall provide a process control plan which details all applicable specifications and procedures, with the associated control numbers and revision levels necessary for all manufacture and inspection of the product (see Table A.1).

A.5 Make-up parameters

The connection manufacturer shall document complete make-up parameters listing the thread compound type, coverage, and application method, along with the make-up speed, required shoulder torque values, and minimum and maximum final torque values and make-up loss. This document shall have a control procedure and revision level and be listed in the manufacturer's process control plan (see Table A.1).

A.6 Connection repair

The connection manufacturer shall provide a complete description of connection repair and methodology for repair and include procedure number and revision number (see Table A.1).

A.7 Performance properties data sheet

The connection manufacturer shall provide a connection performance properties data sheet in terms of tension, compression, internal pressure, external pressure and bending relative to the pipe body (see Table A.1).

A.8 Test load envelope

The manufacturer shall fully quantify the test load envelope for the connection so that test loads can be efficiently derived to account for the actual properties of the test specimens relative to the minimum properties usually assumed for ratings (refer to 7.3 and to B.4 and B.5). Example test load envelopes in tabular and graphic form are provided in Table A.2 and Figure A.1 for a connection rated equal to the pipe body. See also Table A.3.

A.9 Limit loads

The manufacturer should quantify the limit loads for connections so that test loads can be efficiently derived to account for the actual properties of the test specimens relative to the minimum properties usually assumed for ratings. Manufacturers should indicate anticipated failure loads.

Table A.1 — Connection geometry and performance property data sheet

A.1 Identification				
Product description	Size, mass (label: weight)	Wall thickness	Grade	Product name
Coupling grade (if different from the pipe body)				
Connection application level (CAL) to which test is performed				
A.2 Connection geometry				
A.3 Diagram: (Attach separate page(s) with schematic cross-sectional diagram)				
A.4 Connection manufacturing specifications				
Provide complete documentation detailing all of the applicable specifications and procedures, with the associated control numbers and revision levels necessary for all manufacture, inspection and installation of the product. At a minimum, the following information shall be provided:				
Process control plan No. (attach copy)		Revision No./Date		
Pin drawing No.		Revision No./Date		
Box drawing No.		Revision No./Date		
Pin thread drawing No.		Revision No./Date		
Box thread drawing No.		Revision No./Date		
Seal ring drawing No.		Revision No./Date		
Pin surface treatment/type specification No.		Revision No./Date		
Box surface treatment/type specification No.		Revision No./Date		
Gauge calibration procedure No.		Revision No./Date		
Gauging and inspection procedures No.		Revision No./Date		
Seal ring inspection procedure No.		Revision No./Date		
Swage/stress relief procedure No.		Revision No./Date		
Mill coupling/accessory make-up procedure No.		Revision No./Date		
Field running procedure No.		Revision No./Date		
First article/last article procedure No.		Revision No./Date		
Field connection repair procedure No.		Revision No./Date		
A.5 Make-up parameters procedure No.		Revision No./Date		
A.6 Connection repair procedure No.		Revision No./Date		
A.7 Performance properties data sheet document No. (attach copy)		Revision No./Date		
A.8 Test load envelope document No. (attach copy)		Revision No./Date		
A.9 Limit loads document No. (attach copy)		Revision No./Date		

Table A.2 — Example Series A test load envelope for a connection rated equal to pipe body — 178 mm $D \times 10,16$ mm wall thickness $\times$ grade P-110 (7 in 29 lb/ft P-110) strength (see Figure A.1)

Load point	Axial load			Pressure + $p_i - p_o$		
	% yield	kN	(kips)	MPa	(psi)	
1	95	4 048	(910)	0,0	(0)	95 % Internal yield VME
2	95	4 048	(910)	70,8	(10 263)	
3	80	3 409	(766)	84,8	(12 302)	
4	CEYP	1 833	(412)	94,1	(13 653)	
5	0	0	(0)	85,7	(12 436)	
6	– 33	– 1 406	(– 316)	69,1	(10 016)	
7	– 67	– 2 855	(– 642)	41,8	(6 068)	
8 and 9	– 95	– 4 048	(– 910)	0,0	(0)	100 % Collapse
10	– 95	– 4 048	(– 910)	– 57,5	(– 8 334)	
11	– 95	– 4 048	(– 910)	– 57,5	(– 8 334)	
12	0	0	(0)	– 57,5	(– 8 334)	
13	33	1 406	(316)	– 50,6	(– 7 339)	
14	67	2 855	(642)	– 36,1	(– 5 243)	
			SI Units	(USC Units)		
Specified D =			177,8 mm	(7.000 in)		
Actual minimum wall thickness =			10,16 mm	(0.400 in)		
D_i based on actual minimum wall thickness =			157,48 mm	(6.200 in)		
Pipe cross-section area =			53,51 cm ²	(8.294 in ²)		
Actual average D_i =			157,0 mm	(6.180 in)		
Actual internal pressure end load =			$0,019\ 4 \times p_i$, kN	[(29.996 $\times p_i$ /1 000) kips]		
Actual pipe minimum yield strength =			796,3 MPa	(115 500 psi)		
Actual pipe body yield =			4 261 kN	(958 kips)		
NOTE 1 kip = 1 000 lbf (pound-force) and 1 kip = 4,448 kN.						

Table A.3 — Detailed load steps

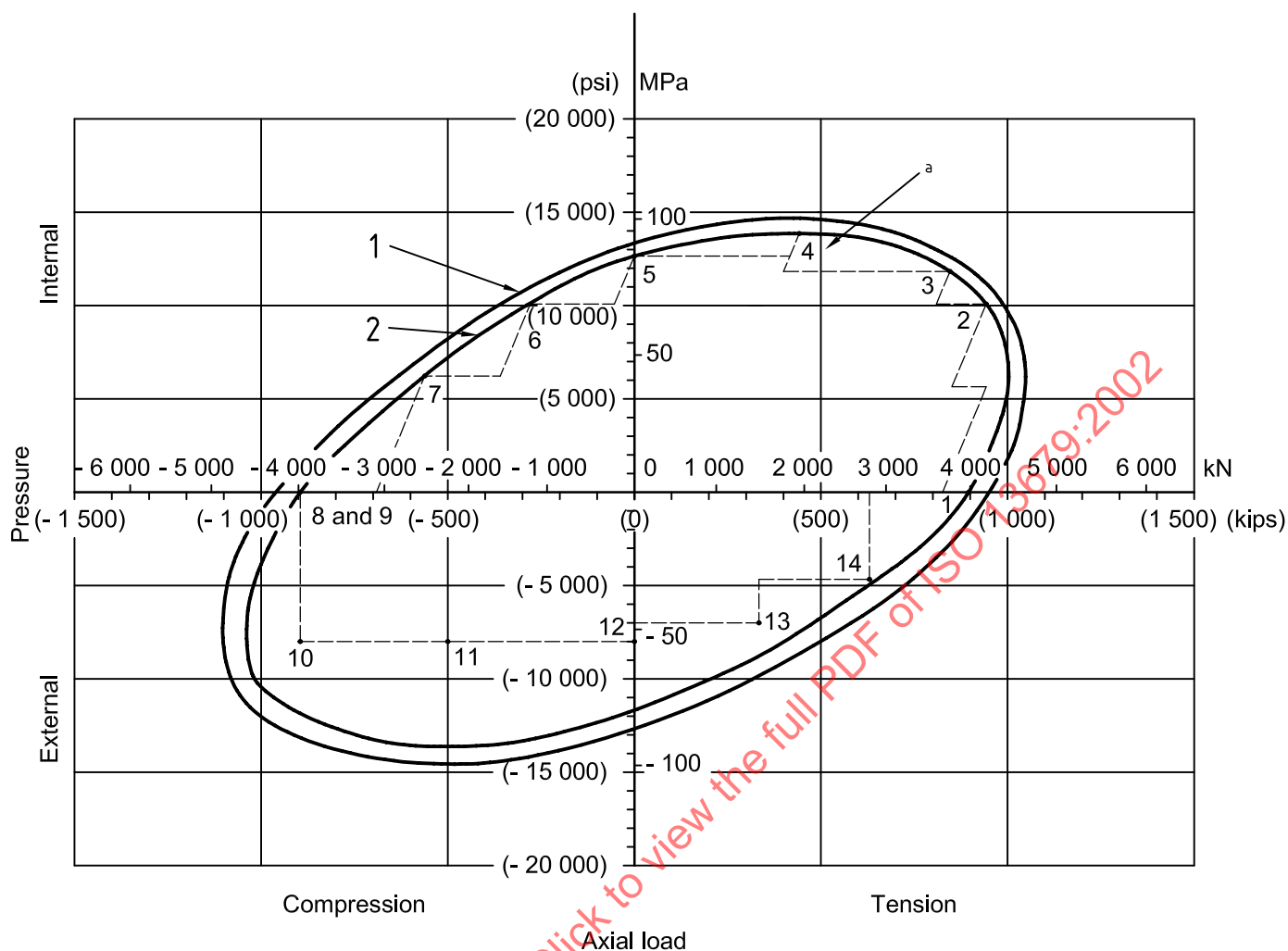
Direction around VME curve	Load step ^a	VME load point	Axial load		Frame load		Pressure, + $p_i - p_o$		Hold time min
			SI units	(USC units)	SI units	(USC units)	SI units	(USC units)	
			kN	(kips)	kN	(kips)	MPa	(psi)	
CCW	1	1	4 048	(910)	4 048	(910)	0,0	(0)	5
	2	—	3 363	(756)	3 363	(756)	0,0	(0)	—
	3	—	4 048	(910)	3 363	(756)	35,4	(5 132)	—
	4	—	3 363	(756)	2 678	(602)	35,4	(5 132)	—
	5	2	4 048	(910)	2 678	(602)	70,8	(10 263)	60
	6	—	3 136	(705)	1 766	(397)	70,8	(10 263)	—
	7	3	3 407	(766)	1 766	(397)	84,8	(12 302)	15
	8	—	1 641	(369)	0	(0)	84,8	(12 302)	—
	9	4	1 833	(412)	0	(0)	94,1	(13 653)	15
	10	—	1 659	(373)	0	(0)	85,7	(12 436)	—
	11	5	0	(0)	– 1 659	(– 373)	85,7	(12 436)	15
	12	—	– 0 325	(– 73)	– 1 659	(– 373)	69,1	(10 016)	—
	13	6	– 1 406	(– 316)	– 2 744	(– 617)	69,1	(10 016)	15
	14	—	– 1 935	(– 435)	– 2 744	(– 617)	41,8	(6 068)	—
	15	7	– 2 811	(– 632)	– 3 621	(– 814)	41,8	(6 068)	15
	16	—	– 3 621	(– 814)	– 3 621	(– 814)	0,0	(0)	—
	17	8 and 9	– 4 048	(– 910)	– 4 048	(– 910)	0,0	(0)	5
	18	—	0	(0)	0	(0)	0,0	(0)	—
	Switch from internal pressure to external pressure								
	19	—	– 4 048	(– 910)	– 4 048	(– 910)	0,0	(0)	—
	20	10	– 4 048	(– 910)	– 4 048	(– 910)	– 57,5	(– 8 334)	15
	21	11	– 2 131	(– 479)	– 2 131	(– 479)	– 57,5	(– 8 334)	15
	22	12	0	(0)	0	(0)	– 57,5	(– 8 334)	15
	23	—	0	(0)	0	(0)	– 50,6	(– 7 339)	—
	24	13	1 406	(316)	1 406	(316)	– 50,6	(– 7 339)	15
	25	—	1 406	(316)	1 406	(316)	– 36,1	(– 5 243)	—
	26	14	2 856	(642)	2 856	(642)	– 36,1	(– 5 243)	15
	27	—	2 856	(642)	2 856	(642)	0,0	(0)	—
	28	1	4 048	(910)	4 048	(910)	0,0	(0)	5
CW	29	—	2 856	(642)	2 856	(642)	0,0	(0)	—
	30	14	2 856	(642)	2 856	(642)	– 36,1	(– 5 243)	15
	31	—	1 406	(316)	1 406	(316)	– 36,1	(– 5 243)	—
	32	13	1 406	(316)	1 406	(316)	– 50,6	(– 7 339)	15
	33	—	0	(0)	0	(0)	– 50,6	(– 7 339)	—
	34	12	0	(0)	0	(0)	– 57,5	(– 8 334)	15
	35	11	– 2 131	(– 479)	– 2 131	(– 479)	– 57,5	(– 8 334)	15
	36	10	– 4 048	(– 910)	– 4 048	(– 910)	– 57,5	(– 8 334)	15
	37	—	– 4 048	(– 910)	– 4 048	(– 910)	0,0	(0)	—
	38	—	0	(0)	0	(0)	0,0	(0)	—

Table A.3 (continued)

Direction around VME curve	Load step ^a	VME load point	Axial load		Frame load		Pressure, + $p_i - p_o$		Hold time
			SI units	(USC units)	SI units	(USC units)	SI units	(USC units)	
			kN	(kips)	kN	(kips)	MPa	(psi)	min
CCW	Switch from external pressure to internal pressure								
	39	—	2 678	(602)	2 678	(602)	0,0	(0)	—
	40	2	4 048	(910)	2 678	(602)	70,8	(10 263)	15
	41	—	3 136	(705)	1 766	(397)	70,8	(10 263)	—
	42	3	3 407	(766)	1 766	(397)	84,8	(12 302)	15
CW	43	—	1 766	(397)	1 766	(397)	0,0	(0)	—
	44	8 and 9	– 4 048	(– 910)	– 4 048	(– 910)	0,0	(0)	5
	45	—	– 3 621	(– 814)	– 3 621	(– 814)	0,0	(0)	—
	46	7	– 2 811	(– 632)	– 3 621	(– 814)	41,8	(6 068)	15
	47	—	– 1 935	(– 435)	– 2 744	(– 617)	41,8	(6 068)	—
	48	6	– 1 406	(– 316)	– 2 744	(– 617)	69,1	(10 016)	15
	49	—	– 0 325	(– 73)	– 1 659	(– 373)	69,1	(10 016)	—
	50	5	0	(0)	– 1 659	(– 373)	85,7	(12 436)	15
	51	—	1 659	(373)	0	(0)	85,7	(12 436)	—
	52	4	1 833	(412)	0	(0)	94,1	(13 653)	15
	53	—	1 641	(369)	0	(0)	84,8	(12 302)	—
	54	3	3 407	(766)	1 766	(397)	84,8	(12 302)	15
	55	—	3 136	(705)	1 766	(397)	70,8	(10 263)	—
	56	2	4 048	(910)	2 678	(602)	70,8	(10 263)	15
	57	—	3 363	(756)	2 678	(602)	35,4	(5 132)	—
	58	—	4 048	(910)	3 363	(756)	35,4	(5 132)	—
	59	—	3 363	(756)	3 363	(756)	0,0	(0)	—
	60	1	4 048	(910)	4 048	(910)	0,0	(0)	5
	CCW	61	—	3 363	(756)	3 363	(756)	0,0	(0)
62		—	4 048	(910)	3 363	(756)	35,4	(5 132)	—
63		—	3 363	(756)	2 678	(602)	35,4	(5 132)	—
64		2	4 048	(910)	2 678	(602)	70,8	(10 263)	15
65		—	3 136	(705)	1 766	(397)	70,8	(10 263)	—
66		3	3 407	(766)	1 766	(397)	84,8	(12 302)	15
67		—	1 641	(369)	0	(0)	84,8	(12 302)	—
68		4	1 833	(412)	0	(0)	94,1	(13 653)	15
69		—	1 659	(373)	0	(0)	85,7	(12 436)	—
70		5	0	(0)	– 1 659	(– 373)	85,7	(12 436)	15
71		—	– 0 325	(– 73)	– 1 659	(– 373)	69,1	(10 016)	—
72		6	– 1 406	(– 316)	– 2 744	(– 617)	69,1	(10 016)	60

Table A.3 (continued)

Direction around VME curve	Load step ^a	VME load point	Axial load		Frame load		Pressure, + $p_i - p_o$		Hold time
			SI units	(USC units)	SI units	(USC units)	SI units	(USC units)	
			kN	(kips)	kN	(kips)	MPa	(psi)	
CCW	73	—	– 1 935	(– 435)	– 2 744	(– 617)	41,8	(6 068)	—
	74	7	– 2 811	(– 632)	– 3 621	(– 814)	41,8	(6 068)	15
	75	—	– 3 621	(– 814)	– 3 621	(– 814)	0,0	(0)	—
	76	8 and 9	– 4 048	(– 910)	– 4 048	(– 910)	0,0	(0)	5
	77	—	0	(0)	0	(0)	0,0	(0)	—
	Switch from internal pressure to external pressure								
	78	—	– 4 048	(– 910)	– 4 048	(– 910)	0,0	(0)	15
	79	10	– 4 048	(– 910)	– 4 048	(– 910)	– 57,5	(– 8 334)	15
	80	11	– 2 131	(– 479)	– 2 131	(– 479)	– 57,5	(– 8 334)	60
	81	12	0	(0)	0	(0)	– 57,5	(– 8 334)	15
CCW	82	—	0	(0)	0	(0)	– 50,6	(– 7 339)	—
	83	13	1 406	(316)	1 406	(316)	– 50,6	(– 7 339)	60
	84	—	1 406	(316)	1 406	(316)	– 36,1	(– 5 243)	—
	85	14	2 856	(642)	2 856	(642)	– 36,1	(– 5 243)	15
	86	—	2 856	(642)	2 856	(642)	0,0	(0)	—
	87	—	0	(0)	0	(0)	0,0	(0)	—
CW	Switch from external pressure to internal pressure								
	88	1	4 048	(910)	4 048	(910)	0,0	(0)	5
	89	—	3 363	(756)	3 363	(756)	0,0	(0)	—
	90	—	4 048	(910)	3 363	(756)	35,4	(5 132)	—
	91	—	3 363	(756)	2 678	(602)	35,4	(5 132)	—
	92	2	4 048	(910)	2 678	(602)	70,8	(10 263)	60
	93	—	2 678	(602)	2 678	(602)	0,0	(0)	—
	94	—	0	(0)	0	(0)	0,0	(0)	—
End of test									
^a Load step numbers are for the test operator and do not correspond to Table 6.									



Key

- 1 100 % VME pipe body yield envelope
- 2 95 % VME pipe body yield envelope body (178 mm $D \times 10,16$ mm wall thickness $\times$ grade P-110)
- ^a Small-sized numbers are load points.

Figure A.1 — Example series A test load envelope for a connection rated equal to pipe body [178 mm $D \times 10,16$ mm wall thickness $\times$ grade P-110 (7 in 29 lb/ft P-110)]

Annex B (informative)

Connection test load envelope and limit loads

B.1 General considerations

It is the manufacturer's responsibility to fully define the test load envelope for his product(s). The test load envelopes should be defined as shown in Annex A. In the event that a manufacturer fails to define the test load envelope, this annex may be used as a means by which a user could estimate the test load envelope using a connection performance model based on rating capacities of specific critical cross-sections in the connection.

It is also the manufacturer's responsibility to fully, or as completely as possible, define the limit loads for his product(s). If the manufacturer elects not to estimate the limit loads, ISO 13679 is designed to provide objective information regarding the limit loads. No equations have been included to estimate the limit loads as these remain under current industry study.

Application of the information given in this annex is optional. However, if this annex is adopted as the basis for a connection test programme, adherence shall be made to the provisions (see the Introduction for the meaning of verbal forms in provisions) contained herein.

B.2 Basic principles

B.2.1 Introduction of critical cross-section connection model

Casing and tubing connections can be considered as concentrically layered mechanisms used to join lengths of pipe to form a casing or tubing string. Connections consist of threads, seals and/or shoulders on a body member. Connections can vary widely in design and function.

Casing and tubing strings are usually suspended and/or cemented in the well-bore and are subject to five distinct types of primary loads:

- a) fluid pressure — internal and/or external;
- b) axial force — tension or compression;
- c) bending — buckling and/or well-bore deviation;
- d) torsion — make-up and rotation;
- e) non-axisymmetric — area, line or point contact.

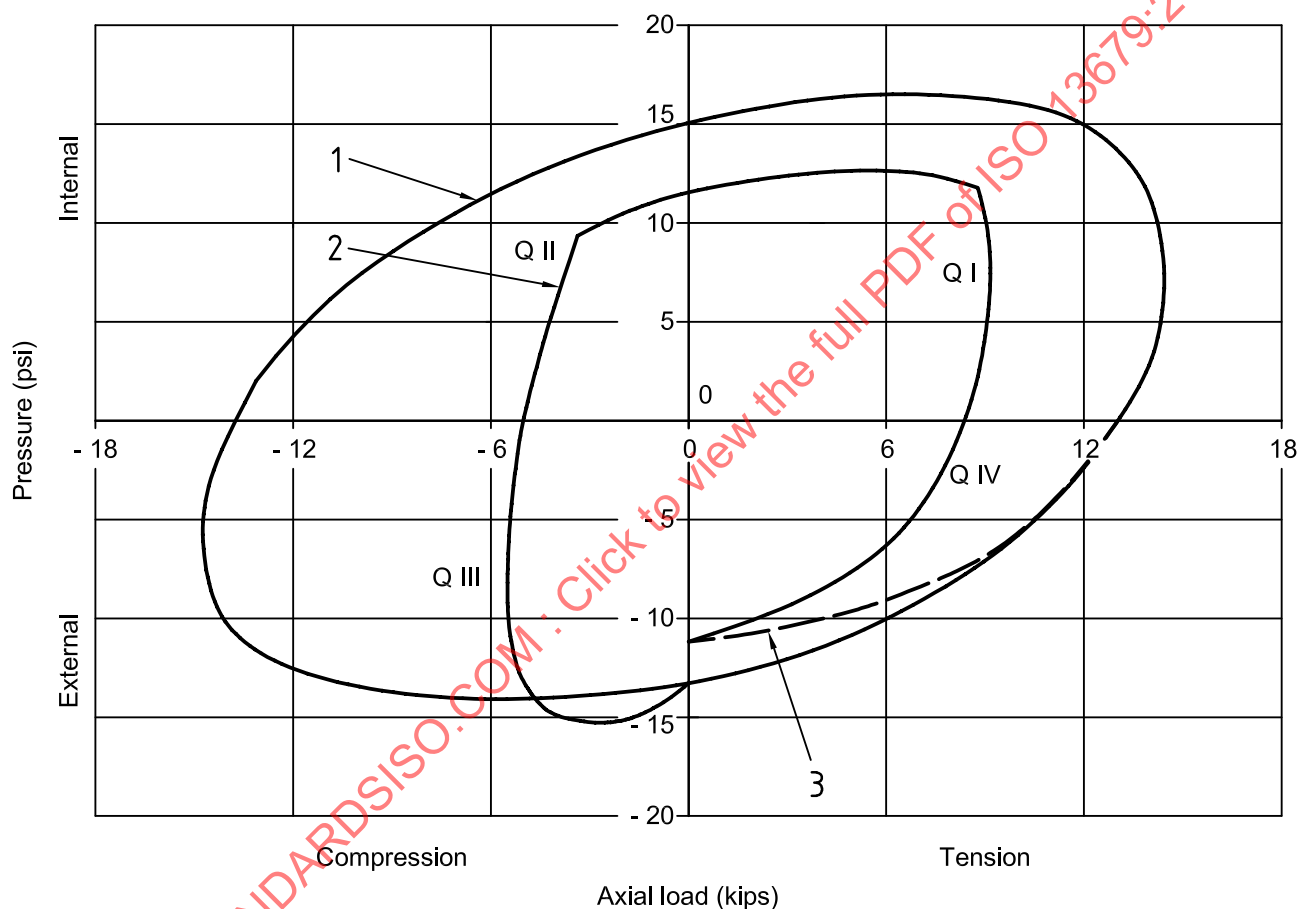
This International Standard only addresses the first three loading modes, which are primary in essentially all wells. The pipe body, as well as the casing or tubing connection, has to successfully withstand (contain and/or transmit) these loads in service.

The test load envelope of a pipe body can be mathematically defined as the various combinations of loads that produce a von Mises equivalent (VME) stress intensity in the pipe body equivalent to the tensile axial yield strength of the material. Similarly, the test load envelope of a connection can be defined as the various combinations of loads that define the sealing (pressure) integrity and structural capacity limits, in which the connection can cyclically operate.

A test load envelope consists of four quadrants:

- Quadrant I: axial tension plus internal pressure with possible bending;
- Quadrant II: axial compression plus internal pressure with possible bending;
- Quadrant III: axial compression plus external pressure with possible bending;
- Quadrant IV: axial tension plus external pressure with possible bending;

An example of the test load envelope of the pipe body and a connection is provided in Figure B.1.



Key

- 1 100 % VME pipe body yield envelope
- 2 100 % connection test load envelope
- 3 100 % API collapse

Efficiency: 0,64 tension; 0,38 compression

NOTE The numbers are illustrative and do not indicate units.

Figure B.1 — Pipe body and connection test load envelopes at specified dimensions

B.2.2 Von Mises equivalent (VME) stress intensity

The peak VME stress intensity under axial and pressure loads always occurs at the inside surface of the member in the absence of bending. With added moderate to severe bending, depending on the specific diameter and wall thickness of the member, the peak VME stress intensity can occur at the outside surface. See B.5 for determining the combination of axial, pressure and bending loads above which the peak VME stress intensity will occur at the outside surface of the member (pipe body or connection; pin or box member).

Depending on the specific design of the connection, both performance (load capacity) and geometry (shape) can vary substantially from that of a pipe body, which is a cylinder. As a result, connections can have a test load envelope either more or less than the pipe body.

B.2.3 The connection test load envelope

The connection test load envelope defines the bounds of the combinations of loads (axial, pressure and bending) within which the connection will maintain its structural and sealing integrity on a cyclical load basis. At loads beyond the test load envelope, damage can occur to the connection, resulting in loss of structural and/or sealing integrity either during a subsequent load reversal, i.e. a cyclic load or an increase in any load component (i.e. a monotonic load).

B.2.4 Connection limit loads and failure loads

The limit of the loads at which a loss in the structural and/or sealing integrity occurs in the connection can be defined as the limit loads. Depending on the specific characteristics of a connection, the limit load may also be the failure load.

The limit loads of a connection can also be more or less than the pipe body. Furthermore, a connection can be sensitive to one type of load, with a capacity substantially less than the pipe body, yet exhibit a load resistance substantially greater than the pipe body in a different loading mode. These factors have to be considered in establishing the test and limit loads of the connection.

B.2.5 The pipe string test load envelope

The test load envelope of a pipe string (the pipe body and the connection combined), is the minimum combination of loads (axial, pressure and bending), within which cyclical pressure and structural integrity is maintained, as limited by the VME stress intensity of the pipe body or in the connection. The pipe string test load envelope is further limited to the biaxial collapse resistance of the pipe body as defined by the equations in ISO 10400 or API Bul 5C3 for the external pressure quadrants III and IV.

The limit loads of a pipe string is the minimum combination of loads (axial, pressure and bending), which results in the loss of sealing integrity or a structural failure (axial separation, rupture or collapse) of the pipe body or connection, i.e. the casing or tubing string.

B.3 Performance properties and dimensions required for the calculation of the elastic test load envelope

B.3.1 Performance properties

The performance properties, i.e. ratings, and their base equations, of the pipe body and standardized connections, and the dimensions of standardized connections, are provided in ISO 10400 or API Bul 5C3 and ISO 10422 or API Spec 5B. However, complete performance properties (ratings) and their base equations, if any, may not be publicly available for proprietary connections.

B.3.2 Areas and dimensions

The critical cross-sectional areas and dimensions required for the calculation of the elastic test envelope in accordance with Annex B are shown in Table B.1.

Table B.1 — Areas and dimensions

Component of pipe string or test load envelope	Dimensions required (see 7.3.1)	Abbreviation	Value for calculation ^a
Pipe body	Outside diameter (specified or actual) Wall thickness Internal diameter (calculated)	D_o t D_i	
Quadrant I: tension and internal pressure	Critical cross-sectional area in tension Corresponding diameter on which the internal pressure acts Corresponding wall thickness on which the internal pressure acts Internal diameter (calculated)	A_p D_o t D_i	
Quadrant II: compression and internal pressure	Critical cross-sectional area in compression Corresponding diameter on which the internal pressure acts Corresponding wall thickness on which the internal pressure acts Internal diameter (calculated)	A_p D_o t D_i	
Quadrant III: compression and external pressure	Critical cross-sectional area in compression Corresponding diameter on which the external pressure acts Corresponding wall thickness on which the external pressure acts Internal diameter (calculated)	A_p D_o t D_i	
Quadrant IV: tension and external pressure	Critical cross-sectional area in tension Corresponding diameter on which the external pressure acts Corresponding wall thickness on which the external pressure acts Internal diameter (calculated)	A_p D_o t D_i	
NOTE There may be more than one (1) critical cross-section per quadrant, especially in connections with load capacities less than the pipe body for axial and/or pressure loads.			
^a To be inserted by the user.			

B.4 Requirements

B.4.1 General

Establish the connection geometry, test load envelope and performance data prior to testing in accordance with 4.1.

B.4.2 Test load envelope

The manufacturer of the proprietary connection to be tested should provide a complete test load envelope and limit loads for the connection at all combinations of pressures (i.e. internal and external) and axial loads, tension and compression. Furthermore, the manufacturer should provide the adjustments to the envelopes required for bending.

The form of the test load envelope and limit loads shall be provided in one of the following forms:

- a) connection rating equation(s);
- b) tabular numeric data; or
- c) graphic representation with intercept and crossover values.

It is critical that the combined load capacity described by the test load envelope be precisely defined near and throughout the conditions where the dominant load sensitivity of the connection may change from pressure to axial and/or bending or vice versa. Connection rating equations, whether analytically or experimentally based, shall completely define the test load envelope for all combinations of pressure and axial force and the combined effect of bending. The form of the rating equation should facilitate the calculation of the pressure value given the axial load, with or without bending.

Since casing and tubing connection designs and the resultant test load envelopes can vary widely, no overall requirement for the minimum number of values in a tabular data format can be mandated. However, if a connection design exhibits changes in load sensitivities, the loads at which the changes in load sensitivity occur shall be unambiguously provided.

Approximately ten (10) combined load values of pressure and axial force per quadrant for a specific bending condition should be sufficient to define the test load envelope and limit loads.

The test and limit loads may also be represented graphically provided numerical values are also listed for the pressure and axial force intercepts and at all discontinuities in the performance envelopes.

B.4.3 Alternate test load envelope

In the absence of a test load envelope B.4.1, the test load envelope can be established by the procedures outlined in B.5.

B.4.4 Limit loads

The development of a limit load prior to limit load testing is not a requirement of this International Standard.

B.5 Calculation of the test load envelopes

B.5.1 General

In the calculation of both pipe body load capacities and critical connection cross-section capacities, it is the intent of this International Standard to test the specimens to as high a load or combination of loads as safely practical. In view of this objective, the following variable definitions for load calculation and TLE and LL

normalization (to minimum service TLE and LL) guidelines should be applied to each specimen. Yield strength, outside diameter and minimum wall thickness shall be the same as specified in 7.3.1.

B.5.2 Pipe body test load envelope

B.5.2.1 General

A VME load capacity envelope is three-dimensional. To facilitate plotting the VME diagram, it is necessary to normalize the hoop stress (internal/external pressure) as if the corresponding external or internal pressure were zero. In other words, for any combination of p_i and p_o , an equivalent p_i and p_o has to be calculated which yields the same hoop stress as if the corresponding p_o and p_i were zero. Otherwise, an infinite number of VME plots would be required, one for each specific p_i and p_o . As a result of the foregoing, a discontinuity in the VME equation exists at the zero pressure axial force coordinate. In other words, Quadrants I and II require different constituent VME equations (σ_h and σ_r) than Quadrants III and IV. See Reference [2] for further treatment of this subject. The pressure normalization equations are listed in B.5.3.

B.5.2.2 Uniaxial pipe body test load envelope values

Calculate the uniaxial pipe body test load envelope from the following equations.

- a) Axial tension force limit under uniform axial stress

$$F_a = \sigma_y A_p = \sigma_y \pi (D - t) t = \sigma_y \frac{\pi}{4} [D^2 - (D - 2t)^2] \quad (B.1)$$

where

F_a is the axial tension force limit;

σ_y is the defined axial tensile yield strength, normally the ISO/API axial tensile yield strength;

A_p is the cross-sectional area of the pipe body;

D is the specified outside diameter;

t is the specified wall thickness;

π is equal to 3,141 6.

- b) Internal pressure limit for initial yield at the D_i surface

$$p_i = \sigma_t \left[\frac{D^2 - (D - 2t)^2}{D^2 + (D - 2t)^2} \right] \quad (B.2)$$

where

p_i is the internal pressure limit;

σ_t is the defined transverse tensile yield strength if available or otherwise axial tensile yield strength.

- c) Axial compression force limit under uniform axial stress

$$F_a = -\sigma_c A_p = -\sigma_c \pi (D - t) t \quad (B.3)$$

where

F_a is the axial compression force limit;

σ_c is the defined axial compressive yield strength if available or otherwise axial tensile yield strength.

d) External pressure (collapse) at the inside surface

$$p_o = \frac{-\sigma_{tc} \left[D^2 - (D - 2t)^2 \right]}{2D^2} = \frac{-2\sigma_{tc} (D/t - 1)}{(D/t)^2} \quad (\text{B.4})$$

where

p_o is the external pressure limit;

σ_{tc} is the defined transverse compressive yield strength if available or otherwise axial tensile yield strength.

The external pressure limit can be governed by instability factors and not the onset of yielding at the inside surface. Therefore, the collapse resistance external pressure limit of the pipe body at zero axial stress shall be calculated as specified in the method detailed in 1.1 of ISO 10400 or API Bul 5C3 collapse pressure equations.

Proprietary grades of pipe may exhibit collapse resistances greater than calculated by the method given in ISO 10400 or API Bul 5C3. Such values can be used in this procedure.

e) bending at the inside surface, convex or concave side

$$D_{\text{leg}} = \frac{\sigma}{0,060\,156(D - 2t)} \quad (\text{B.5})$$

where

D_{leg} is the bending, expressed in degrees per 30 m, i.e. centreline deviation per unit axial length limited at the inside surface of the pipe;

σ is the defined tensile or compressive yield strength, expressed in newtons per square millimetre (N/mm²), if available, or otherwise longitudinal tensile yield strength, at the inside surface of the pipe;

D is the specified outside diameter, expressed in millimetres;

t is the specified wall thickness, expressed in millimetres.

Bending caused by transverse loads (i.e. three-point bending) is not covered by Equation (B.5).

Since some materials, particularly cold worked CRA pipe (see ISO 13680) can exhibit significant through wall and tensile/compressive variations in mechanical properties, the bending limit may be dictated at the outside or inside surface of the pipe body and on the convex (tensile) or concave (compressive) side of the bend.

B.5.2.3 Pipe body combined loads test load envelope

The combined load test load envelope is calculated by utilizing the von Mises strain energy theory. It states the onset of combined load yielding can be calculated from the individual principal stresses by the following expression. Isotropic material behaviour is assumed for Equation B.6.

a) Von Mises equivalent stress

$$\sigma_v = \sqrt{\sigma_a^2 + \sigma_h^2 + \sigma_r^2 - \sigma_a\sigma_h - \sigma_h\sigma_r - \sigma_r\sigma_a} \quad (\text{B.6})$$

where

σ_v is von Mises equivalent stress;

σ_a is the axial stress;

σ_h is the hoop (tangential) stress;

σ_r is the radial (normal) stress.

b) Without bending

In the absence of bending, the peak VME stress for either internal or external pressures always occurs at the inside surface. Consequently, for a specific axial force, the limiting internal and external pressure can be calculated by the following method:

The principal stresses are determined as follows:

1) Hoop stress from internal pressure (p_i) at the inside surface

$$\sigma_h = \frac{p_i \left[D^2 + (D-2t)^2 \right]}{\left[D^2 - (D-2t)^2 \right]} = p_i k_i$$

$$k_i = \frac{\left[D^2 + (D-2t)^2 \right]}{\left[D^2 - (D-2t)^2 \right]} \quad (\text{B.7})$$

where k_i is a geometric constant.

2) Hoop stress from external pressure p_o at the inside surface

$$\sigma_h = -\frac{2p_o D^2}{D^2 - (D-2t)^2} = -p_o k_o$$

$$k_o = \frac{2D^2}{D^2 - (D-2t)^2} \quad (\text{B.8})$$

where k_o is a geometric constant.

3) Axial stress from axial forces

$$\sigma_a = \frac{F_a}{\pi(D-t)t} = \frac{F_a}{A_p} \quad (\text{B.9})$$

where A_p is the cross-sectional area of the pipe.

4) Radial stress from internal pressure at the inside surface

$$\sigma_r = -p_i \quad (\text{B.10})$$

5) Radial stress from external pressure at the inside surface

$$\sigma_r = 0 \quad (\text{B.11})$$

Thus, for a specific F_a , within the bounds of the uniaxial test load envelope values, the corresponding maximum internal pressure p_i or external pressure p_o for the defined yield strength is calculated as follows using the quadratic solution. The real value(s) governs.

6) For internal pressure

$$p_i = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A} \quad (\text{B.12})$$

where (for Equation B.12)

$$A = k_i^2 + k_i + 1;$$

$$B = \sigma_a - k_i \sigma_a;$$

$$C = \sigma_a^2 - \sigma_v^2;$$

σ_v is the defined stress level at the inside surface.

7) For external pressure

$$p_o = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A} \quad (\text{B.13})$$

where (for equation B.13)

$$A = k_o^2;$$

$$B = \sigma_a k_o;$$

$$C = \sigma_a^2 - \sigma_v^2;$$

σ_v is the defined stress level at the inside surface.

For the purposes of determining the testing loads, the defined stress level, σ_v , shall be set at 95 % of the average actual yield strength of the material as established by tests at the specified testing temperature.

8) Maximum loads

An examination of a pipe body test load envelope, Figure B.1, shows Quadrants I and III exhibit peak pressure and axial loads along the test load envelopes. These inflection points are defined as:

$$\frac{dF_a}{dp_{i \text{ or } o}} = 0 \text{ and } \frac{dp_{i \text{ or } o}}{dF_a} = 0$$

The four pairs of peak axial force and pressure values can be calculated from the following equations:

i) Quadrant I

$$p_{i,\max} = \frac{2\sigma}{\sqrt{3}(k_i + 1)} \quad (\text{B.14})$$

$$\text{at } F_a = \frac{\sigma A_p (k_i - 1)}{\sqrt{3}(k_i + 1)}$$

$$F_{a,\max} = \frac{2\sigma A_p \sqrt{k_i^2 + k_i + 1}}{\sqrt{3}(k_i + 1)} \quad (\text{B.15})$$

$$\text{at } p_i = \frac{\sigma(k_i - 1)}{\sqrt{3}\sqrt{k_i^2 + k_i + 1}(k_i + 1)}$$

ii) Quadrant III

$$p_{o,\max} = \frac{\sigma A_p}{A_o \sqrt{3}} \quad (\text{B.16})$$

$$\text{at } F_a = \frac{\sigma A_p}{\sqrt{3}}$$

$$F_{a,\max} = \frac{2\sigma A_p}{\sqrt{3}} \quad (\text{B.17})$$

$$\text{at } p_o = \frac{\sigma A_p}{2\sqrt{3}A_o}$$

where

$$k_i = \frac{D^2 + (D - 2t)^2}{D^2 - (D - 2t)^2}$$

$$A_p = \frac{\pi}{4} [D^2 - (D - 2t)^2]$$

$$A_o = \frac{\pi D^2}{4}$$

c) With bending

If bending is present, as in a directional well or induced as by helical or sinusoidal buckling, the bending stress, tensile or compressive at the D_i surface of the pipe must be superimposed on the axial stress in the pipe.

$$\sigma_{ab} = \sigma_a \pm \sigma_b \quad (\text{B.18})$$

where

σ_{ab} is total axial stress with bending;

σ_a is the axial stress from axial forces

$$\text{where } \sigma_a = \frac{F_a}{\pi(D-t)t} = \frac{F_a}{A_p}$$

σ_b is the axial stress due to bending expressed in MPa;

$$\text{where } \sigma_b = \pm \frac{M(D/2-t)}{I}$$

M is the bending moment;

I is the moment of inertia;

$$\text{where } I = \frac{\pi}{64} [D^4 - (D-2t)^4]$$

d) The bending moment M and pipe curvature are related as follows:

$$\sigma_b = \pm \frac{M(D/2-t)}{I} = \pm 0,060\,156 D_{\text{leg}} (D-2t) \quad (\text{B.19})$$

where

D_{leg} is the bending (dog leg severity) expressed in degrees per 30 m;

D is pipe diameter, expressed in millimetres;

t is pipe wall thickness, expressed in millimetres;

σ_b is the axial stress due to bending expressed in MPa.

The radius of curvature of the pipe body is related to the dog leg severity as follows:

$$R = \frac{1\,719}{D_{\text{leg}}} \quad (\text{B.20})$$

where R is the radius of curvature, expressed in metres, of the pipe body at the axis of the pipe.

Consequently, substituting σ_{ab} for σ_a in B.5.2.3 a) will provide the maximum internal and external, p_i and p_o respectively, which can be applied to generate the specified σ_v level at the inside surface of the pipe body for a specific axial load, F_a , and degree of bending, D_{leg} .

NOTE Depending on the geometry of the pipe, i.e. D and t , the applied axial force, F_a , the pressure p_i or p_o , and the degree of bending, D_{leg} , the peak VME stress can occur at the *outside* surface of the pipe body.

- e) The degree of bending which can be applied to a pipe body under pressure and axial force, above which the maximum VME stress will occur at the outside surface of the pipe body can be calculated from the following quadratic equations:

- 1) For internal pressure

$$M = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A} \quad (B.21)$$

where [for Equation (B.21)]

$$A = \frac{t(D-t)}{I^2}$$

$$B = \pm \frac{t(2\sigma_a + p_i - \sigma_{hi})}{I}$$

$$C = -3p_i\sigma_{hi}$$

p_i is the internal pressure;

D is the outside diameter;

t is the wall thickness;

σ_{hi} is the hoop (tangential stress at the inside surface).

- 2) For external pressure

$$M_{max} = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A} \quad (B.22)$$

where [for Equation (B.22)]

$$A = \frac{D^2}{4I^2} - \frac{(D/2 - t)^2}{I^2}$$

$$B = \pm \frac{2\sigma_a t}{I} - \frac{\sigma_{hi} t}{I}$$

$$C = 3p_o(\sigma_{hi} + p_o)$$

Note, only real numbers are valid, i.e. $(B^2 - 4AC)$ is required to be greater than zero, or $4AC \leq B^2$. Also for p_i , it is required that $p_o = 0$ and for p_o , it is required that $p_i = 0$. Furthermore, note as previously stated, it is *not acceptable* to use a differential pressure approach, i.e. $\Delta p = p_i - p_o$, for this analysis.

- 3) The degree of bending allowed before the outside VME stresses become critical is therefore:

$$D_{leg} = \frac{M}{0,060\,156I}$$

B.5.3 Connection test load envelopes

B.5.3.1 General

Connections can be considered as concentric layered cylinders, frustums and/or partial spheres positioned by shoulder(s) and/or axially joined by threads, snap rings or other means. It can be demonstrated that concentrically layered cylinders in contact at the mating surface, i.e. exhibiting a bearing pressure between them will, under the influence of pressure, internal or external, behave as if the combined layered (shrink fit) cylinders were a continuous cylinder.

A review of both public and proprietary connections shows that due to geometric (D_i , D_o) constraints, most connections are designed so that the initial bearing pressure and resulting hoop stress in the member primarily resisting the load are not dominant when service loads are applied. In other words, the service load capacity of a connection to specific loads is predominantly a function of the service load forces, not the forces and stresses generated as a result of make-up.

For example, it is recognized that the end of an ISO 10422 or API Spec 5B Labels 1: 2-7/8 EUE 8 round thread pin undergoes plastic deformation in hoop compression during make-up, thus generating a high bearing pressure (radial stress) between the pin and box member, yet the pressure integrity of the coupling at this plane is not compromised. ISO 10400:1993 (Equation 3.1.2) or API Bul 5C3 rates the internal pressure resistance of an API coupling solely on the dimensions of the coupling and the material properties at that plane.

NOTE Since the connection test envelope is essentially defined as a maximum elastic load, relative movement between connection members will be small. In other words, connection geometry will be essentially constant within the test load envelope.

As a result, the principles of superposition can be applied to establish the test load envelope of a connection. Thus, knowing the various critical cross-sections of the connection subject to axial loads, i.e. tension or compression and the diameter and thickness resisting the pressure loads, internal or external at those cross-sections allows the calculation of a test load envelope of a multi-body member, such as OCTG connections.

For superposition, the critical cross-section resisting an axial load need not have the same diameter and wall thickness (D and t) as that resisting the pressure load. It is, however, necessary to know the diameter on which the pressure acts, i.e. the internal diameter (D_i) for internal pressure and the external diameter (D_o) for external pressure. Of course, the specific critical cross-sectional area of the connection under analysis shall be planar (coincident) with the diameter and wall thickness.

The critical cross-section (CCS) approach to calculating the test load envelope of connections further assumes that long cylinder equations are valid. In other words, no shear reinforcement occurs at a critical cross-section due to a nearby or adjacent thick wall section.

This assumption is conservative and reasonable since the central design objectives for a connection are to achieve a performance and geometry as close to the pipe body as practical.

In the case of connections machined on heavy hot-forged upsets, shear reinforcement from adjacent heavy wall sections can significantly contribute to the rated connection test load envelope. However, most such connections are designed to achieve at least 100 % pipe body performance at the expense of geometry and, therefore, the connection test envelope is likely to be fully exterior to the pipe body. Thus, the exact connection test load envelope is a moot point since the testing and test loads would be set by the pipe body, not the connection.

It can possibly also be argued that the hoop stress, maximum at the D_i of the inside member, should not be combined with the axial stress of an outer member to calculate the VME stress of the critical member. Such an argument, however, is not valid for the purposes of the procedures defined in this International Standard. First, one of the VME limiting critical cross-sections in a connection is usually at the terminus of the pin or box, i.e. a single body member. Second, using a higher hoop stress in the VME equation does compensate for the exclusion of make-up stresses.

The peak VME stress intensity in a connection for a specific set of loads, i.e. pressure, axial and bending, is not readily predictable from merely a cursory examination of the connection. Consequently, it is necessary to make a detailed examination of the connection to establish *all* of the planes in a connection at which the limiting stress intensity can possibly occur, in all four (4) load quadrants. It has already been established that a discontinuity in the VME functions occurs between internal and external pressures due to the intrinsic nature of the equations from the principal pressure stresses, σ_h and σ_r . Moreover, the specific structure (design) of the connection can generate a discontinuity in the VME functions between tension and compression. Consequently, it is necessary to closely examine the structure of a connection and assess the potential critical cross-sectional (CCS) planes in each quadrant.

B.5.3.2 Uniaxial connection test load envelope values

B.5.3.2.1 General equations

The following Equations (B.24) to (B.26) are identical to those given for the pipe body as described in B.5.2.2. Calculate the uniaxial connection test load envelope values by substituting the appropriate D and t values for the connection geometry at a critical plane instead of the pipe body. In a given critical cross-sectional plane, the correct D and t for axial stresses need not be the same D and t for hoop stresses. It is merely necessary that the specific D and t correspond to the values regulating axial stress, including bending, and that another, not necessarily the same D and t correspond to the values resisting the pressure loads. Furthermore, internal pressure, p_i , always acts on the inner diameter, D_i , which is expressed as:

$$D_i = D - 2t \quad (B.24)$$

External pressure, p_o , always acts on the outer diameter, D . Also be aware that for field service loads which likely to have both a p_i and p_o , it is necessary to normalize these pressures to a p_{in} and p_{on} such that p_o and p_i , respectively, are zero before a comparison with test pressures can be made. The normalization of simultaneous internal and external pressures to solely p_i and p_o is accomplished by the following equations:

$$p_{in} = p_i - \frac{2D^2}{D^2 + D_i^2} p_o \quad (B.25)$$

$$p_{on} = p_o - \frac{D^2 + D_i^2}{2D^2} p_i \quad (B.26)$$

where

D is the outside diameter;

D_i is the inside diameter;

Only positive values of pressure, i.e. p_i or $p_o > 0$, are valid. As a result, at low differential pressures, there will be a discontinuity in the p_{in} , p_{on} function.

B.5.3.2.2 High bending

Should a testing requirement for high (super) bending develop which would cause the peak VME stress to occur at the outside surface of a critical member in the connection or the pipe body, the appropriate hoop, radial and axial stress with bending values shall be used.

a) Internal pressure — hoop stress at the outside surface

$$\sigma_{ho} = \sigma_h - p_i \quad (B.27)$$

- b) External pressure — hoop stress at the outside surface

$$\sigma_{ho} = \sigma_h + p_o \quad (B.28)$$

- c) The radial stress from internal pressure at the outside surface of a critical member at a critical plane is zero

$$\sigma_{ro} = 0 \quad (B.29)$$

- d) The radial stress from external pressure at the outside surface of a critical member at a critical plane is:

$$\sigma_{ro} = -p_o \quad (B.30)$$

- e) Axial stress with super critical bending

$$\sigma_{ao} = \sigma_a \pm \sigma_{bo} \quad (B.31)$$

$$\sigma_{bo} = \pm \frac{MD}{2I}$$

Thus, the maximum super bending moment M_o at the external surface of a connection member at a critical section or at the outside surface of a pipe body, subject to pressure and axial loads, is as follows:

- For internal pressure:

$$M_o = \frac{-B_o \pm \sqrt{B_o^2 - 4A_o C_o}}{2A_o} \quad (B.32)$$

where

$$A_o = \frac{D^2}{4I^2}$$

$$B_o = \frac{(2\sigma_a - \sigma_{ho})D}{2I}$$

$$C_o = \sigma_a^2 + \sigma_{ho}^2 - \sigma_v^2 - \sigma_a \sigma_{ho}$$

$$\sigma_{ho} = -\frac{2p_i D_i^2}{D^2 - D_i^2}$$

- For external pressure:

$$M_o = \frac{-B_o \pm \sqrt{B_o^2 - 4A_o C_o}}{2A_o} \quad (B.33)$$

where

$$A_o = \frac{D^2}{4I^2}$$

$$B_o = \frac{(2\sigma_a - \sigma_{ho} + p_o)D}{2I}$$

$$C_o = \sigma_a^2 + \sigma_{ho}^2 + p_o^2 - \sigma_a \sigma_{ho} + (\sigma_{ho} + \sigma_a) p_o$$

$$\sigma_{ho} = -\frac{p_o(D^2 + D_i^2)}{D^2 - D_i^2}$$

The bending moment M_o is related to the dog leg severity D_{leg} as follows:

$$D_{leg} = \frac{M_o}{0,060\,156I} \quad (B.34)$$

NOTE For D_{leg} expressed in degrees per 100 ft, M expressed in inch-lbs and I in inch⁴, the constant is 436.

B.6 Implementation

B.6.1 General

The test load envelope of a pipe string with an undefined connection service envelope is calculated as that combination of loads, pressure (internal and external) and axial, static tension or compression plus bending, which produces a VME stress intensity in the pipe body or in a critical connection member equivalent to 95 % of the axial tensile yield strength, of the material for that member.

Although the calculations for determining the maximum combination of loads can be performed by hand, they are extremely computational intensive. Consequently, a computer program is suggested to perform these calculations. A suggested method of implementation is given in B.6.2 to B.6.6.

B.6.2 Uniaxial pipe body values

Calculate the uniaxial (single load) pipe body test load envelope values as shown in B.5.2.2 for:

- a) tension [Equation (B.1)];
- b) internal pressure [Equation (B.2)];
- c) compression [Equation (B.3)];
- d) external pressure [Equation (B.4)];
- e) bending [Equation (B.5)].

B.6.3 Combined load cross-check

As a cross-check, calculate the four sets of maximum pressure and axial loads as specified by Equations (B.14), (B.15), (B.16) and (B.17). These values are also valuable for setting the iteration limits described in B.6.4.

B.6.4 Combined load pressure

Calculate the combined limiting pressure value for a specified axial force, with a sufficient number of points to facilitate the generation of a smooth curve across the entire range of applicable axial forces (see Figure B.1) as follows:

- a) axial force plus internal pressure using Equation (B.12);
- b) axial force plus external pressure using Equation (B.13).

B.6.5 Bending effects

The effect of bending is to change, i.e. increase or decrease, the effective axial stress. Thus, it is possible to construct a test load envelope (constant VME stress intensity) of pressure and axial force values with bending. Based on the computer program developed for B.5.3.2, add a provision to include various specific values of bending, then solve for the corresponding pressure value using Equations (B.12) and (B.13) for internal and external pressure, respectively.

With bending, it is necessary to change the axial stress, σ_a , in Equations (B.9), (B.12) and (B.13) by the bending stress value as shown by Equations (B.18), (B.19) and (B.20). The equations for p_i and p_o thus become for internal pressure,

$$p_{ib} = \frac{-B_b \pm \sqrt{B_b^2 - 4A_b C_b}}{2A_b} \quad (B.35)$$

where [for Equation (B.35)]

$$A_b = k_i^2 + k_i + 1$$

$$B_b = \sigma_a \pm \sigma_b - k_i [\sigma_a \pm \sigma_b]$$

$$C_b = (\sigma_a \pm \sigma_b)^2 - \sigma_v^2$$

for external pressure,

$$p_{ob} = \frac{-B_b \pm \sqrt{B_b^2 - 4A_b C_b}}{2A_b} \quad (B.36)$$

where [for Equation (B.36)]

$$A_b = k_o^2$$

$$B_b = (\sigma_a \pm \sigma_b) k_o$$

$$C_b = (\sigma_a \pm \sigma_b)^2 - \sigma_v^2$$

As shown in B.5, Equations (B.35) and (B.36) are only valid as long as the peak VME stress occurs at the inside surface. The limit of the bending for a specific pressure and axial load can be calculated from Equations (B.21) and (B.22), respectively for internal and external pressure. For super bending, where the peak VME stress occurs at the outside surface, Equations (B.32) and (B.33) shall be used. The pressure and axial load test envelope of the pipe body without bending is a limiting value. Consequently, if at a specific axial load and bending, an internal pressure value is calculated which is greater than with no bending. Such a pressure value is not valid. For example, the pressure value is likely limited to a lower value as dictated by

compression restraints in Quadrant II and the value calculated for Quadrant I is not valid. A corresponding situation can also occur for external pressure and tension in Quadrant IV.

B.6.6 Pipe body and connection

The methods of calculating the test load envelope of the pipe body, the various peak uniaxial and the combined inflection loads can be applied to connection members, as well by substituting the appropriate diameter and wall thickness into the constituent equations. Therefore, the computer program developed for the pipe body can also be used for the connection or any concentrically layered mechanism.

While a pipe body only requires one cross-section to derive its test load envelope, a connection requires several, from three to six, cross-sections to define its test load envelope. These critical cross-sections have to be defined by the user of this International Standard. Table B.2 lists the required data needed to perform the critical cross-section calculations.

The critical cross-section (planes) of standardized connections can be readily defined since the dimensions are specified in ISO 10422 or API Spec 5B. Furthermore, the dimensions of an industry common two-step cylindrical thread, frustum seal, tubing connection, a metal-to-metal and integral joint connection have been made public through engineering data donated to the API.

Most proprietary connection rating charts and sales literature provide sufficient information to construct an approximate connection test envelope without requiring the disclosure of specific dimensional data, considered confidential by some proprietary connection manufacturers. The data required for the construction of a test envelope and its source are tabulated in Table B.2.

Additional information useful for establishing critical cross-section dimensions outside the planes of the specified critical cross-sections are the thread height, thread taper, and seal taper. Usually, these values are noted in the descriptive literature of the proprietary connection. Furthermore, in most cases, proprietary connections follow a general design pattern. Knowledge of that pattern can be of valuable assistance in establishing the appropriate dimensions for use in the procedures outlined herein.

As an example, the threads of most Label 1: 4-1/2 to Label 1: 13-3/8 metal-to-metal seal threaded and coupled (MTC) connections closely follow the dimensions of buttress thread coupled threads, which are published in ISO 10422 or API Spec 5B. Consequently, one of the critical planes in the coupling, namely that at the first engaged thread, has its dimensions already defined. For the axial stress component, D is merely W , the D_o of the coupling, and D_i can be approximated by the major diameter at the end of the pin, designated as D_i in ISO 10422 or API Spec 5B. At this plane, the internal pressure acts on the D_i of the pipe, which is known and internal pressure resistance occurs all the way to the outside of the coupling. Thus, both the D and t affecting the axial and the hoop stresses in the connection from service loads are easily established.

Furthermore, most proprietary MTC connections joint strength ratings are derived from the performance property equation. Thus, since MTC joint strength ratings are almost always published, it is a relatively simple matter to calculate the outer critical diameter of the pin member.

Table B.2 — Required dimensions for critical cross-section computation

Pipe body diameter (D)	Specified
Pipe body wall thickness (t)	Specified
Connection D_o of the box member	Specified
Connection D_i of the pin member	Specified
Critical section in tension	Specified ^a
Critical section in compression	Specified ^b
^a Either as a tension force rating for a specific grade, or as a percent (%) of the pipe body or as a critical section area. ^b Either as a compressive force rating for a specific grade, or as a percent (%) of the pipe body or tension rating or as a critical section area.	

Annex C

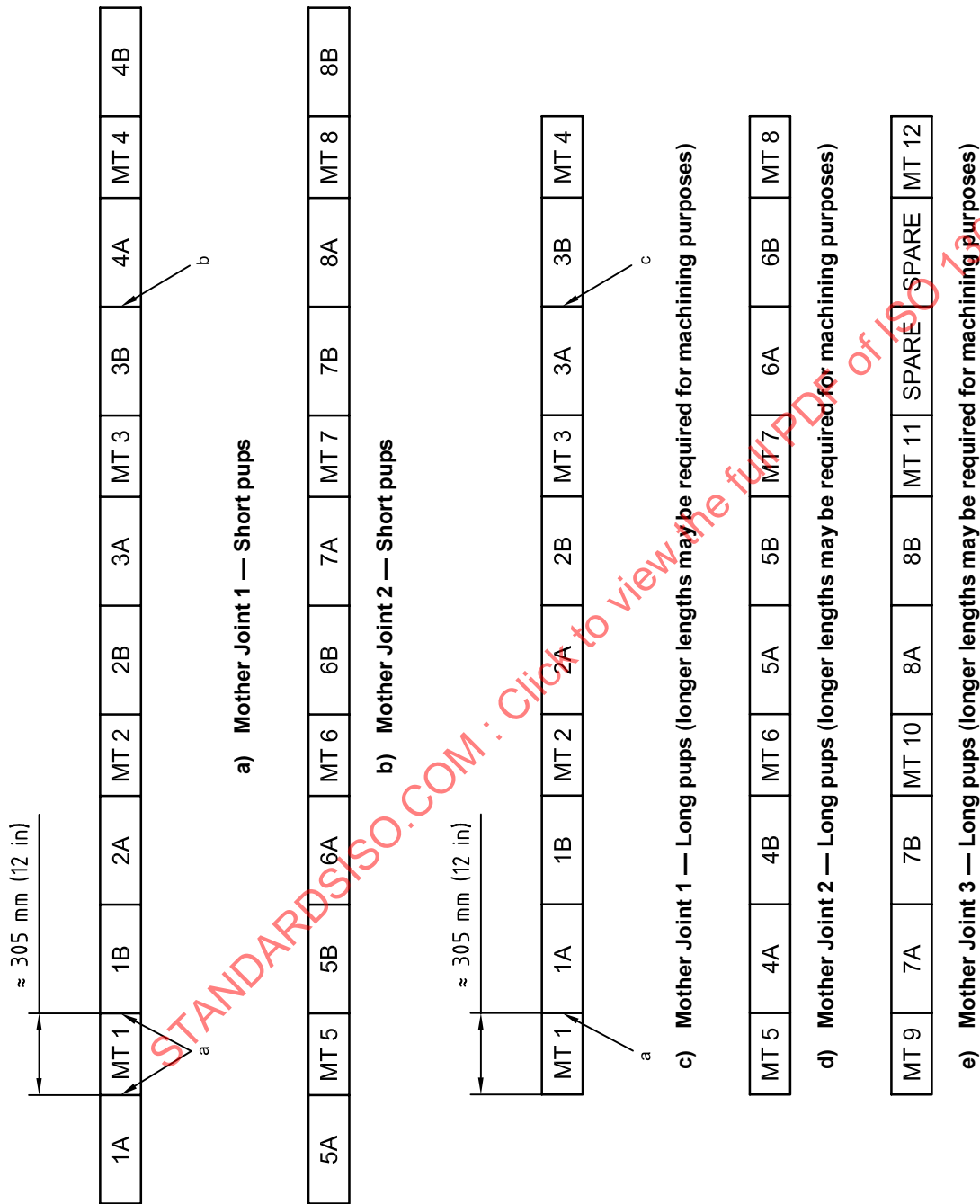
(normative)

Data forms

If the data are inserted by hand, then use A3 data sheets (or equivalent size) to report actual test data. If the data sheets are filled out by typed print or spreadsheet, then A4 data sheets (or equivalent size) may be used to report the data, provided the same format is used and all data are clear and easily read. It is permissible to use enlarged reproduced copies of the data forms in this annex.

Data Form C.9, similar to API RP 5C5 Test load calculation sheet, is included to assist with comparison to earlier test results prior to this International Standard.

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MT = Material test coupon
a Connections to be adjacent to material test.
b Plain end (torch or saw cut anytime).
c Plain end (torch or saw cut after threading).

Figure C.1 — Recommended layout of mother joints for test and material specimens

Form C.1 — Material property data sheet

Specimen pin numbers (e.g. 1A, 1B, 2A, etc.)		Specimen coupling numbers (e.g. 1,2,3, etc.)										Test coupon sketch with nominal dimensions (to be completed by manufacturer)					
Connection manufacturer		Steel manufacturer															
Tensile test performer		Location															
Tensile test machine type		Date															
Strain measurement method		Method of control															
Chemical constituents		C	Si	M	Cr	Mo	Nb	Ti	Al	P	S	B	Grade				
Coupling mother joint chemistry													Ni	Cu	V	N	Other
Pin A mother joint chemistry																	
Pin B mother joint chemistry																	
Room temperature	Location	Heat No.	Joint No.	Coupon	ISO yield strength as specified by API	0,2 % yield strength offset	Ultimate stress	Elongation %	Young's modulus	Test temperature °C							
				End 1													
				End 2													
				Middle													
			Average														
	Pin B mother joint chemistry			End 1													
				End 2													
				Middle													
				Average													
	Coupling mother joint chemistry			End 1													
				End 2													
				Middle													
			Average														
Elev.	Pin A mother joint ^a																
	Pin B mother joint ^a																
	Coupling mother joint ^a																

^a At the CAL temperature selected in Table 1.

Form C.2 — Specimen make-up/break-out data sheet

Page ____ of pages ____

Specimen number		Coupling (box) number		Pin A number		Pin B number	
Specified <i>D</i>		Specified mass (label: weight) or wall thickness		Grade			
Connection manufacturer		Connection type		Drawing number		Revision number	
						Revision date	
Make-up site		Date(s)		Make-up machine			
Anti-galling treatment box		Pin					
Thread lubricant manufacturer		Type		Product number			
Seal ring material							
Reference torque for torque versus make-up position plot							
Type test	Make-up number	Pin number	Box number	Pin mass (label: weight) of lubricant g	Box mass (label: weight) of lubricant g	Planned make-up torque	Shoulder torque
							Turns to shoulder
							Total torque
							Total turns
							Make-up speed r/min
							Break-out torque
							Refurbishing and galling observations
Data recorded by				Date			
Data witnessed by				Date			

Form C.3 — Specimen geometry data sheet

Specimen number		Coupling (box) number		Pin A number		Pin B number	
Specified D		Specified mass (label: weight) or wall thickness		Grade		Revision number	
Connection manufacturer		Connection type		Drawing number		Revision date	
				L_A			
				L_B			
				L_C Length coupling upset or box for integral connections			

	Box	Pin A	Pin B	End A			End B		
				As ^a machined	After initial break-out if needed	As ^a machined	After initial break-out	After last break-out	
			In	Out		In	Out		
Outer diameter	E-F								
	G-H								
	I-J		—						
	K-L		—						
	E (min.)	—							
Wall thickness	F	—							
	G	—							
	H	—							

Date
 Before plating or coating or any other surface treatment
 a

Data may be reported as a percentage of tolerance range of the measured dimension
 Data recorded by
 Date
 Data witnessed by
 Date

Form C.4 — Limit load test data sheet

Specified specimen number		Test number	
Test description			
Specified D	Specified wall thickness	Grade	
Connection manufacturer		Connection type	
Pressure medium			
Pressurizing rate		Axial loading rate	
At leakage pressure	Machine load	Total load	Pin number
At failure pressure	Machine load	Total load	
Maximum test parameters	Machine load	Total load	
Final length: L_A	Final length: L_B	Final length: L_C	
Manufacturer's anticipated failure load based on actual yield (if any)			
Manufacturer's rated failure load			
Anticipated failure load using actual mechanical properties and dimensions			
Actual failure load			
Actual failure pressure			
The ratio of actual failure load to anticipated failure load			
Actual failure mode			
Description and location of failure: Leakage rate ($\text{cm}^3/15 \text{ min}$) and other comments.		Test machine	
Data recorded by		Date	
Data witnessed by		Date	

Form C.5 — Connection leak test log sheet

[illegible]

Form C.6 — Test Series A — Summary of observed bubble tube water displacement

Load step numbers to be completed by test engineer. Specimen number to be according to the specimens tested together, if any. Comments shall be added as needed to explain test events (add and use rows). Report displacement in rolling 15-min intervals, recorded every 5 min, to determine leak characteristics (see 7.3.2).

VME LP	Load step	Hold time min	Water displacement cm ³		Rolling 15 min Water displacement cm ³	
			Specimen 2	Specimen 4	Specimen 2	Specimen 4
1	1	5				
during load change						
2		60				
during load change						
3		15				
during load change						
4		15				
during load change						
5		15				
during load change						
6		15				
during load change						
7		15				
during load change						
8		15				
during load change						
9		5				
during load change						
10		15				
during load change						
11		15				
during load change						
12		15				
during load change						
13		15				
during load change						
14		15				
during load change						
1		5				
during load change						

Form C.6 (continued)

VME LP	Load step	Hold time min	Water displacement cm ³		Rolling 15 min Water displacement cm ³	
			Specimen 2	Specimen 4	Specimen 2	Specimen 4
14		15				
during load change						
13		15				
during load change						
12		15				
during load change						
11		15				
during load change						
10		15				
during load change						
2		15				
during load change						
3		15				
during load change						
9		5				
during load change						
8		15				
during load change						
7		15				
during load change						
6		15				
during load change						
5		15				
during load change						
4		15				
during load change						
3		15				
during load change						
2		15				
during load change						
1		5				
during load change						

Form C.6 (continued)

VME LP	Load step	Hold time min	Water displacement cm ³		Rolling 15 min Water displacement cm ³	
			Specimen 2	Specimen 4	Specimen 2	Specimen 4
2		15				
during load change						
3		15				
during load change						
4		15				
during load change						
5		15				
during load change						
6		60				
during load change						
7		15				
during load change						
8		15				
during load change						
9		5				
during load change						
10		15				
during load change						
11		60				
during load change						
12		15				
during load change						
13		60				
during load change						
14		15				
during load change						
1		5				
during load change						
2		60				
during load change						

Form C.7 — Test Series B — Summary of observed bubble tube water displacement

Load step numbers to be completed by test engineer. Specimen number to be according to the specimens tested together, if any. Comments shall be added as needed to explain test events (add and use rows). Report displacement in rolling 15-min intervals, recorded every 5 min, to determine leak characteristics (see 7.3.2).

VME LP	Load step	Hold time min	Water displacement cm ³		Rolling 15 min Water displacement cm ³	
			Specimen 1	Specimen 3	Specimen 1	Specimen 3
1	1	5				
during load change						
2		60				
during load change						
3		15				
during load change						
4		15				
during load change						
5		15				
during load change						
6		15				
during load change						
7		15				
during load change						
8		15				
during load change						
9		5				
during load change						
2		15				
during load change						
9		5				
during load change						
8		15				
during load change						
7		15				
during load change						
6		15				
during load change						
5		15				

Form C.7 (continued)

VME LP	Load step	Hold time min	Water displacement cm ³		Rolling 15 min Water displacement cm ³	
			Specimen 1	Specimen 3	Specimen 1	Specimen 3
		during load change				
4		15				
		during load change				
3		15				
		during load change				
2		15				
		during load change				
1		5				
		during load change				
2		15				
		during load change				
3		15				
		during load change				
4		60				
		during load change				
5		15				
		during load change				
6		60				
		during load change				
7		15				
		during load change				
8		15				
		during load change				
9		5				
		during load change				
2		60				
		during load change				

**Form C.8.1 — Test Series C — Summary of observed bubble tube water displacement —
10 thermal cycles**

Form C.8.1		Bubble tube displacement cm ³								Barometer
Cycle No.	Time 24 h	Specimen 1		Specimen 2		Specimen 3		Specimen 4		
		A	B	A	B	A	B	A	B	
MC 1	Loads applied									
	Hold period									
	Loads removed									
MC 2	Loads applied									
	Hold period									
	Loads removed									
MC 3	Loads applied									
	Hold period									
	Loads removed									
MC 4	Loads applied									
	Hold period									
	Loads removed									
MC 5	Loads applied									
	Hold period									
	Loads removed									
<i>Initial heatup</i>										
TC 1	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 2	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 3	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 4	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									

Form C.8.1 (continued)

Form C.8.1		Bubble tube displacement cm ³								Barometer
Cycle No.	Time 24 h	Specimen 1		Specimen 2		Specimen 3		Specimen 4		
		A	B	A	B	A	B	A	B	
TC 5	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
MC 1	Loads applied									
	Hold period									
	Loads removed									
MC 2	Loads applied									
	Hold period									
	Loads removed									
MC 3	Loads applied									
	Hold period									
	Loads removed									
MC 4	Loads applied									
	Hold period									
	Loads removed									
MC 5	Loads applied									
	Hold period									
	Loads removed									
TC 6	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 7	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 8	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									

Form C.8.1 (continued)

Form C.8.1		Bubble tube displacement cm ³								Barometer
Cycle No.	Time 24 h	Specimen 1		Specimen 2		Specimen 3		Specimen 4		
		A	B	A	B	A	B	A	B	
TC 9	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 10	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
<i>Final cooldown</i>										
MC 11	Loads applied									
	Hold period									
	Loads removed									
MC 12	Loads applied									
	Hold period									
	Loads removed									
MC 13	Loads applied									
	Hold period									
	Loads removed									
MC 14	Loads applied									
	Hold period									
	Loads removed									
MC 15	Loads applied									
	Hold period									
	Loads removed									

**Form C.8.2 — Test Series C — Summary of observed bubble tube water displacement —
100 thermal cycles**

Form C.8.2		Bubble tube displacement cm ³								Barometer
Cycle No.	Time 24 h	Specimen 1		Specimen 2		Specimen 3		Specimen 4		
		A	B	A	B	A	B	A	B	
MC 1	Loads applied									
	Hold period									
	Loads removed									
MC 2	Loads applied									
	Hold period									
	Loads removed									
MC 3	Loads applied									
	Hold period									
	Loads removed									
MC 4	Loads applied									
	Hold period									
	Loads removed									
MC 5	Loads applied									
	Hold period									
	Loads removed									
<i>Initial heatup</i>										
TC 1	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 2	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 3	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 4	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									

Form C.8.2 (continued)

Form C.8.2		Bubble tube displacement cm ³								Barometer
Cycle No.	Time 24 h	Specimen 1		Specimen 2		Specimen 3		Specimen 4		
		A	B	A	B	A	B	A	B	
TC 5	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 6	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 7	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 8	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 9	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 10	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 11	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 12	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									

Form C.8.2 (continued)

Form C.8.2		Bubble tube displacement cm ³								Barometer
Cycle No.	Time 24 h	Specimen 1		Specimen 2		Specimen 3		Specimen 4		
		A	B	A	B	A	B	A	B	
TC 13	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 14	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 15	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 16	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 17	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 18	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 19	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 20	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									

Form C.8.2 (continued)

Form C.8.2		Bubble tube displacement cm ³								Barometer
Cycle No.	Time 24 h	Specimen 1		Specimen 2		Specimen 3		Specimen 4		
		A	B	A	B	A	B	A	B	
TC 21	Hot hold									
	Cool down									
	Cool hold									
	Heat up									
TC 22	Hot hold									
	Cool down									
	Cool hold									
	Heat up									
TC 23	Hot hold									
	Cool down									
	Cool hold									
	Heat up									
TC 24	Hot hold									
	Cool down									
	Cool hold									
	Heat up									
TC 25	Hot hold									
	Cool down									
	Cool hold									
	Heat up									
TC 26	Hot hold									
	Cool down									
	Cool hold									
	Heat up									
TC 27	Hot hold									
	Cool down									
	Cool hold									
	Heat up									
TC 28	Hot hold									
	Cool down									
	Cool hold									
	Heat up									

Form C.8.2 (continued)

Form C.8.2		Bubble tube displacement cm ³								Barometer
Cycle No.	Time 24 h	Specimen 1		Specimen 2		Specimen 3		Specimen 4		
		A	B	A	B	A	B	A	B	
TC 29	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 30	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 31	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 32	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 33	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 34	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 35	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 36	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									

Form C.8.2 (continued)

Form C.8.2		Bubble tube displacement cm ³								Barometer
Cycle No.	Time 24 h	Specimen 1		Specimen 2		Specimen 3		Specimen 4		
		A	B	A	B	A	B	A	B	
TC 37	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 38	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 39	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 40	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 41	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 42	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 43	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 44	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									

Form C.8.2 (continued)

Form C.8.2		Bubble tube displacement cm ³								Barometer
Cycle No.	Time 24 h	Specimen 1		Specimen 2		Specimen 3		Specimen 4		
		A	B	A	B	A	B	A	B	
TC 45	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 46	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 47	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 48	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 49	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 50	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
MC 1	Loads applied									
	Hold period									
	Loads removed									
MC 2	Loads applied									
	Hold period									
	Loads removed									
MC 3	Loads applied									
	Hold period									
	Loads removed									

Form C.8.2 (continued)

Form C.8.2		Bubble tube displacement cm ³								Barometer
Cycle No.	Time 24 h	Specimen 1		Specimen 2		Specimen 3		Specimen 4		
		A	B	A	B	A	B	A	B	
MC 4	Loads applied									
	Hold period									
	Loads removed									
MC 5	Loads applied									
	Hold period									
	Loads removed									
TC 51	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 52	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 53	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 54	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 55	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 56	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									

Form C.8.2 (continued)

Form C.8.2		Bubble tube displacement cm ³								Barometer
Cycle No.	Time 24 h	Specimen 1		Specimen 2		Specimen 3		Specimen 4		
		A	B	A	B	A	B	A	B	
TC 57	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 58	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 59	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 60	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 61	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 62	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 63	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 64	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									

Form C.8.2 (continued)

Form C.8.2		Bubble tube displacement cm ³								Barometer
Cycle No.	Time 24 h	Specimen 1		Specimen 2		Specimen 3		Specimen 4		
		A	B	A	B	A	B	A	B	
TC 65	Hot hold									
	Cool down									
	Cool hold									
	Heatup									
TC 66	Hot hold									
	Cool down									
	Cool hold									
	Heatup									
TC 67	Hot hold									
	Cool down									
	Cool hold									
	Heatup									
TC 68	Hot hold									
	Cool down									
	Cool hold									
	Heatup									
TC 69	Hot hold									
	Cool down									
	Cool hold									
	Heatup									
TC 70	Hot hold									
	Cool down									
	Cool hold									
	Heatup									
TC 71	Hot hold									
	Cool down									
	Cool hold									
	Heatup									
TC 72	Hot hold									
	Cool down									
	Cool hold									
	Heatup									

Form C.8.2 (continued)

Form C.8.2		Bubble tube displacement cm ³								Barometer
Cycle No.	Time 24 h	Specimen 1		Specimen 2		Specimen 3		Specimen 4		
		A	B	A	B	A	B	A	B	
TC 73	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 74	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 75	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 76	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 77	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 78	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 79	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									
TC 80	Hot hold									
	Cooldown									
	Cool hold									
	Heatup									