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Plastics piping systems — Glass-reinforced thermosetting plastics (GRP) pipes — System design of above ground pipe and joint installations without end thrust

Systèmes de canalisations en plastiques — Tubes en plastiques thermodurcissables renforcés de verre (PRV) — Conception de système d'installations de tubes et d'assemblages en aérien sans poussée d'extrémité

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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 138, *Plastics pipes, fittings and valves for the transport of fluids*, Subcommittee SC 6, *Reinforced plastics pipes and fittings for all applications*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

While pipes manufactured according to ISO 23856 are typically utilized in buried installations, there are circumstances where installing above ground is the preferred practice. These can include terrain not suitable for burial (e.g. rock), road or river crossings, unsuitable soils and installation on steep slopes.

For information on subjects such as shipping, handling, inspecting, rigid connections, thrust restraint and joining pipes, refer to ISO/TS 10465-1 which addresses the buried installation of GRP pipes. The guidelines and information on these subjects are also applicable to pipes used above ground. The information in this document is intended to supplement ISO/TS 10465-1 with practices and guidelines specific to above ground installation.

Plastics piping systems — Glass-reinforced thermosetting plastics (GRP) pipes — System design of above ground pipe and joint installations without end thrust

1 Scope

This document addresses the system design of pipe and joints of above ground installations without end-thrust as specified in systems standard ISO 23856. It is directed to pipelines with a minimum stiffness of SN 5000 laid in a straight line between thrust blocks. It is based on the safety concepts described in ISO TS 20656-1, with consequence class 2 (CC2) as default. For other consequence classes, certain details specified in this document can need to be modified. This document is directed to double bell coupling. However, much of the information can be adapted and utilized for other flexible joints systems.

This document does not cover fittings nor detailled engineering work like thrust blocks, support and anchor designs.

As installation is not included in the scope of this document and to assist system design, Annex A provides a pressure testing and inspection procedure. However, to ensure the use of clearly defined field test data in system design, Annex A can be used normatively by agreement between purchaser and supplier. An example of recording above ground joint deflection data is given in Annex B.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

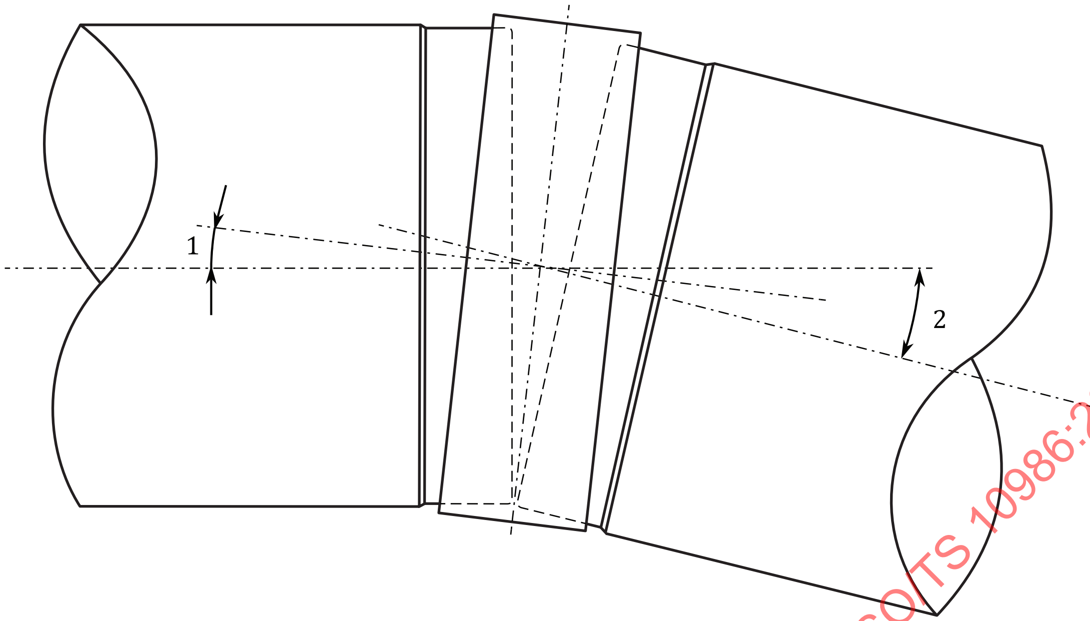
— IEC Electropedia: available at http://www.electropedia.org/

4 Angular deflection of joints

4.1 General

The angular deflection at flexible joints shall be controlled to avoid excessive loads on the pipeline and its supporting structures. Above ground installations do not benefit from the stabilizing support that is given by the soil in buried installations, and they are therefore more susceptible to problems of joint misalignment. For this reason, control and measurement of joint angular deflection is of great importantance. It is necessary to limit angular deflections to lower values than those normally permitted for buried applications.

There are two types of deflection to consider: pipe-to-pipe angular deflection and coupling-to-pipe deflection, as shown in Figure 1. Both need to be considered as coupling-to-pipe angular deflection can be larger than the pipe-to-pipe angular deflection.



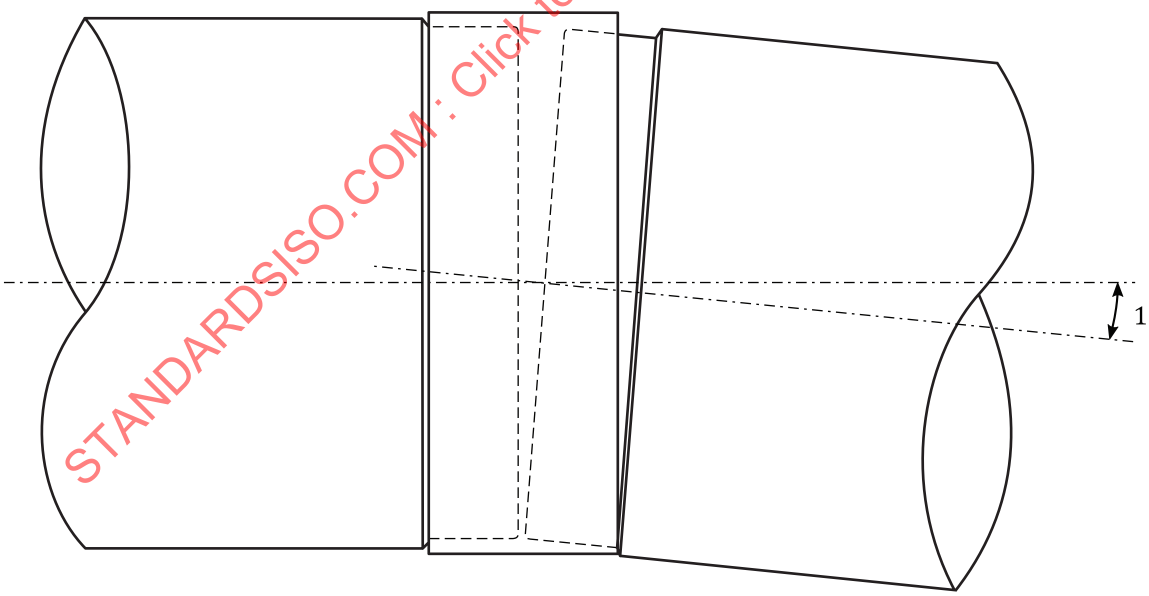
Key

1 coupling-to-pipe angular deflection

2 pipe-to-pipe angular deflection

Figure 1 — "Pipe-to-pipe" and "coupling-to-pipe" deflection, example 1

For some designs of double socket joint the pipe can only move on one side of the coupling. In that case, the pipe-to-pipe angular deflection is equal to the coupling-to-pipe angular deflection on one side (see Figure 2). The manufacturer should advise which case will occur with their design of joint.



Key

1 pipe-to-pipe = pipe-to-coupling angular deflection

Figure 2 — "Pipe-to-pipe" and "coupling-to-pipe" deflection, example 2

4.2 Effects of loads on joint angular deflection

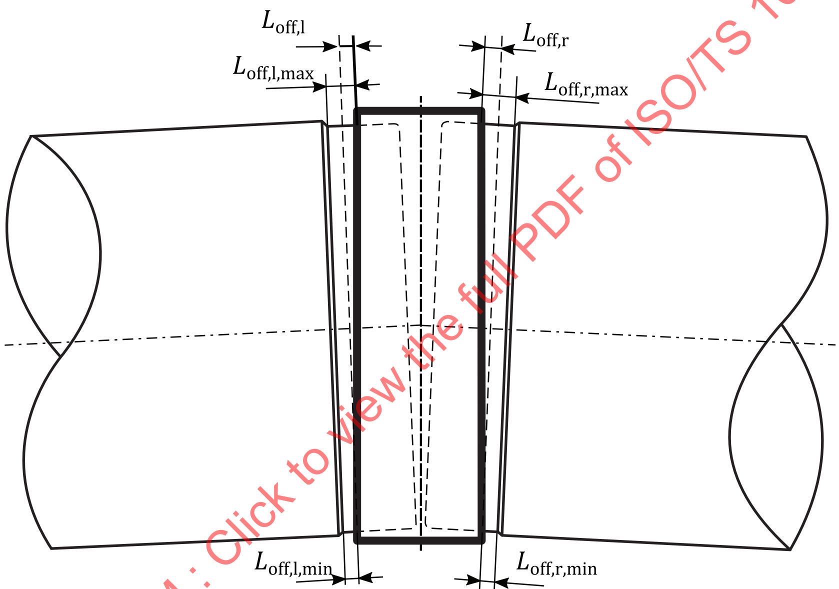
The angular deflection is influenced by several factors in addition to the initial pipe installation, such as load-induced pipe deflections and support settlement.

Pipe deflections after inital installation are caused by forces produced by the weight of fluid in the pipe, external loads and pressure within the pipeline. These forces can produce significant pipe-to-coupling deflections which, if acting in a similar plane to the initial installation deflection, can result in the total deflection at the coupling exceeding the allowable limit. An example of this effect is shown in Figure A.3.

The initial pipe angular deflection therefore should be limited to allow for this effect to ensure that the total deflection does not exceed the maximum coupling deflection specification.

4.3 Measuring deflections

The coupling-to-pipe angular deflection is measured as an angular offset, see Figure 3.



Key

$L_{off,l}$ coupling offset (left pipe) = $L_{off,l,max} - L_{off,l,min}$

$L_{off,r}$ coupling offset (right pipe) = $L_{off,r,max} - L_{off,r,min}$

$L_{off,l,min}$ minimum coupling offset (left pipe)

$L_{off,l,max}$ maximum coupling offset (left pipe)

$L_{off,r,min}$ minimum coupling offset (right pipe)

$L_{off,r,max}$ maximum coupling offset (right pipe)

Figure 3 — Measurements for determining the angular offset

Coupling offsets $L_{off,l}$ and $L_{off,r}$ should be measured as follows:

Find the maximum and the minimum distance between the homeline and the face of the coupling along the circumference of the pipe. Subtract the minimum found value from the maximum found value.

The total pipe-to-pipe offset, $L_{off,tot}$, is calculated by additioning $L_{off,l}$ and $L_{off,r}$, see Formula (1):

$$L_{off,tot} = L_{off,l} + L_{off,r} \tag{1}$$

The total pipe-to.pipe offset, $L_{off,tot}$, shall be smaller or equal to the maximum allowable coupling offset $L_{off,max}$, see Formula (2):

$$L_{off,tot} \leq L_{off,max} \tag{2}$$

with Formula (3):

$$L_{off,max} = DN \cdot \frac{\alpha_{max} \pi}{180} \tag{3}$$

NOTE Formula (1) and Formula (2) are only valid for conditions given in Figure 3, but not for conditions seen in Figure 9, where the coupling-to-pipe angular deflection is larger than the pipe-to-pipe angular deflection. However, the same logic applies.

The maximum pipe-to-pipe offset for empty pipes installed in straight alignment is shown in Table 1.

Table 1 — Maximum pipe-to-pipe offset for pressure pipes installed in straight alignment

Pipe nominal size DN	**Declared allowable joint (pipe-to-pipe) angular deflection,** α_{max}, **in degrees**	**Maximum allowable installed angular deflection,** α, **in degrees (not filled, no pressure)**	**Example**	
			DN	Maximum value ($L_{off,l}$+$L_{off,r}$) in mm
≤ 500	3	1	500	9
500 < DN ≤ 900	2	2/3	900	10
900 < DN ≤ 1 800	1	1/3	1 800	10
> 1 800	0,5	1/6	3 600	10

In service, the following factors cause an increase in the angle, α, and as a result, $L_{off,tot}$:

— weight of water

— pressurizing

— creep in the pipe material.

See 5.5.9.3 for further details.

4.4 Checking the installed joint

4.4.1 General

The quality of the joint installation should be checked as soon as possible after assembly as correction can be difficult when the coupling gaskets have settled. Information regarding forms that can be used for recording the joint quality control is given in Annex B.

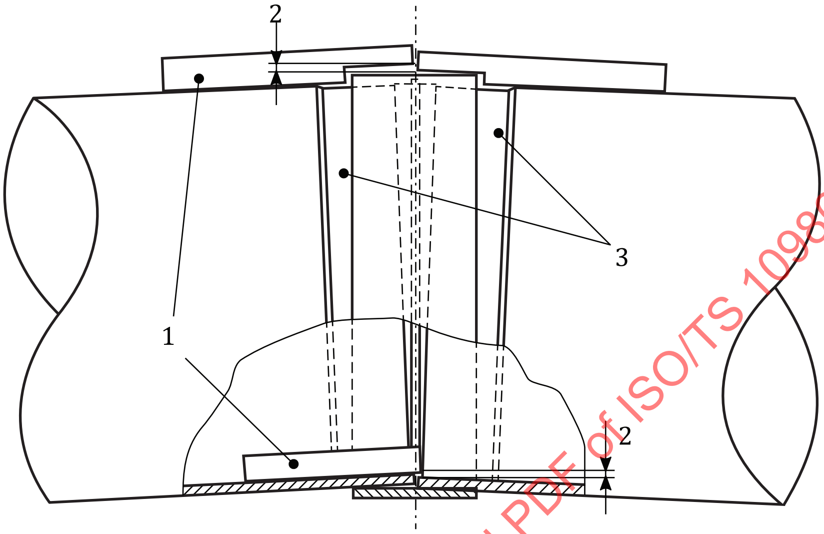
The installed joint should be checked at normal ambient temperatures. High or uneven pipe temperatures as can be caused by direct sunlight, for example, affect the results of the checks.

4.4.2 Coupling-to-pipe position

It is important for the coupling to be located as centrally as possible between the two pipe ends in order to avoid interference of the pipe end with the gasket or the pipe ends touching during operation.

4.4.3 Joint misalignment

Maximum misalignment of pipe ends should not exceed the lesser of 0,5 % of pipe diameter or 3 mm. The misalignment can be measured with two identical notched rulers pressed against the pipe at both sides of the coupling, see Figure 4. If the depth of the machined spigot surface is different for the two pipes, the measured misalignment should be corrected accordingly. For pipes 700 mm and larger the misalignment can be measured with a ruler from the inside of the pipe, see Figure 4.



Key

1 rulers

2 joint misalignment

3 machined spigot surfaces (measure gaps between rulers and spigot surface)

NOTE On some pipes there is no machined spigot surface, either because it is not designed to have one or because it is negligible because the pipe barrel OD is the correct spigot diameter.

Figure 4 — Misalignment

4.4.4 Gap between pipe ends

The gap between pipe ends is checked by measuring the distance between the homelines (see Figure 5). The gap, d_g, is then calculated using Formulae (4) and (5):

$$d_{g,min} = d_{min} - 2 d_1 \quad (4)$$

$$d_{g,max} = d_{max} - 2 d_1 \quad (5)$$

where

$d_{g,min}$ is the minimum measured gap between pipe ends;

$d_{g,max}$ is the maximum measured gap between pipe ends;

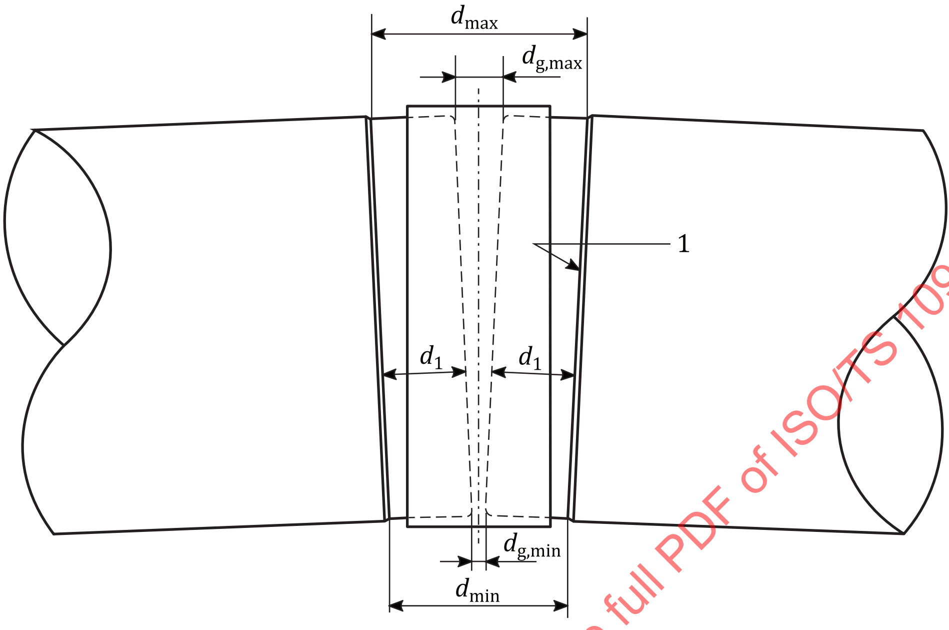
d_{min} is the minimum measured distance between homelines;

d_{max} is the maximum measured distance between homelines;

d_1 is the distance from the pipe end to the homeline

The engineer should decide what the value of the gap should be, based on maximum and minimum allowable draw and installation and service conditions. These include at least increased rotation due to weight of water and effects of pressure and creep, Poisson's effect and temperature change.

The distance from the pipe end to the homeline, d_1, can be found in the pipe specifications or measured prior to installation, see Figure 5.



Key

1 homeline

d_{min} minimum measured distance between homelines

d_{max} maximum measured distance between homelines

d_1 distance of homeline from end of pipe

$d_{g,min}$ minimum measured gap between pipe ends

$d_{g,max}$ maximum measured gap between pipe ends

Figure 5 — Gap between pipe ends

For pipes 700 mm and larger the gap can be measured directly from the inside of the pipe.

4.4.5 Adjusting joints

The joint should be adjusted if any of the checks described in the preceding clauses fall outside the specified limits. The necessary adjustments of coupling or pipe position should be made carefully, avoiding concentrated loads or impact loads that can damage the pipe or the coupling.

5 Installation of above ground pipes

5.1 General

The designer of an above ground pipe installation should be aware of the forces that act on the pipe system, particularly where high system pressures exist.

When a component in a pressurized pipeline has a change in cross-sectional area or alignment direction, a resultant force is induced. All components such as bends, reducers, tees, wyes or valves shall be anchored or restrained to withstand these loads. This is the case for above ground as well as buried pipes.

In buried pipelines, adequate resistance to movements at joints in undeflected installations is generally provided by the pipe embedment. Such resistance shall be provided at the supports of an above ground pipeline. Care shall be exercised to minimize misalignments and all components shall be properly supported to ensure the stability of the pipeline.

5.2 Supporting of pipes

5.2.1 General

A range of joint designs are manufactured for which a variety of support configurations are recommended. Generally, pipes are supported on either side of the joint, but some systems allow direct support under the joint.

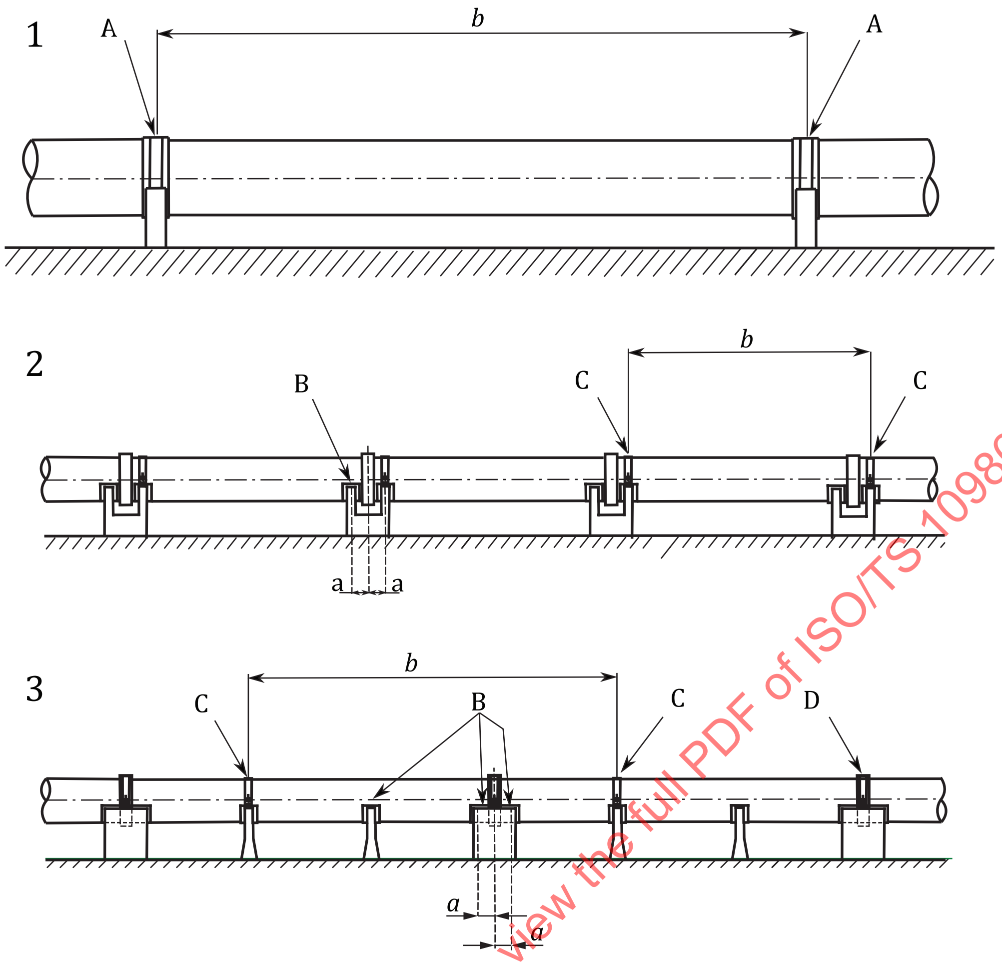
To minimize the loads induced in pipes and supports, the supports should not restrain longitudinal expansion of the pipes. However, it is essential that the pipe movements be guided and controlled in such a way that all pipe sections are stable and that acceptable longitudinal movement of the pipe in the couplings is not exceeded.

As non-restrained couplings are flexible, it is very important for the stability of every pipe component to be ensured by the supports. Each pipe should therefore be supported by at least two cradles and anchored by a pipe anchor at one of these cradles, while the remaining cradles should be designed as guides, allowing longitudinal expansion of the pipe but restraining lateral movements. With direct support under the joints, the coupling clamp can act as anchor, see Figure 6 (1) and Figure 8.

For pipes supported in more than two cradles, the cradle closest to the middle of the pipe should be used as an anchor.

The anchors should be located with regular spacing to ensure even distribution of longitudinal pipe expansion on the joints. However, the maximum distance between two anchors shall not result in exceeding the draw limits specified for the joint given in ISO 23856.

Figure 6 shows typical support arrangements for pipes.



Key

1 one cradle
2 two cradles
3 multiple cradles
a maximum distance from the centreline of the joint to centreline of a support, see Table 2
b maximum distance between two pipe anchors, depending on the limits specified for the joint given in ISO 23856

A coupling with anchor, which acts as pipe anchor
B guide
C pipe anchor
D coupling anchor, if necessary, see 5.4

Figure 6 — Typical support arrangements

Table 2 — Maximum distance from the centreline of the joint to centreline of a support, *a*

DN	*a*
DN ≤ 500	max. 250 mm
600 ≤ DN ≤ 1 000	max. 0,5 × DN
DN > 1 000	max. 500 mm

When a pipe is supported on more than two supports, the pipe supports should be in straight alignment. The maximum deviation from the straight alignment should not exceed 0,1 % of the span length, L_s. This applies to all load conditions of the system.

It is important that support displacement does not exceed the maximum misalignment of pipe ends in joints as specified in 4.4.3.

The pipes shall be supported adjacent to the joints, or directly under the joints, to ensure the stability of the couplings.

5.2.2 Support design

Any excessive point or line loading should be avoided when pipes are installed above ground. Above ground pipes should therefore be supported in cradles. Typically, the cradles are made from concrete or steel, with a supporting angle of 150°. A smaller angle (but never smaller than 120°) or a larger angle (but never larger than 180°) may be used, if it can be demonstrated that it will not cause excessive local stresses.

The diameter of the finished cradle, with cradle liners, should be 0,5 % larger than the outer diameter of the non-pressurized pipe. The cradles should have a minimum width of:

— 150 mm for all pipes with DN ≤ 1 000 mm,

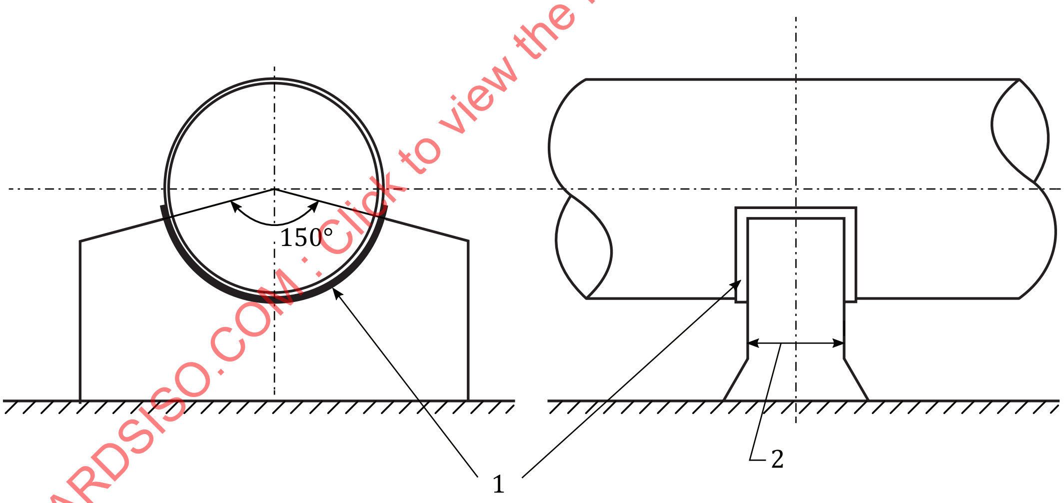
— 200 mm for pipes with 1 000 mm < DN ≤ 2 000 mm, and

— 250 mm for pipes with DN > 2 000 mm.

See Figure 7.

Cover the inside of the cradles with a 5 mm thick cradle liner to avoid direct contact between pipe and cradle. Liners should be made from materials that are resistant to the actual environment. High friction liners should be applied at anchors while low friction liners should be applied at guides. See 5.3 and 5.4.

Figure 7 shows the cradle design for support under the pipe barrel.



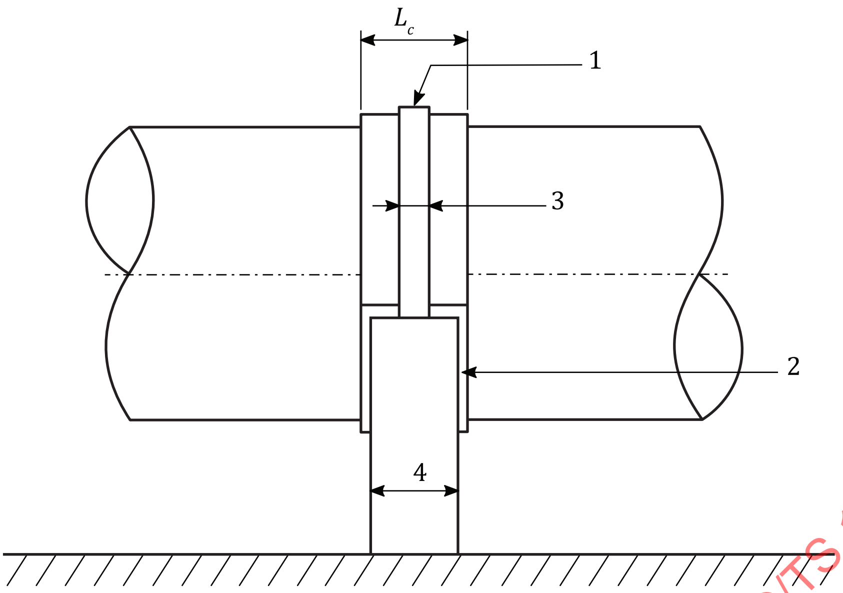
Key

1 cradle liner, minimum thickness 5 mm

2 cradle width

Figure 7 — Typical cradle design for support under the pipe barrel

Figure 8 shows the cradle design for support under the coupling.



Key

1 anchor strap also lined

2 cradle liner 25 mm larger than cradle

L_c coupling length

3 anchor strap width, equal to 30 % of L_c

4 cradle width, equal to 90 % of L_c

Figure 8 — Typical cradle design for support under the coupling

5.2.3 Loads on supports

The supports should be rigid and designed to withstand the loads caused by:

— external and environmental loads,

— weight of pipe and fluid,

— reaction forces caused by internal pressure,

— friction induced in couplings and against guides in case of temperature and/or pressure variations.

— head loss in pipe.

It is the responsibility of the owner's engineer to determine the actual design loads for the supports.

NOTE The reaction forces, caused by the weight of water, act perpendicular to the pipe. For pipe installations on steep slopes this results in a significant horizontal load component acting on the pipe foundations. A common error is to regard the reaction from water as vertical since it is a gravitational force.

Table 3 provides approximate axial forces that should be considered in the design of support cradles. These loads result from contraction and elongation of pipes during operation and frictional resistance in the gasketed joint.

Table 3 assumes simultaneous expansions and contractions of the neighbouring pipes. If non-simultaneous expansions and contractions can be expected, contact the pipe supplier for adequate axial forces.

Frictional force between pipe and guide should be determined based on total compression between pipe and cradle and the frictional coefficient between the pipe material and the cradle liner.

For the cradle liners suggested in 5.4, the frictional coefficient can be assumed to be 0,3.

Table 3 — SN 5 000 pipes — Typical axial loads due to pipe expansion/contraction and friction at joints in kN

DN	PN 6	PN 10	PN 16
≤ 300	5	6	7
350	6	6	8
400	6	7	8
450	6	7	9
500	7	8	10
600	8	9	11
700	8	10	12
800	9	11	14
900	10	12	15
1 000	11	13	16
1 200	12	15	19
1 400	14	17	21
1 600	15	19	24
1 800	17	21	27
2 000	18	23	29
2 200	20	25	32
2 400	22	27	35
2 600	23	29	37
2 800	25	31	40
3 000	26	33	43
3 200	28	35	45
3 400	30	37	48
3 600	31	39	51
3 800	33	41	53
4 000	34	43	56
NOTE These typical values result from experience and depend on sealing type used. For exact figures, consult the manufacturer.			

5.3 Anchor design

The function of the anchor support is to prevent the pipe from moving in the longitudinal and vertical direction. It also needs to be able to transfer the longitudial loads (see 5.2.3) acting on the pipe to the fixed supports.

There are several ways to design the anchor, such as clamping or using bonded saddles.

When clamping is used, the designer needs to be aware that GRP pipes have higher design strain and can have higher coefficient of thermal expansion than steel. The anchor shall therefore be designed to compensate for these differences. It shall be designed to give sufficient strap tension at low temperatures without overloading the strap or the pipe in situations involving high temperatures and high pressure which cause diametral expansion of the pipe. As an example, spring loaded bolts could be considered.

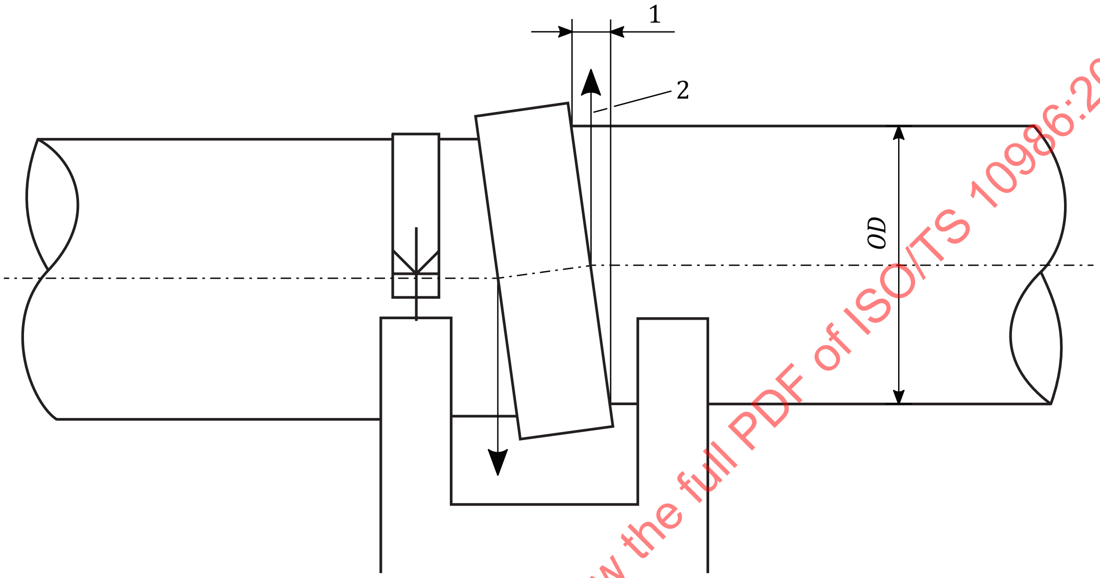
5.4 Guide design

Guides should be designed as cradles with low-friction cradle liners. This requirement is fulfilled by using liners such as Ultrahigh-molecular Polyethylene and Polytetrafluorethylene. It shall be ensured that the liner material will not deteriorate in the anticipated environment.

The cradle liner should be permanently attached to the guide cradle to ensure its stability.

In many situations, the weight of pipe and fluid is sufficient to ensure the lateral stability of a pipe in a guide. The ends of short high-pressure pipes may lift up from guides as a result of an unfavourable combination of high-compression forces in the fluid and pipe-to-coupling angular deflection. The need for securing of pipe ends depends on the combination of internal pressure, pipe diameter, pipe-to-coupling angular deflection and the supporting conditions.

Pipe-to-coupling vertical convex offset and internal pressure results in a force that tends to lift the pipe end, as illustrated in Figure 9.



Key

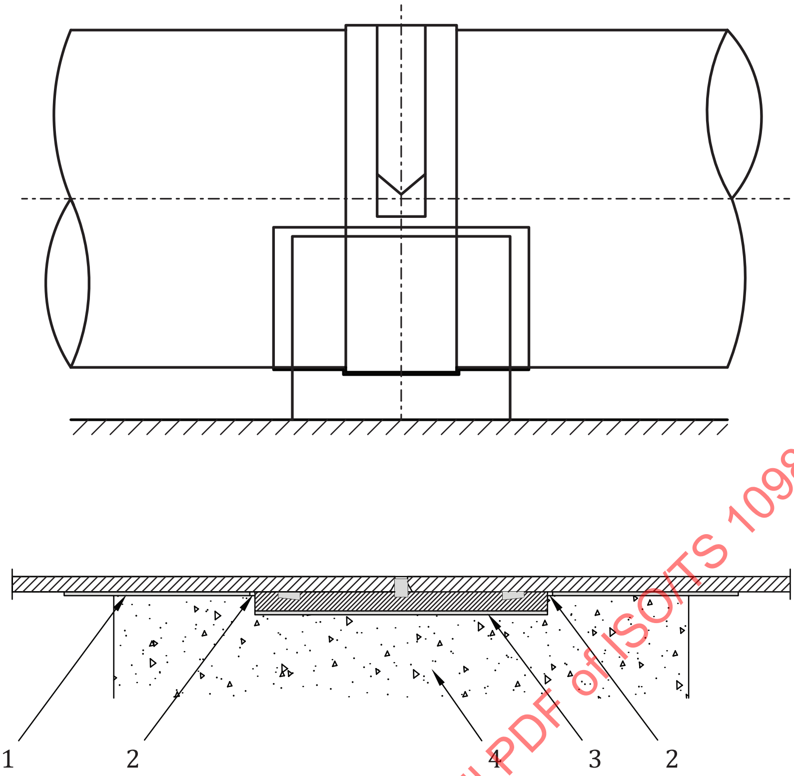
1 Pipe-to-coupling vertical convex offset

2 lift

OD outer diameter of the pipe

Figure 9 — Instability of pipe ends on guides

If this lifting force under unfavourable conditions is large enough to lift the pipe end, the end shall be secured. The securing of pipe ends is best achieved by anchoring the coupling to the foundation supporting the pipe ends. For supports made in-situ from concrete, the lower half of the coupling can be embedded, and the coupling anchored to the support with steel strap, see Figure 10.



Key

1 cradle liner: high friction for anchors; low friction for guides
2 sealing compound
3 high friction cradle liner
4 sectional detail

Figure 10 — Anchoring of couplings to concrete supports

A typical clamp design for anchoring couplings to concrete supports is shown in Figure 10.

NOTE When couplings are embedded it is necessary to ensure that the gap between coupling and pipe is kept free from concrete, e.g. by applying sealing compound “B”, see Figure 10.

The weight of pipe and fluid is sufficient to stabilize the pipe ends if the buckling length, L_b (see Figures 12, 13, 15 and 16), exceeds the amounts calculated by the following Formulae (6) and (7).

For a pipe on two supports:

$$L_{b,min,2S} = \frac{f_s \cdot p_{max} \cdot A_x \cdot \left(L_{off,c,max} / OD \right)}{\cos\phi \cdot \left(w_p + w_f \right) \cdot 0{,}5} \quad (6)$$

For pipe on three or more supports:

$$L_{b,min,3S} = \frac{f_s \cdot p_{max} \cdot A_x \cdot \left(L_{off,c,max} / OD \right)}{\cos\phi \cdot \left(w_p + w_f \right) \cdot 0{,}375} \quad (7)$$

where

$L_{b,min}$ is the minimum buckling length;

f_s is the factor of safety;

p_{max} is the maximum pressure occurring in the pipe (including field hydrotest, surge pressure etc.);

A_x is the cross-sectional area of the pipe, $\pi \times OD^2/4$;

$L_{off,c,max}$ is the pipe-to-coupling vertical convex offset (A in Figure 9);

OD is the outer diameter of the pipe;

ϕ is the slope angle of the pipe;

w_p is the dead weight of the pipe;

w_f is the dead weight of fluid in the pipe.

5.5 Maximum support spacing

5.5.1 General

This subclause provides guidance on computation of pipe stresses and deflections as well as requirements for pipe buckling stability for pressure pipes installed above ground on supports at intervals to determine maximum support spacing.

A pressurized water column by itself is unstable. The stability of the pressurized water column is provided by the axial stiffness of the pipe.

The water column within a pressure pipe carries an axial pressure thrust. In a flexible, non-restraint joint piping system, this axial pressure thrust is restrained by external anchoring but not by the pipe itself. The axial thrust does, however, typically affect the stresses and deflections of an above ground pipe to a significant extent. The thrust affects the bending moments and deflections of the pipe. Pipe bending moments and deflections shall therefore be computed using beam-column formulation. Ultimately, an above ground pipe with flexible, non-restrained joints can buckle as a column if not properly supported.

To determine the maximum support spacing for a pipe the following forces, stresses and deformations shall be computed and checked against allowable limits:

— maximum total axial compressive force acting in the pipe and the water column to be checked against global buckling of pipe as a column;

— maximum axial tensile stress acting in the pipe wall to be checked against allowable stress;

— maximum pipe deflection (sagging) to be checked against allowable deflection;

— maximum pipe end rotation to be checked against joint capacity for angular deflection accounting for installation tolerances.

Both long- and short-term loading conditions need to be analysed.

As the critical force for a long-term load is lower than the critical force for short-term, both long- and short-term loading conditions need to be analysed.

The dead weight of fluids and some environmental loads result in loading perpendicular to the pipe whilst loads from the dead weight of the pipe and external loads such as snow act vertically (see 5.2.2). A combination of vertical and perpendicular loads give the largest sum for a horizontal pipe therefore the horizontal case should be assumed for general evaluation of a project.

In order to limit the complexity of calculations, loads are classified as being either short-term or long-term. Long-term loads cause creep and the apparent axial long-term modulus shall be used to calculate long-term deflections. It is assumed that short-term loads do not cause creep and a short-term modulus with an aging factor (and where appropriate an environmental factor) is used to estimate deflections.

The apparent axial long-term modulus shall be determined according to the procedures in ISO 4152.

Loads can be classified as longitudinal or perpendicular to the pipe direction. Angular deviation at the coupling produces a perdendicular component from the longitudinal force acting on the end of the pipe.

5.5.2 Perpendicular forces

The typical perpendicular loads acting on the pipe are the dead weights of the pipe and the fluid in the pipe, environmental loads (e.g. snow, wind), and live loads (e.g. people, traffic, construction), as well as seismic loads.

5.5.3 Forces due to angular deviation

Angular deviation, α, between the pipe and coupling creates a lateral force, V_p, on the end of the pipe. When evaluating this force, maximum angular deviation should be assumed in the most unfavourable direction, considering rotation of the pipe end due to deflection. This lateral force can be calculated using Formula (8).

$$V_p = F_A \cdot \tan\alpha \qquad (8)$$

where

F_A is the total axial force;

α is the angular deviation.

5.5.4 Axial forces

5.5.4.1 General

The typical axial loads are those created by the fluid static pressure, the dynamic pressure (resulting from head loss or surge) and friction forces induced in the pipe at the coupling or pipe support by axial movement of the pipe resulting from temperature or pressure changes.

5.5.4.2 Axial forces due to pressure

Internal pressure results in force acting in both the fluid and the pipe. The working pressure, p_w, can be considered as creating a long-term load whereas the surge pressure, p_s, and the field hydro-test pressure will create a short-term loading condition.

The long-term axial pressure force, F_{pwfl}, acting in the fluid, is described in Formula (9):

$$F_{pwfl} = p_w \cdot A_b \tag{9}$$

The long-term axial pressure force, F_{pwp}, acting in the pipe, is described in Formula (10):

$$F_{pwp} = p_w \cdot A_p \tag{10}$$

The short-term axial pressure force, F_{psfl}, acting in the fluid, is described in Formula (11):

$$F_{psfl} = p_s \cdot A_b \tag{11}$$

The short-term axial pressure force, F_{psp}, acting in the pipe, is described in Formula (12):

$$F_{psp} = p_s \cdot A_p \tag{12}$$

where

p_w is the long-term working pressure;

p_s is the short-term pressure, e.g. surge pressure or field hydro-test pressure;

A_p is the cross-sectional area of pipe wall;

A_b is the cross-sectional area of pipe bore

Unless defined otherwise by client's engineer, the surge pressure and the field hydro-test pressure used in general evaluation of a pipe installation is limited to 1,4 PN and 1,5 PN respectively.

Where surge- and/or field hydro-test pressure exceeds these values, the use of a sufficiently higher rated PN product should be considered.

5.5.4.3 Axial forces due to friction

Friction forces between the pipe and coupling, F_c, and between the pipe and the support, F_s, are the result of axial movement in the pipe caused by temperature and/or pressure changes. These can cause either tensile or compressive axial forces to act on the pipe. These forces are considered to be short term loads.

Friction forces between the pipe spigot and the sealing ring, which is constrained within the coupling, are a function of gasket width, gasket compression, pipe diameter and fluid pressure. Friction forces will vary according to the coupling/gasket design and will vary from one product to another. Empirical values related to pressure activated seals are given in Table 3.

The friction between the support and the pipe is a function of the reaction force, the saddle geometry and the coefficient of friction for the saddle lining material. The force due to this friction, F_s, is estimated using Formula (13):

$$F_s = \frac{\mu \cdot R \cdot \pi \cdot \beta}{2 \cdot 360 \cdot \sin\left(\frac{\beta}{2}\right)} \tag{13}$$

where

μ is the coefficient of friction between pipe and saddle lining material;

R is the reaction force at support, see calculation in 5.5.6 and 5.5.7;

β is the cradle support angle.

5.5.4.4 Axial forces due to head loss

Head loss which occurs due to the flow of liquid within the pipe creates an axial force on the pipe, due to friction between the liquid and the pipe. This can be calculated as the head loss over the pipe times the cross-sectional area of the pipe wall and the pipe bore. This force is small when compared to other forces and can be neglected when calculating pipe stresses and deflections, but in extreme cases can affect the design of pipe anchors.

The magnitude of the axial head loss force, $F_{hl,}$ can be calculated using Formula (14):

$$F_{hl} = \Delta h \cdot \gamma_{fl} \cdot g \cdot \left(A_p + A_b \right) \quad (14)$$

where

Δh is the head loss in pipe (fluid column);

γ_{fl} is the unit weight of fluid in pipe;

g is gravity;

A_p is the cross-sectional area of pipe wall;

A_b is the cross-sectional area of pipe bore.

5.5.4.5 Axial force of vertical loads

When pipes are installed on slopes, ϕ, the vertical loads resulting from items such as pipe weight and environmental loads will have axial components. These components will not cause increased stresses in the pipe, but it is necessary to consider them when designing the pipe anchors. This force, F_q, can be calculated using Formula (15):

$$F_q = q_{vert} \cdot L_p \cdot \sin\phi \quad (15)$$

where

q_{vert} is the sum of vertical loads on pipe;

L_p is the pipe length;

ϕ is the slope angle of the pipe.

5.5.5 Maximum total axial force

The maximum long- and short-term compressive forces, F_{Alt} and F_{Ast}, shall be calculated as the most unfavorable combination of axial forces due to pressure thrust and axial forces due to friction. The compressive forces consist of at least the following components, see Formulae (16) and (17):

$$F_{Alt} = F_{pwfl} + F_{pwp} + F_{hl} + F_q \quad (16)$$

$$F_{Ast} = F_{psfl} + F_{psp} + F_{hl} + F_q \quad (17)$$

where

F_{pwfl} is the long-term axial pressure force, acting in the fluid, see Formula (9);

F_{pwp} is the long-term axial pressure force, acting in the pipe, see Formula (10);

F_{hl} is the axial head loss force, see Formula (13);

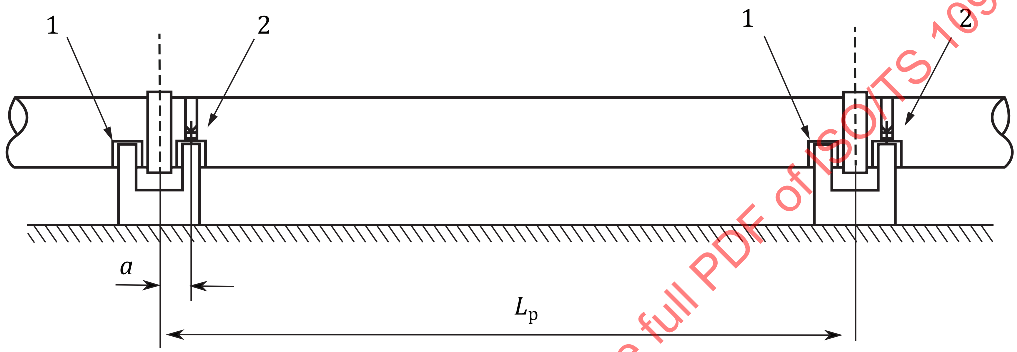
F_q is the axial component of vertical load, see Formula (14);

F_{psfl} is the short-term axial pressure force, acting in the fluid, see Formula (11);

F_{psp} is the short-term axial pressure force, acting in the pipe, see Formula (12).

5.5.6 Deformations and bending moments for pipes resting on two supports

This subclause is valid for pipes resting on two supports as shown in Figure 11.



Key

1 guide

2 anchor

L_p pipe length

a maximum distance from the centreline of the joint to centreline of a support, calculation see Table 2

Figure 11 — Pipes supported on two cradles

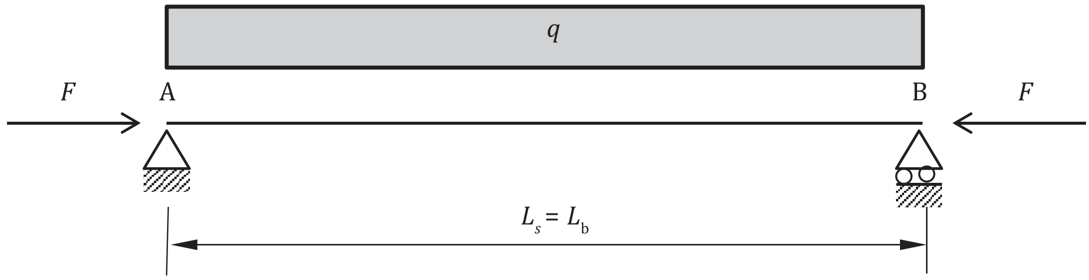
The calculation of maximum flexural deflection, y_{max}, pipe end rotation, θ, and maximum bending moment, M_{max}, is provided:

a) for pipes supported at the ends, see Figure 12; or

b) close to the ends, see Figure 13.

NOTE An example for case a) is shown in Figure 6 (1) and for case b) in Figure 6 (2).

Pipes supported on two supports at pipe ends



Key

F axial force

q load

L_b buckling length

A, B support

L_s span length

Figure 12 — Pipes supported at ends (static model)

The pipe maximum flexural deflection, y_{max}, at the centre of the pipe span is calculated using Formula (18):

$$y_{max} = \frac{5qL_s{}^4}{384E_A I} \cdot a_1 \tag{18}$$

The rotation of the pipe end, θ, is calculated using Formula (19):

$$\theta = \frac{qL_s{}^3}{24E_A I} \cdot a_1 \tag{19}$$

The maximum bending moment, M_{max}, at the centre of the pipe span is calculated using Formula (20):

$$M_{max} = \frac{qL_s{}^2}{8} \cdot a_1 \tag{20}$$

with the magnification factor, a_1, calculated using Formula (21):

$$a_1 = \frac{1}{1 - \frac{F}{F_{crit}}} \tag{21}$$

where

E_A is the apparent axial modulus of elasticity, short-term E_{Ast} or long-term E_{Alt}, as applicable;

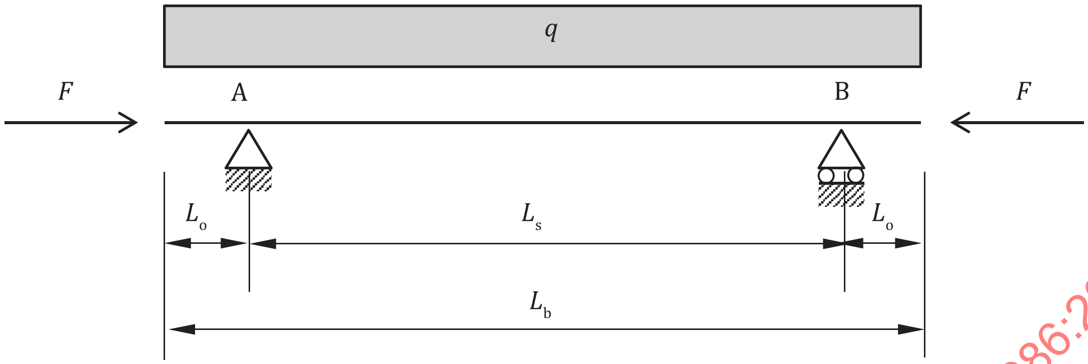
I is the moment of inertia for the pipe cross section: $I = \pi\left(DO^4 - ID^4\right)/64$ with DO as pipe outer diameter and ID as pipe inner diameter;

F_{crit} is the critical beam column buckling force, see Formula (49) and (50).

The reaction forces, R, at support A and B are calculated using Formula (22):

$$R_A = R_B = \frac{qL_b}{2} \tag{22}$$

Pipes supported on two supports close to pipe ends



Key

F	axial force	L_o	overhang length
q	load	L_s	span length (length between the centre of the supports)
L_b	buckling length	A, B	support

Figure 13 — Pipes supported close to ends (static model)

The exact beam column solution of a pipe with overhanging ends is complicated. The bending deflections, rotations and bending moments can, however, be calculated with sufficient accuracy using the following formulae, provided that the overhang length, L_o, is 10 % or less of the buckling length, $L_o/L_b \leq 0{,}10$.

The pipe maximum flexural deflection, y_{max}, at the centre of the pipe span is calculated using Formula (23):

$$y_{max} = \left[\frac{q\left(5L_s^4 - 24L_o^2 L_s^2\right)}{384 E_A I} \right] \cdot a_1 \tag{23}$$

The rotation of the pipe end, θ, is calculated using Formula (24):

$$\theta = \left[\frac{q\left(L_s^3 - 6L_o^2 L_s - 4L_o^3\right)}{24 E_A I} \right] \cdot a_1 \tag{24}$$

The maximum bending moment, M_{max}, at the centre of the pipe span is calculated using Formula (25):

$$M_{max} = \frac{q\left(L_s^2 - 4L_o^2\right)}{8} \cdot a_1 \tag{25}$$

where

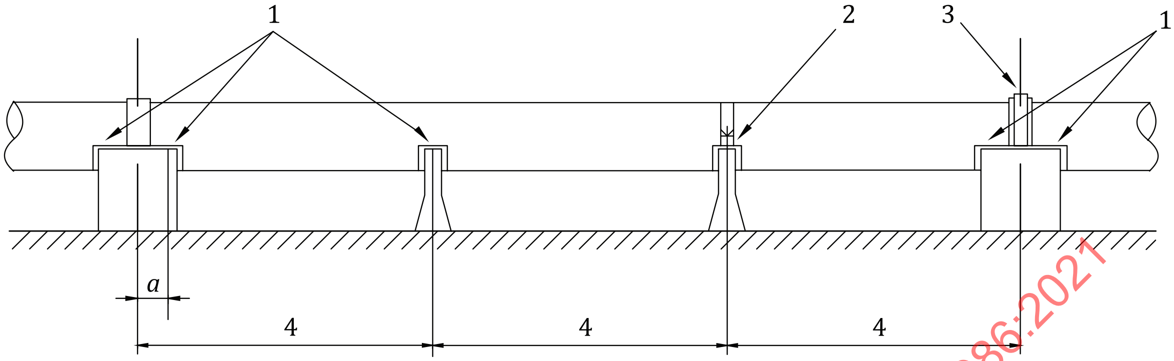
a_1 is the magnification factor, see Formula (21).

The reaction forces, R, at support A and B are calculated using Formula (26):

$$R_A = R_B = \frac{qL_b}{2} \tag{26}$$

5.5.7 Deformations and bending moments for pipes resting on multiple supports

This subclause is valid for pipes resting on multiple supports as shown in Figure 14.



Key

1 guides

2 anchor

3 coupling anchor, if necessary, see 5.4

4 support spacing from centre to centre

a maximum distance from the centreline of the joint to centreline of a support, calculation see Table 2

Figure 14 — Typical multiple span installation

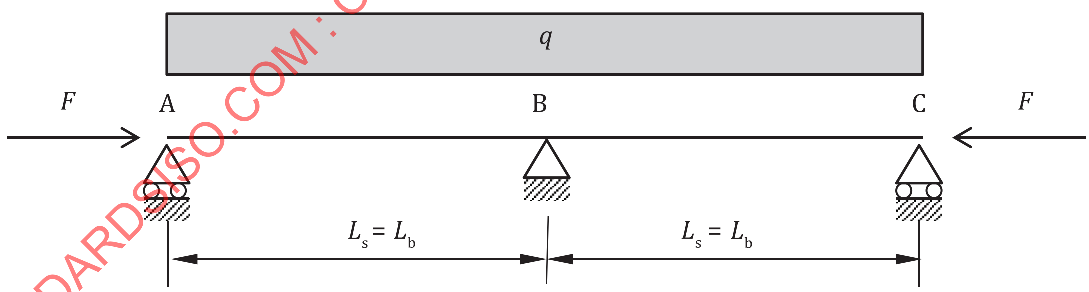
The calculation of pipe end rotation, θ, and maximum bending moment, M_{max}, is provided for

a) pipes supported at the ends and at the centre, see Figure 15 or

b) close to the ends and at the centre, see Figure 16.

Pipes supported on three supports, two at pipe ends and one at pipe centre

Because of symmetry around the centre support this case can be analysed as a beam simply supported at one end and built-in at the other.



Key

F axial force

q load

L_b buckling length

A, B, C support

L_s span length

Figure 15 — Pipes supported at ends and centre (static model) (change

The rotation of the pipe end, θ, is calculated using Formula (27):

$$\theta = \frac{qL_s^{\ 3}}{48E_A I} a_{2r} \tag{27}$$

with the magnification factor, a_{2r}, calculated using Formula (28):

$$a_{2r} = \frac{1}{1-0{,}5\frac{F}{F_{crit}}} \tag{28}$$

The maximum negative bending moment, M_B, occurring at the centre pipe support, B, is calculated using Formula (29):

$$M_B = \frac{-qL_s^{\ 2}}{8} a_{2m} \tag{29}$$

with the magnification factor, a_{2m}, calculated using Formula (30):

$$a_{2m} = \frac{1}{1-0{,}35\frac{F}{F_{crit}}} \tag{30}$$

The reaction forces, R, at support A, B and C are calculated as Formulae (31) and (32):

$$R_A = R_C = \frac{3qL_b}{8} a_{2rs} \tag{31}$$

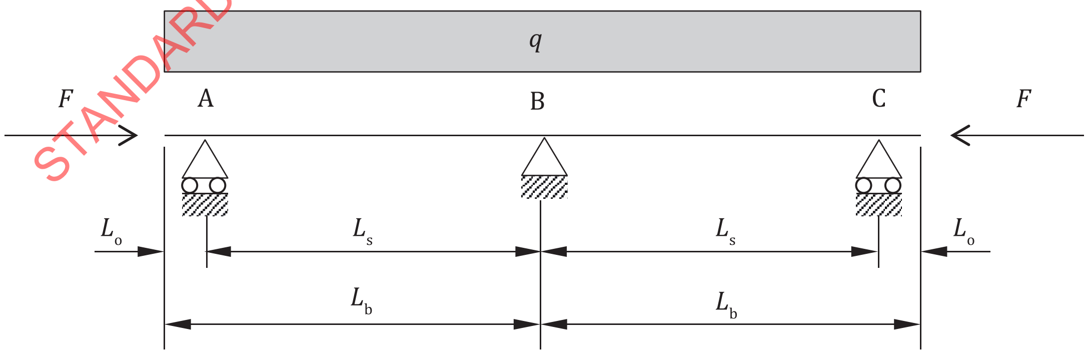
$$R_B = 2qL_b - R_A - R_C \tag{32}$$

with the magnification factor, a_{2rs}, calculated using Formula (33):

$$a_{2rs} = \frac{1}{1+0{,}14\frac{F}{F_{crit}}} \tag{33}$$

If a pipe is supported at more than 3 locations, formulae for 3 supports can be used. This will yield a somewhat conservative outcome.

Pipes supported on two supports close to pipe ends and one at pipe centre



Key

F axial force

q load

L_b buckling length

L_o overhang length

L_s length between supports

A, B, C support

Figure 16 — Pipes supported close to ends and at centre (static model)

The exact beam column solution of a pipe with overhanging ends is complicated. The bending deflections, rotations and bending moments can, however, be calculated with sufficient accuracy using the following formulae provided that the overhang length is 10 % or less of the buckling length, $L_o/L_b \leq 0{,}10$.

The rotation of the pipe end, θ, is calculated using Formula (34):

$$\theta = \left[\frac{q\left(L_s^3 - 6L_o^2 L_s - 8L_o^3\right)}{48 E_A I} \right] a_{2r} \tag{34}$$

The maximum negative bending moment, M_B, occurring at the centre pipe support, B, is calculated using Formula (35):

$$M_B = \left[\frac{q\left(2L_o^2 - L_s^2\right)}{8} \right] a_{2m} \tag{35}$$

where

a_{2r} is a magnification factor, see Formula (30);

a_{2m} is a magnification factor, see Formula (32).

The reaction forces, R, at support A, B and C are calculated using Formulae (36) and (37):

$$R_A = R_C = \left[\frac{q\left(3L_s + 8L_o + 6L_o^2 / L_s\right)}{8} \right] a_{2rs} \tag{36}$$

$$R_B = 2qL_b - R_A - R_C \tag{37}$$

with the magnification factor, a_{2rs}, see Formula (33).

5.5.8 Load cases and combinations of long- and short-term loads

As the load response and allowable stresses are dependent on the duration of the loads, the pipe installation shall be analysed separately for long- and short-term loads.

When analysing long-term loads, the apparent axial long-term modulus, E_{Alt}, shall be used to calculate deformations and bending moments.

When analysing initial short-term loads, the short-term modulus, E_{Ast}, shall be used to calculate deformations and bending moments.

A special procedure is required when analysing pipes subjected to short-term loads (e.g. water hammer), after having been exposed to long term service loads. When analysing for such combinations of long- and short-term loads the short-term modulus, E_{Ast}, shall be used to calculate deformations and bending moments but creep caused by previous long-term loads shall be considered.

The effect of creep caused by previous long-term loads can be approximated using equivalent lateral load. A pipe that has been exposed to long-term load will have permanent creep deformation (that means permanent creep deflection, y_{perm}, and permanent creep rotation, θ_{perm}) that can be estimated using Formulae (38) and (39):

$$y_{perm} = y_{lt} \cdot \left(1 - E_{Alt} / E_{Ast}\right) \tag{38}$$

$$\theta_{perm} = \theta_{lt} \cdot \left(1 - E_{Alt} / E_{Ast}\right) \tag{39}$$

where

y_{lt} is the deflection caused by the previous long-term loads;

θ_{lt} is the rotation caused by the previous long-term loads;

E_{Alt} is the apparent axial long-term modulus;

E_{Ast} is the apparent axial short-term modulus.

For a uniformly loaded pipe supported at the ends, see 5.5.6 a), the equivalent uniform lateral load, q_{eq}, shall be calculated using Formula (40):

$$q_{eq} = \frac{384 E_{Ast} I y_{perm}}{5 L_b^4} \tag{40}$$

For a uniformly loaded pipe supported at the ends and the centre, see 5.5.7 a), the equivalent uniform lateral load, q_{eq}, shall be calculated using Formula (41):

$$q_{eq} = \frac{48 E_{Ast} I \theta_{perm}}{L_b^3} \tag{41}$$

The load response shall then be calculated for the equivalent load in combination with the long- and short-term loads using the beam-column equations and the apparent short-term modulus, E_{Ast}. The deformation result of the beam-column equations can be used directly, while ordinary beam formulation bending moments caused by the equivalent load, q_{eq}, shall be subtracted from the beam-column moments calculated using the total load.

5.5.9 Checking of stresses and deformations

5.5.9.1 General

The maximum span length, L_s, and the maximum buckling length, L_b (see Figures 12, 13, 15 and 16), shall be determined such that the requirements of subclauses 5.5.9.2 to 5.5.9.4 are fulfilled for the applicable loading conditions. Alternatively, a pipe with higher PN or SN, as applicable, can be selected to increase the maximum length.

5.5.9.2 Axial tensile stresses

The axial tensile stresses, σ_A, occurring in a pipe section for a given load combination, are computed using Formula (42):

$$\sigma_A = \frac{M}{W} - \frac{F_{pp}}{A_p} \tag{42}$$

where

M is the pipe bending moment for load combination analysed;

F_{pp} is the axial force acting in the pipe itself for load combination analysed;

W is the sectional modulus of the pipe cross-section;

A_p is the cross-sectional area of pipe wall.

For long-term loading the axial force, F_{pp}, in Formula (42) is replaced by:

$$F_{pplt} = F_{Alt} - F_{pwfl} \tag{43}$$

For short-term loading the axial force, F_{pp}, in Formula (42) is replaced by:

$$F_{ppst} = F_{Ast} - F_{psfl} \tag{44}$$

where

F_{Alt} is the maximum long-term compressive force, see Formula (16);

F_{Ast} is the maximum short-term compressive force, see Formula (17);

F_{pwfl} is the long-term axial pressure force, acting in the fluid, see Formula (9);

F_{psfl} is the short-term axial pressure force, acting in the fluid, see Formula (11);

The computed axial stresses shall comply with the requirements set out in Formulae (45) and (46), where the appropriate design factors have been applied:

$$\sigma_{ATlt} \leq S_{AT} / 5{,}0 \tag{45}$$

$$\sigma_{ATst} \leq S_{AT} / 3{,}75 \tag{46}$$

where

σ_{ATlt} is the pipe axial tensile stresses computed for a long-term load case;

σ_{ATst} is the pipe axial tensile stresses computed for a short-term load case;

S_{AT} is the pipe wall short-term axial strength value in tension.

NOTE As Formula (42) shows the pressure acts to reduce the axial tensile stresses in the pipe wall, see Formulae (10) and (12) for the effect of pressure on F_{pp}. Because of the beam column behaviour of pressurized pipes, the first term of Formula (42) is also affected by the pressure to increase the axial tensile stress. While the axial force increases linearly with pressure, the increase of the moment depends on the ratio of the total axial force to the critical beam column buckling force, F/F_{crit}; see Formulae (21) and (30) for beam column moment magnification. Therefore, it is necessary to check both the highest and the lowest pressure to calculate the highest axial tensile stress.

5.5.9.3 Deformations

Maximum pipe deformations shall comply with the following requirements:

— Pipe end long-term rotation, θ_{lt}, shall not exceed the joint maximum allowable angular deflection (pipe end to pipe end) as declared by manufacturers divided by a safety factor of 1,5.

— Pipe end short-term rotation, θ_{st}, shall not exceed the joint maximum allowable angular deflection (pipe end to pipe end) as declared by manufacturers divided by a safety factor of 1,5.

— Maximum pipe long-term deflection, $y_{max,lt}$, shall not exceed $L_b/300$.

— Maximum pipe short-term deflection, $y_{max,st}$, shall not exceed $L_b/250$.

5.5.9.4 Buckling stability

The maximum long- and short-term compressive forces calculated by Formulae (16) and (17) in 5.5.5, shall comply with the requirements laid out in Formulae (47) to (50):

$$F_{\text{Alt}} \leq F_{\text{CRlt}} / 2{,}5 \tag{47}$$

$$F_{\text{Ast}} \leq F_{\text{CRst}} / 2{,}5 \tag{48}$$

$$F_{\text{CRlt}} = \frac{\pi^2 E_{\text{Alt}} I}{L_{\text{b,max}}^2} \tag{49}$$

$$F_{\text{CRst}} = \frac{\pi^2 E_{\text{Ast}} I}{L_{\text{b,max}}^2} \tag{50}$$

where

F_{Alt} is the maximum long-term compressive force;

F_{Ast} is the maximum short-term compressive force;

F_{CRlt} is the critical long-term buckling force;

F_{CRst} is the critical short-term buckling force;

E_{Alt} is the apparent axial long-term modulus;

E_{Ast} is the apparent axial short-term modulus;

I is the moment of inertia for the pipe cross section: $I = \pi\left(OD^4 - ID^4\right)/64$ with OD as pipe outer diameter and ID as pipe inner diameter;

$L_{\text{b,max}}$ is the maximum buckling length.

Annex A
(informative)

Pipeline pressure testing and inspection

A.1 General

The completed pipe installation shall be inspected and hydrotested prior to commissioning to identify installation flaws and detect damaged products, thus allowing for correction of such flaws before it is put in service.

The system test pressure (STP) depends on the consequence class for the installation, with CC1 requiring the lowest requirements, while CC3 requires the most rigorous pressure testing (see A.4.6).

A.2 Safety

A.2.1 Equipment and clothing

Prior to the commencement of operations, a check shall be made that the appropriate safety equipment is available, and the personnel have the correct protective clothing.

Prior to carrying out a pressure test a check shall be made to ensure that the test equipment is calibrated, is in good working order and correctly fitted to the pipelines.

A.2.2 Test site guarding

The test site shall remain adequately guarded from commencing and until completion of field pressure testing. Work not related to pressure tests shall not be permitted in the vicinity of the pipeline during pressure tests.

A.3 Pre-test inspection

Permanent abutments or anchorages shall be constructed to withstand thrust at the test pressure. Concrete supports and anchor blocks shall be allowed to develop adequate strength before testing begins. Care shall be taken to ensure that caps or other temporary blanking fittings are adequately anchored. Any temporary supports or anchorage at the ends of the test section shall not be removed until the pipeline is depressurized.

Any debris and foreign matter shall be removed from the pipeline before testing.

The pipeline should not be filled with water until the pre-test inspection has been satisfactorily completed.

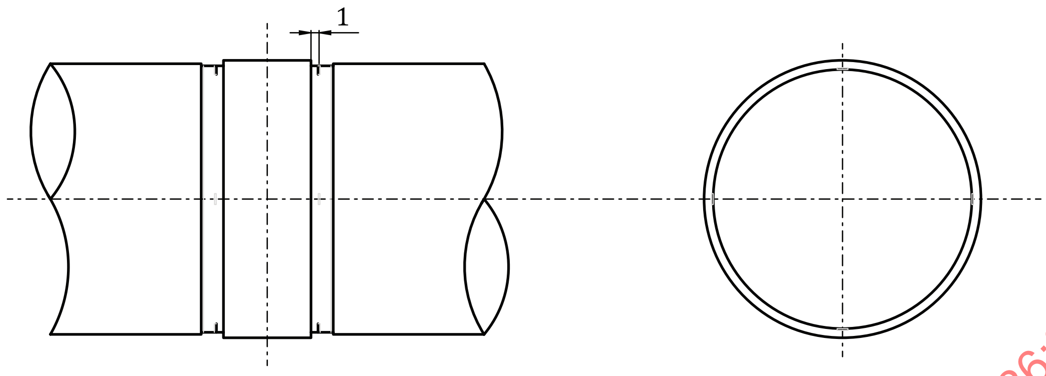
In addition to the routine care, normal precautions and typical procedures used in this work, it is recommended that the following matters should be included in the pre-test inspection procedure.

Inspect the completed installation to ensure that all work has been finished properly. The following points are of critical importance:

a) The quality records for the joints should be checked to verify acceptable measurements for pipe offset, coupling offset and position, joint alignment and the gap between the pipe ends.

b) Every joint should be visually inspected, position of couplings checked for movements, and spot checks should be made to verify that the quality records are correct.

c) The coupling position relative to both of the pipes should be marked at 4 points around the circumference, see Figure A.1 as reference for later checks.



Key

1 fixed distance (15 mm to 20 mm)

Figure A.1 — Marking Coupling Positions

d) Check that the gaskets are correctly seated and that the gap between pipe spigot and coupling is free of concrete or other foreign inclusions.

e) Check that the cradle gives even and continuous support to the pipe and that the cradle diameter is 0,5 % ± 0,25 % larger than the pipe. Check the support angle is as specified with a tolerance of ±5°.

f) The cradle support angle and cradle diameter should be checked with a template. Prefabricated cradles should be checked prior to pipe installation. For pipes supported on more than two supports, the alignment of pipe supports should be checked. Maximum allowable deviation from straight alignment is 0,1 % of the span length.

g) Check that the cradle liner is in place between the pipe and the cradle and ensure that there is no direct contact between cradle and pipe. Check that there is no concrete or other foreign inclusion between the pipe and the cradle liner.

h) Check that the liner is correctly positioned between the clamp and the pipe or coupling.

i) Check that there are high-friction liners at anchors and low-friction liners at guides.

j) Check the structural integrity of the supports.

k) Mark the position of the pipe relative to the anchors, as reference for later inspection.

l) Check, if appropriate, the number and compression of disk springs against the specification.

m) Check structural integrity of the steel clamp and anchor bolts.

n) Check that the steel clamp is positioned perpendicular to the pipe axis.

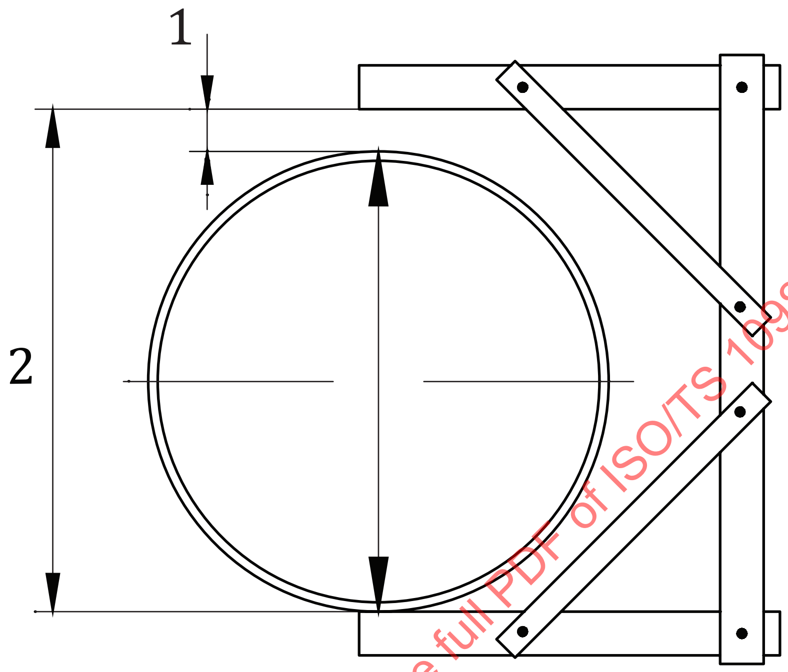
o) Measure and record the maximum diameter, D_{max}, and minimum diameter, D_{min}, of pipes at supports, thrust blocks and other encasements that restrain the natural expansion and rerounding of the pipes. The maximum deflection should be calculated as follows.

$$\frac{y}{D}=\frac{D_{max}-D_{min}}{D_{max}+D_{min}}\cdot 100$$

— For large diameter pipes the maximum and the minimum internal diameter may be measured from the inside provided that the slope of the pipe is such that it is safe to work inside the pipe.

— For pipes that are not accessible from the inside, the maximum and the minimum outer diameter may be measured by applying a rigid frame see Figure A.2.

— If the maximum deflection of the pipe at supports and encasements exceeds 1 %, contact the pipe supplier.



Key

1 frame clearance

2 measured gap between frame and pipe

Figure A.2 — Example of measuring maximum and minimum diameter of pipe

p) Inspect the pipes to ensure that they have not been damaged in the installation phase.

q) Check the support spacing against specifications.

r) Check system restraints (i.e. thrust blocks, and other anchors) are in place and properly cured.

s) Check flange bolting is torqued as per instructions.

t) Check that valves and pumps are anchored.

u) Check the correct support types (guides, anchors, cradle types, etc.) as specified and as described in this document are in place.

A.4 Hydrostatic test procedure

A.4.1 General

Field hydro testing shall be carried out on all pipeline systems and shall involve both an integrity test and a leak test.

The purpose of the integrity test is to locate any inherent weaknesses in the piping system that could result in failure within the design life. The system test pressure, STP_I, shall be as defined in A.4.6.

