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Glass reinforced thermosetting plastic (GRP) pipes — Determination of initial specific ring stiffness using segment test species cut from a pipe

Tubes en plastique thermodurcissables renforcés de verre (PRV) — Détermination de la rigidité annulaire spécifique initiale et de la résistance à la déflexion annulaire initiale en utilisant des éprouvettes segmentaires découpées dans un tube

Reference number
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Foreword

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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).

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For an explanation on 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 the following URL: www.iso.org/iso/foreword.html.

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

Introduction

This document develops an alternative to the testing of full pipe rings to measure initial specific ring stiffness (ISO 7685). The goal was to use ring segments which ideally would have led to the use of smaller and more easily handled test specimens and standard testing machines. Much work was done on developing equipment for testing ring segments and on the analysis of loading conditions and calculation procedures and conducting testing programs.

There was neither sufficient nor uniform correlation of segment testing results to standard ring testing results to allow the use of segment testing as an alternative stiffness test procedure. There were indications that correlation was perhaps diameter (DN), stiffness class (SN) and pressure class (PN), as well as specimen width, dependent. As initial ring stiffness (SN) is a key classification parameter for GRP pipes this resulted in the segment test being not accepted as a viable alternative stiffness testing procedure.

This document presents the last draft of the segment test method. It was agreed to issue this last draft as a Technical Specification so that the work done would not be lost and perhaps will allow interested parties to continue to develop the analysis of loading conditions, equipment development and calculation procedures. It may also prove useful as a research tool.

Glass reinforced thermosetting plastic (GRP) pipes — Determination of initial specific ring stiffness using segment test species cut from a pipe

1 Scope

This document specifies a method for determining the initial specific ring stiffness of pipes having a nominal size of DN 2000 or larger, using segment test pieces cut from a glass-reinforced thermosetting plastics (GRP) 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 7685, *Plastics piping systems — Glass-reinforced thermosetting plastics (GRP) pipes — Determination of initial specific ring stiffness*

3 Terms and definitions

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

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

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

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

3.1
compressive load
F
load applied to a pipe to cause a diametric deflection

Note 1 to entry: Compressive load is expressed in newtons (N).

3.2
load applied to 79 ° segmental test piece
F_{79}
load applied to 79 ° segmental test piece to cause deflection

Note 1 to entry: Load applied to 79 ° segmental test piece is expressed in newtons (N).

3.3
deflection coefficient applied to 79 ° segmental test piece
ξ
coefficient given by Formula (1):

$$\xi = \left\{1860 + \left(2500 \times y_s / d_m\right)\right\} \times 10^{-5} \quad (1)$$

where

y_s is the vertical deflection of the pipe ring derived from the 79 ° pipe segment (see 3.7);

d_m is the mean diameter of the pipe ring (see 3.8).

Note 1 to entry: Deflection coefficient applied to 79 ° segmental test piece is a dimensionless number.

3.4
vertical deflection
y
vertical change in diameter of a pipe in a horizontal position in response to a vertical *compressive load* (3.1)

Note 1 to entry: Vertical deflection is expressed in metres (m).

3.5
relative vertical deflection
y/d_m
ratio of the *vertical deflection* (3.4) of a pipe, *y*, to its *mean diameter*, d_m (3.8)

Note 1 to entry: Relative vertical deflection when multiplied by 100 is expressed in percent (%). Otherwise it is a dimensionless number.

3.6
derived vertical deflection of pipe segment
y_d
vertical deflection of the pipe segment, using Formula (2), which is derived by finite element analysis of a pipe ring and which results in the same loading conditions as if the pipe segment were part of a pipe ring deflected by the vertical deflection *y*

$$y_d = y \times \alpha_{79} \quad (2)$$

where α_{79} is the conversion factor for 79 ° segment test piece determined by finite element analysis (see Table 1).

Note 1 to entry: Derived vertical deflection is expressed in metres (m).

3.7
vertical deflection of pipe ring y_s derived from 79 ° pipe segment test
ratio of the vertical deflection of a pipe ring, to the derived vertical deflection of a 79 ° pipe segment taken from the same pipe, when the same deflection force is applied to each unit is given by the following formula:

$$y_s = 3{,}469\ y_d \quad (3)$$

where

y_s is the vertical deflection of pipe ring;

y_d is the derived vertical deflection of 79° segment.

3.8
mean diameter
d_m
diameter of the circle corresponding with the middle of the pipe wall cross-section

It is given by either Formula (4) or (5):

$$d_m = d_i + e \quad (4)$$

$$d_m = d_e - e \quad (5)$$

where

d_i is the average of the measured internal diameters (see 6.3.3);

d_e is the average of the measured external diameters (see 6.3.3);

e is the average of the measured wall thicknesses of the pipe (see 6.3.2).

Note 1 to entry: Mean diameter is expressed in metres (m) when the wall thickness and diameters are measured in metres (m).

3.9
specific ring stiffness
S
physical characteristic of the pipe, which is a measure of the resistance to ring deflection under external load

Note 1 to entry: Specific ring stiffness is determined by testing and is defined, in newtons per square metre (N/m^2), by Formula (6):

$$S = EI/d_m^3 \quad (6)$$

where

E is the apparent modulus of elasticity as determined in the ring stiffness test, expressed in newtons per square metre (N/m^2);

d_m is the *mean diameter* (3.8) of the test piece, in metres;

I is the second moment of area in the longitudinal direction per metre length, expressed in metres to the fourth power per metre, i.e.

$$I = e^3 / 12 \quad (7)$$

where e is the wall thickness of the test piece, in metres.

3.10
initial specific ring stiffness
S_0
initial value of S obtained by testing in accordance with this document.

Note 1 to entry: Initial specific ring stiffness is expressed in newtons per square metre (N/m^2).

3.13
average width of 79 ° segmental test piece
b
average of three measurements taken at specified locations on the segment test piece (see 6.1 and 6.3.1)

Note 1 to entry: Average width is expressed in metres (m).

3.14
load correction factor
β
factor applied to the measured deflection load F_{79} applied to a 79° segment during test

$$\beta = (d_m - e)/d_m \quad (8)$$

where

d_m is the mean diameter (see 3.8) of the test piece, in metres;

e is the wall thickness of the test piece, in metres

Note 1 to entry: This compensates for the supports being placed at segment the edges instead of centre of segment edges

4 Principle

4.1 Overview

To overcome problems with the size of the testing equipment and test pieces, when using full rings of large diameter pipes to determine the initial stiffness, the test procedures described in this document have been developed using 79 ° segments taken from full rings of pipe. Using formulae given in the document, the required deflection, to be applied to the segment, is determined which ensures that the test piece will be subject to the same level of strain as a full ring test piece when testing in accordance with ISO 7685.

4.2 Principle of test procedures to determine initial specific ring stiffness

A segment of pipe is loaded across its width to deflect it vertically. Two ways are given for doing this: method A (constant load) and method B (constant deflection), either of which can be used.

4.2.1 Method A

A load is applied to a segment test piece to give a deflection equal to the segment's deflection when considered as part of a full ring which is deflected to (3 ± 0,5) % in accordance with ISO 7685. The load is kept constant for a specified period of time and the final deflection is determined at the end of this period.

4.2.2 Method B

A load is applied to a segment test piece to give a deflection equal to the segment's deflection when considered as part of a full ring which is deflected to (3 ± 0,5) % in accordance with ISO 7685. The deflection is kept constant for a specified period of time and at the end of this period the final load being applied is determined.

It is assumed that the following test parameters specified in this Test Method will be either accepted or restated in any International Standard referring to this Test Method:

a) the method to be used (A or B);

b) the width of the test pieces (see 6.1);

c) the number of test pieces (see 6.2);

d) if applicable, the details of conditioning of the test pieces (see Clause 7).

5 Apparatus

5.1 Compressive-loading machine, comprising a system capable of applying, without shock, a compressive force, F, (suitable for the applicable test method described in Clause 4) at a controlled rate through a load application surface conforming to 5.2 so that a horizontally orientated segmental test piece conforming to Clause 6 can be deflected vertically. The accuracy of loading shall be within ± 1 % of the maximum indicated load.

5.2 Load application surface — General arrangement

The surface shall be provided by a plate (see 5.2.1), or a beam bar (see 5.2.2), with their major axis perpendicular to and centred on the direction of application of the load, *F*, by the compressive-loading machine, as shown in Figures 1 and 2. The surfaces in contact with the test piece shall be flat, smooth, clean and parallel. A plate or beam bar shall have a length at least equal to the width of the test piece (see Clause 6) and a thickness such that visible deformation does not occur during the test.

5.2.1 Plate, shall have a width of at least 100 mm.

5.2.2 Beam bar, shall have rounded edges, a flat face (see Figure 1) without sharp edges and a width of 50 mm ± 5 mm. The beam bars shall be designed and supported such that no other surface of the beam bar structure comes into contact with the test piece during the test.

5.3 Dimension-measuring instruments

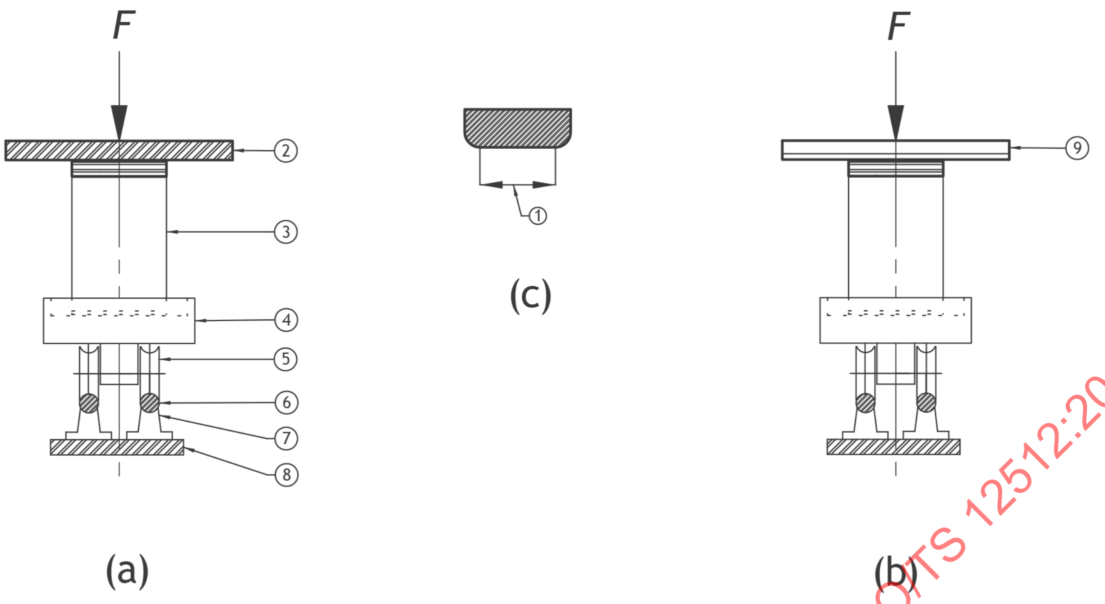
Capable of determining:

— the necessary dimensions (length, width, diameter, wall thickness) to an accuracy of within ± 0,1 mm;

— the deflection of the test piece in the vertical direction to an accuracy of within ± 1,0 % of the maximum value.

5.4 Temperature-measuring instrument

If applicable, capable of verifying conformity to the specified test temperature (see 8.1).



Key

(a) load application using plate
(b) load application using beam bar
(c) cross section of beam bar
1 width of flat face, 50 mm ± 5 mm
2 plate load application surface
3 segmental test piece
4 sledge to enable free movement of test piece
5 wheel, four per sledge
6 rail
7 rail support
8 metal plate forming top of beam
9 beam bar load application surface
F vertical load applied to test piece

Figure 1 — Schematic diagram of the alternative load application arrangements

6 Test pieces

6.1 Preparation

Each segmental test piece shall be obtained from a complete ring cut from the pipe to be tested. The width of the test piece shall be 125 ± 25 mm.

The cut ends shall be smooth and cut on a radial line perpendicular to the axis of the pipe.

Straight lines, to serve as reference lines, shall be drawn on the inside or the outside across the width of the segmental test piece at three approximately equally spaced intervals around its circumference.

6.2 Number

Three segmental test pieces shall be cut from the complete ring.

6.3 Determination of dimensions

6.3.1 Width

Measure the width, *b*, of the test piece along each of the three reference lines (see 6.1) to an accuracy of 0,2 mm.

From the three measured values calculate the average width, *b*, in millimetres (mm), of the test piece. The calculated value of *b* shall be within 125 mm ± 25 mm. If the test piece exceeds these limits it shall either be corrected or discarded.

6.3.2 Wall thickness

Measure to within ± 0,2 mm the wall thickness, *e*, of the test piece at each end of each reference line. Calculate the average wall thickness in metres, of the six measured values.

6.3.3 Mean diameter

Measure to an accuracy of within ± 0,5 mm either of the following:

a) the internal diameter, d_i, of the complete ring of pipe at six approximately equally spaced locations around the circumference, e.g. by means of a pair of calipers;

b) the external diameter, d_e, of the test piece, e.g. by means of a circumferential-wrap steel tape.

Calculate the mean diameter, d_m, of the test piece using the values obtained for wall thickness, *e*, and either the internal or the external diameter (see 3.8).

7 Conditioning

Unless otherwise specified by the referring standard, store the test pieces for at least 0,5 h at the test temperature (see 8.1) prior to testing.

In cases of dispute, condition the test pieces for 24 h at 23 °C ± 3 °C prior to testing, or subject them to a mutually agreed conditioning schedule.

8 Procedure

8.1 Test temperature

Conduct the following procedures at the temperature specified in the referring standard.

8.2 Positioning of the test piece

Place test piece in apparatus with each end resting in a sledge with the centre of the test piece located immediately below the centre of the load application axis (see Figure 2(b)). Ensure that the test piece is located in the sledges with its edges immediately above the centre lines between the wheels (see Figure 2(c)).

Bring the test piece in contact with the plate or beam bar. Ensure that the contact between the test piece and plate or beam bar is as uniform as possible and that the plate or beam bar is not tilted laterally.

8.3 Determination of initial specific ring stiffness

Carry out a test in accordance with either 8.3.1 or 8.3.2.

Using Formula (9) calculate the required deflection, y_d, in metres, for the segmental test piece assuming that when testing a full ring test piece, in accordance with ISO 7685, a relative deflection of 3 % would be required:

$$y_d = (0{,}03 \times d_m) \times \alpha_{79} \qquad (9)$$

where

y_d is the required segment test piece vertical deflection, expressed in metres;

0,03 is 3 % relative deflection of a full ring test piece;

d_m is the mean diameter of the pipe, expressed in metres;

α_{79} is the deflection conversion factor, obtained from Formula 10 or Table 1.

$$\alpha_{79} = 0{,}04970745\, x^2 - 0{,}09802235\, x + 0{,}29516521 \quad (10)$$

where x is relative deflection y/d_m.

For some nominal stiffnesses of pipe a deflection other than 3 % may be specified by the product standard. In such cases the 0,03 in Formula (9) will need to be corrected to the specified deflection.

Depending on assumptions and the like in the finite element analysis, the equation and/or the α_{79} value may vary. Therefore, when trying the segment test, it is advised that a correlation between the pipe ring test and the segment test is examined beforehand.

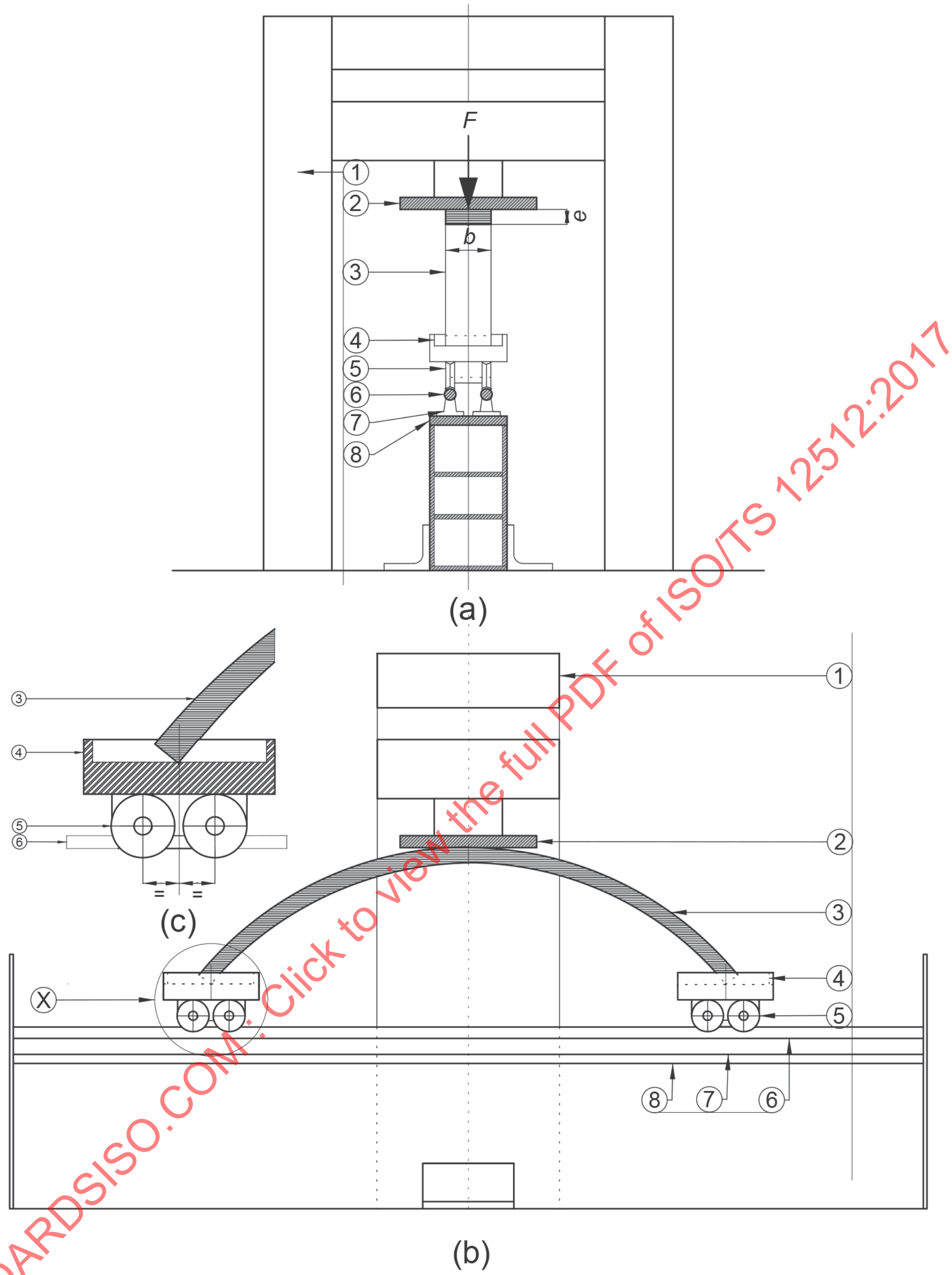
Table 1 — Deflection conversion factor, α_{79}, for 79 ° segment test pieces and derived segment deflection as a % of d_m

	Relative vertical deflection, y/d_m, of full pipe ring %						
Ring deflection %	**3,0**	**6,0**	**9,0**	**12,0**	**15,0**	**18,0**	**21,0**
Factor α_{79}	0,2923	0,2895	0,2867	0,2841	0,2816	0,2791	0,2768
Segment deflection %	0,8768	1,7368	2,5807	3,4094	4,2237	5,0244	5,8122
Ring deflection %	**24,0**	**27,0**	**30,0**	**33,0**	**36,0**	**39,0**	**42,0**
Factor α_{79}	0,2745	0,2724	0,2703	0,2683	0,2664	0,2645	0,2626
Segment deflection %	6,5881	7,3527	8,1070	8,8516	9,5875	10,3154	11,0361

8.3.1 Method A: Using constant load

See Figure 3.

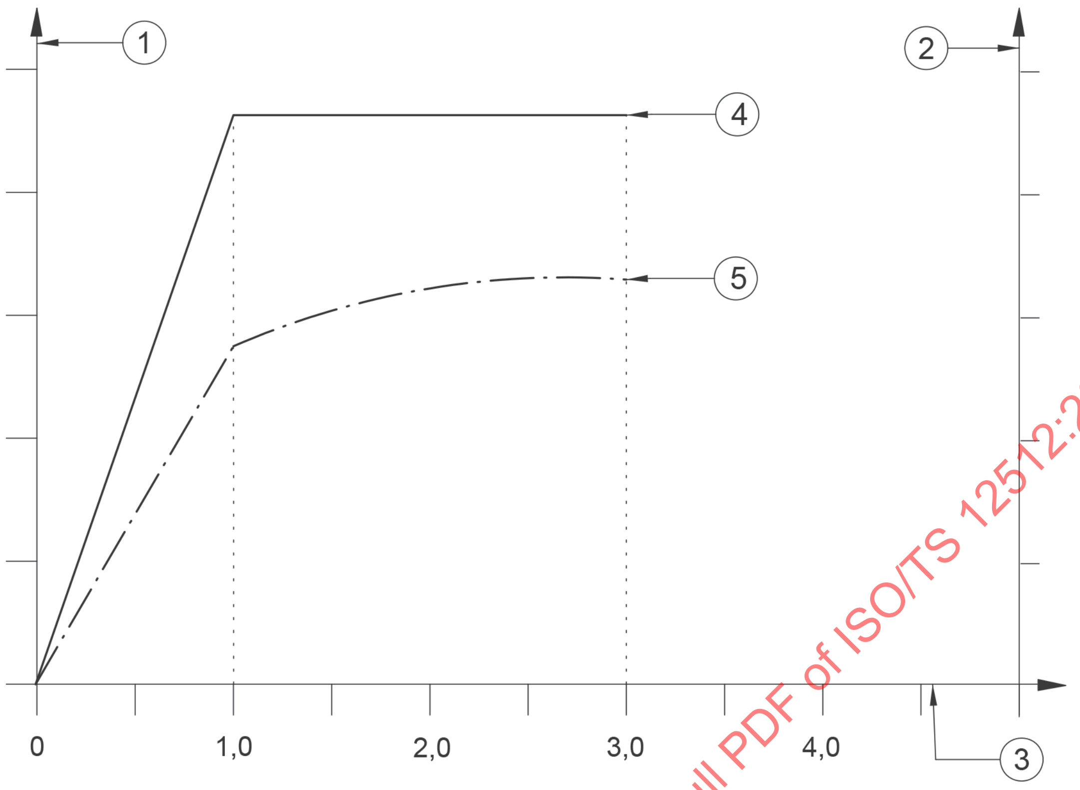
Apply the compressive load at an approximately constant rate so that the deflection, y_d, is reached in (60 ± 10) s. Maintain this load constant for 2 min, and at the end of this period determine and record the load and the deflection.



Key

(a) end view of test arrangement
(b) side view of test arrangement
(c) detail X – showing location of test piece end inside sledge
1 compressive test machine
2 plate or beam bar load application surface
3 segmental test piece
4 sledge to enable free movement of test piece
5 wheel, four per sledge
6 rail
7 rail support
8 metal plate forming top of beam
b width of test piece
e thickness of test piece
F vertical load applied to test piece

Figure 2 — Typical test arrangement



Key

1 load axis

2 deflection axis

3 elapsed time, expressed in minutes

4 load applied to segmental test piece, F_{79}

5 resulting deflection

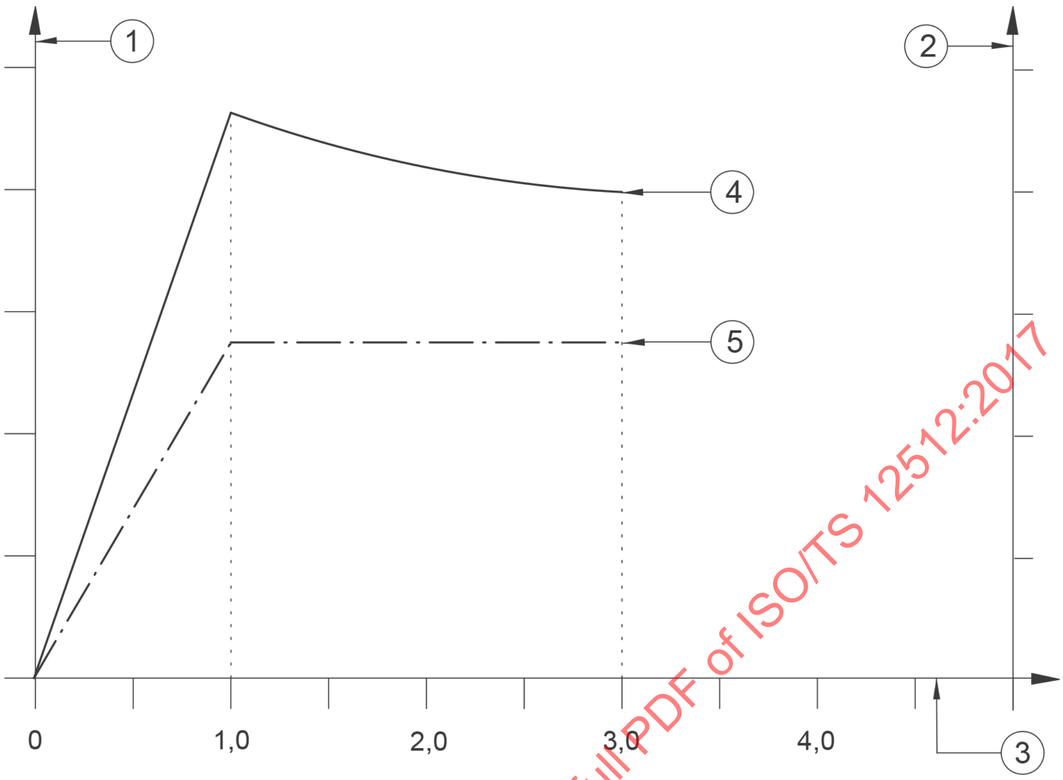
Figure 3 — Method A: Load and corresponding deflection versus time

8.3.2 Method B: Using constant deflection

See Figure 4.

Using Formula (8) calculate the required deflection, y_d, in metres, for the segmental test piece assuming that when testing a full ring test piece in accordance with ISO 7685 a relative deflection of 3 % would be required.

Apply the compressive load at an approximately constant rate so that the deflection, y_d, is reached in (60 ± 10) s. Maintain this deflection constant for 2 min, and at the end of this period determine and record the load and the deflection.



Key

1 load axis
2 deflection axis
3 elapsed time, expressed in minutes
4 load applied to segmental test piece, F_{79}
5 maintained deflection

Figure 4 — Method B: Deflection and corresponding load versus time

9 Calculations

For each segmental test piece subject to the test described in 8.3, calculate the initial specific ring stiffness, S_0, using Formula (11):

$$S_0 = 0{,}2883\beta \frac{F_{79}}{y_d} \frac{\xi}{b} \quad (11)$$

where

F_{79} is the applied load, expressed in newtons;

y_d is measured deflection of segmental test piece, expressed in metres;

b is the average width of the test piece, expressed in metres;

β is the load correction factor = $(d_m - e)/d_m$

where

d_m is the mean diameter of the tested pipe, expressed in metres;

e is the wall thickness of the test piece, in metres.

ξ is the deflection coefficient, given by Formula (12):

$$\xi = \left\{1860 + \left(2500 \times y_s / d_m\right)\right\} \times 10^{-5} \quad (12)$$

where

d_m is the mean diameter of the tested pipe, expressed in metres;

y_s is the deflection of the pipe ring derived from the deflection of the segmental test piece using Formula (13), expressed in metres (for details refer to Formula (A.14)):

$$y_s = 3{,}469\ y_d \quad (13)$$

Calculate the average of the three values and record this value as the initial specific ring stiffness, expressed in newtons per metre squared (N/m^2).

10 Test report

The test report shall include the following information:

a) a reference to this document, i.e. ISO/TS 12512:2017, and other standards, if applicable;

b) all details necessary for complete identification of the pipe tested;

c) the dimensions of each test piece;

d) the number of test pieces;

e) the positions in the pipe from which the test pieces were obtained;

f) the equipment details, including whether a beam bar or plate were used;

g) the test temperature;

h) the test method used, i.e. method A or B, if applicable ;

i) for each test piece, the loads and corresponding deflections used to calculate the initial specific ring stiffness, if applicable;

j) the initial specific ring stiffness of each test piece, if applicable;

k) any factors which may have affected the results, such as any incidents which may have occurred or any operating details not specified in this document;

l) the date of the test.

Annex A
(informative)

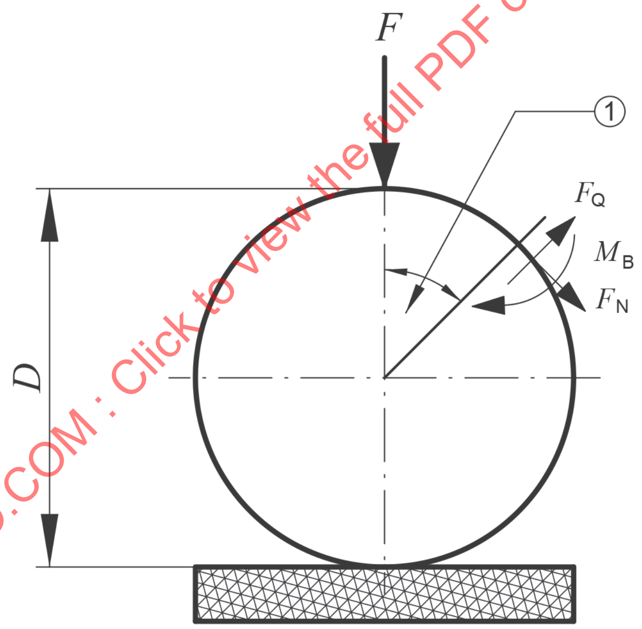
Principles forming basis for use of segmental test pieces

A.1 Introduction

Testing of stiffness and ultimate ring deflection of GRP pipes is done using test pieces of length 300 mm cut from pipes. When testing pipes of large diameters this results in large test pieces and high deformation energies.

A.2 Mechanical basics

The principles relating to the basis of the mechanical system of a stiffness test, (see Figure A.1), involves the following formulas which describe forces and bending moments in the pipe ring.



Key

1 angle φ
D diameter
F compressive load
F_N normal force
F_Q transverse force
M_B bending moment

Figure A.1 — Mechanical system of the stiffness test

A.2.1 Normal and transverse forces

$$F_N = -\frac{1}{2} \cdot F \cdot \sin(\varphi) \tag{A.1}$$

$$F_Q = \frac{1}{2} \cdot F \cdot \cos(\varphi) \tag{A.2}$$

A.2.2 Bending moment

$$M = -\frac{F \cdot D}{2} \cdot \left(\frac{1}{\pi} - \frac{\sin(\varphi)}{2} \right) \tag{A.3}$$

Normal forces are defined as positive when leading to tensile stresses. Positive transverse forces are aligned away from the pipe centre in a radial direction. Bending moments are defined as positive when they increase the curvature of the pipe wall. Therefore positive bending moments result in tensile bending stresses at the pipe outside (see Figure A.2).

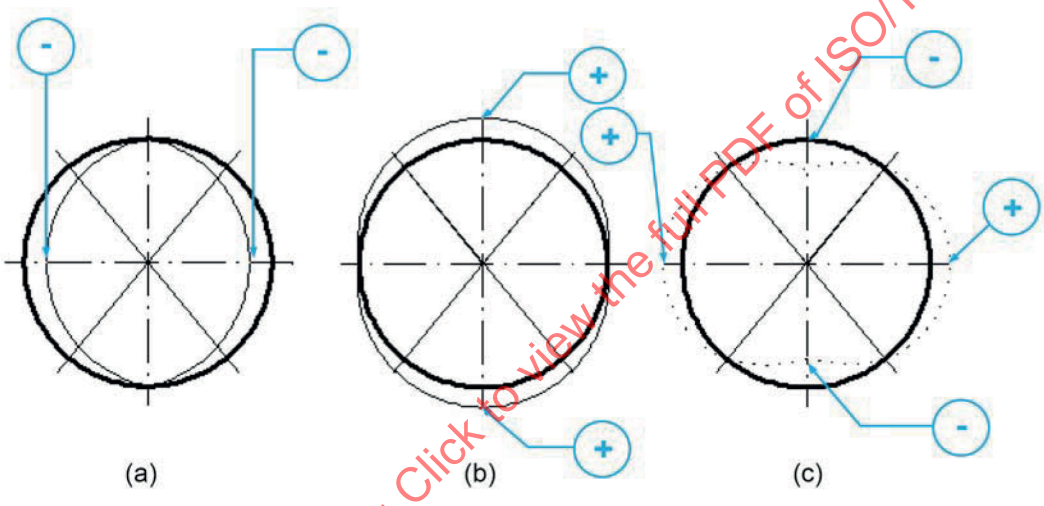
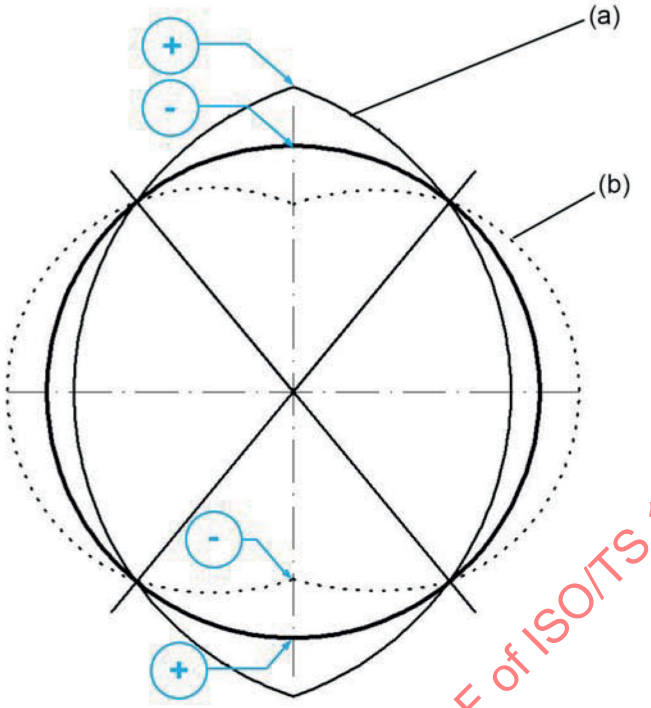


Figure A.2 — Distribution of a) normal force, b) transverse force, c) bending moment

Both the forces and the bending moment have a symmetrical distribution around the circumference with respect to the symmetry lines, (see Figure A.2). Therefore it is sufficient to consider only one quarter of the pipe ring.

Normal forces are negative around the whole circumference, having a minimum at φ = 90 °, and therefore a maximum compression stress at this point (see Figure A.2). Transverse forces are leading to shear stresses which are maximum at φ = 0 ° and have the same magnitude as the maximum normal stress (see Figure A.2). The bending moment is at a minimum at φ = 0 °, which results in tensile stresses on the inside of the pipe and are at a maximum at φ = 90 ° with resulting tensile stresses on the outside of the pipe. This is in accordance with the principle that “positive moments give tensile stresses on the outside of the pipe and compressive stresses on the inside, and this is reversed for negative moments”.

At φ = 90 ° where compressive bending stresses are superimposed on compressive normal stresses, bending stresses are higher than normal stresses by a factor of approximately D/e (diameter to wall thickness). This means that normal stresses do not significantly contribute to the stress state in the pipe ring. Hence the stress state in the pipe ring is mainly given with the bending stresses (see Figure A.3).



Key

(a) inside of pipe wall

(b) outside of pipe wall

Figure A.3 — Distribution of bending stresses

A.3 Modified test pieces

As one can see from Figure A.3, the moment changes sign four times around the circumference of the pipe ring. The angles φ_{0M}, where the bending moment becomes zero, can easily be investigated from Formula (A.3) with:

$$M = 0 = -\frac{F \cdot D}{2} \cdot \left(\frac{1}{\pi} - \frac{\sin(\varphi_{0M})}{2} \right) \tag{A.4}$$

$$\frac{1}{\pi} - \frac{\sin(\varphi_{0M})}{2} = 0 \tag{A.5}$$

$$\varphi_{0M} = \arcsin\left(\frac{2}{\pi} \right) \tag{A.6}$$

$$\varphi_{0M} = (39{,}5°; 129{,}5°; 219{,}5°; 309{,}5°) \tag{A.7}$$

By dividing the pipe ring at these calculated angles into four parts it is possible to obtain four test pieces which have the same distribution of forces and bending moments, compared to the full ring, when loaded and supported appropriately as described below.

The four test pieces consist of two 79 ° sections and two 101 ° sections of a circular beam, whereas only two test pieces, one 79 ° test piece and one 101 ° test piece, are necessary to completely simulate the loading conditions of the full ring.

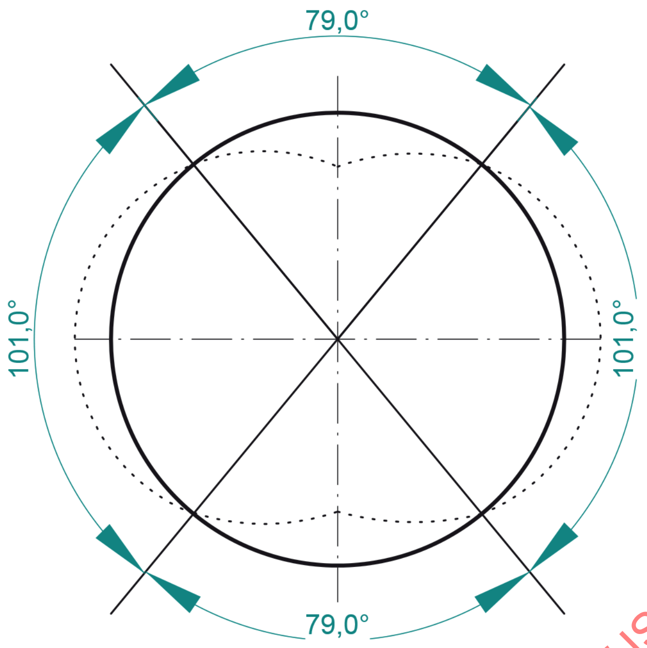


Figure A.4 — Locations of four test pieces

A.3.1 The 79 ° test piece

The 79 ° test piece is used for simulating the loading conditions at φ = 0 ° pipe angle (see Figure A.2). The required supporting conditions to be applied for the 79 ° test piece takes advantage of zero bending moment at the test piece ends which means that clamping of the test piece is not necessary and not allowed in order to ensure zero bending moments at the test piece ends (see Figure A.5).

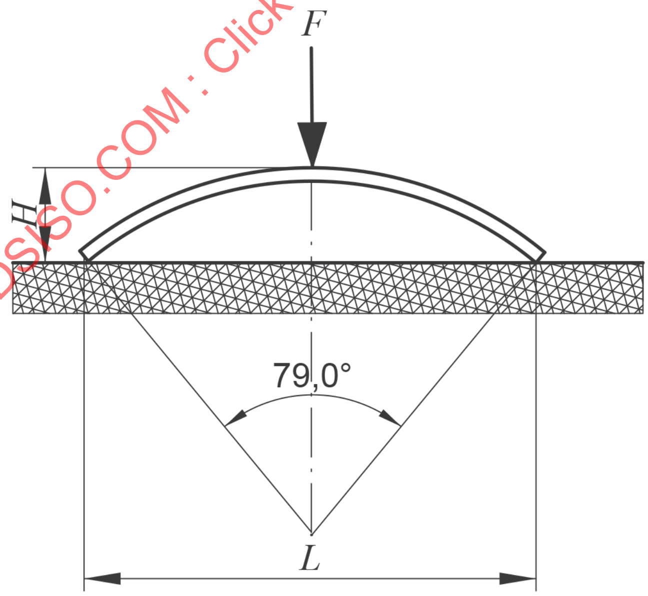


Figure A.5 — Principle of testing with the 79 ° segmental test piece

The 79 ° segmental test piece is supported on both ends so that it is free to move and the deformation force has to act on the test piece centre (see Figure A.5). The amounts of deflection required for the segment tests, in order to simulate the normal ring tests, have been determined using finite element analysis. This analysis showed that the deflections of the segment elements within the pipe wall are not