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## Glass-reinforced thermosetting plastics (GRP) pipes — Determination of the long-term ultimate bending strain and the long-term ultimate relative ring deflection under wet conditions

*Tubes en plastiques thermodurcissables renforcés de verre (PRV) — Détermination de l'effort à la flexion ultime à long terme et réflexion annulaire relative ultime à long terme dans des conditions mouillées*



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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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# Foreword

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ISO 10471 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*.

# Glass-reinforced thermosetting plastics (GRP) pipes — Determination of the long-term ultimate bending strain and the long-term ultimate relative ring deflection under wet conditions

## 1 Scope

This International Standard specifies a method for determining by extrapolation the long-term ultimate bending strain and the calculation of the long-term ultimate relative ring deflection of glass-reinforced thermosetting plastics (GRP) pipes, under wet conditions.

Two methods of loading are given, one using plates the other beam bars.

NOTE Either method may be used for measurements of relative vertical deflection up to 28 %. When it is expected that this level is going to be exceeded then the procedure is limited to the use of at least one beam bar.

## 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*

ISO 10928:1997, *Plastics piping systems — Glass-reinforced thermosetting plastics (GRP) pipes and fittings — Methods for regression analysis and their use*

## 3 Terms and definitions

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

**3.1**
**vertical compressive force**
$F$
vertical force, expressed in newtons, applied to a horizontal pipe to cause a vertical deflection

**3.2**
**mean diameter**
$d_m$
diameter, expressed in metres, of the circle corresponding with the middle of the pipe wall cross-section and given by either of the following equations:

$$d_m = d_i + e \tag{1}$$

$$d_m = d_e - e \tag{2}$$

where

$d_i$ is the internal diameter, in metres;

$d_e$ is the external diameter, in metres;

$e$ is the wall thickness of the pipe, in metres.



**3.3**
**vertical deflection**
$y$
vertical change in diameter of a pipe in a horizontal position, expressed in metres, in response to a vertical compressive force (see 3.1)

**3.4**
**relative vertical deflection**
$y/d_m$
ratio of the vertical deflection, $y$ (see 3.3), to the mean diameter of the pipe, $d_m$ (see 3.2)

**3.5**
**ultimate vertical deflection under wet conditions**
$y_{u, wet}$
vertical deflection of the pipe, $y$ (see 3.3), expressed in metres, when failure occurs under wet conditions (see Clause 4)

**3.6**
**ultimate relative vertical deflection under wet conditions**
$y_{u, wet}/d_m$
ratio of the ultimate vertical deflection under wet conditions, $y_{u, wet}$ (see 3.5), to the mean diameter of the pipe, $d_m$ (see 3.2)

**3.7**
**long-term ultimate ring deflection under wet conditions**
$y_{u, wet, x}$
extrapolated value of the ultimate vertical deflection, expressed in metres, of the pipe under wet conditions, $y_{u, wet}$ (see 3.5), when failure is expected to occur at a time, $x$, specified in the referring standard

**3.8**
**long-term ultimate relative ring deflection under wet conditions**
$y_{u, wet, x}/d_m$
ratio of the long-term ultimate ring deflection under wet conditions, $y_{u, wet, x}$ (see 3.7), to the mean diameter of the pipe, $d_m$ (see 3.2)

**3.9**
**failure**
loss of the structural integrity of a test piece as evidenced by the inability of the test piece to carry the load

**3.10**
**time to failure**
$t_u$
time elapsed, expressed in hours, until failure (see 3.9) occurs

**3.11**
**specific ring stiffness**
$S$
physical characteristic of a pipe, expressed in newtons per square metre, that is a measure of the resistance to ring deflection per metre length under external load and is defined by Equation (3):

$$S = \frac{E \times I}{{d_m}^3} \tag{3}$$



where

$E$ is the apparent modulus of elasticity, in newtons per square metre, determined by testing in accordance with ISO 7685;

$I$ is the second moment of area in the longitudinal direction per metre length, in metres to the fourth power per metre ($m^4/m$), i.e.

$$I = \frac{e^3}{12} \quad (4)$$

$e$ being the wall thickness of the pipe, in metres;

$d_m$ is the mean diameter of the pipe, in metres (see 3.2)

**3.12**
**initial specific ring stiffness**
$S_0$
value of $S$, expressed in newtons per square metre, determined by testing in accordance with ISO 7685

**3.13**
**strain factor**
$D_g$
dimensionless factor used to transform a deflection value into a strain value

## 4 Principle

Each of several cut lengths of pipe is supported horizontally and loaded throughout its length to compress it diametrically to achieve a desired level of strain. The force application surfaces are either bearing plates or beam bars.

The pipe is immersed in water at a given temperature for a period of time during which the force remains constant and the increasing vertical deflection is measured at intervals until failure (see 3.9) occurs. The relative vertical deflection at failure [ultimate relative vertical deflection, $y_{u,\,wet}/d_m$ (see 3.6)] is converted into a bending strain at failure (ultimate bending strain, $\varepsilon_{u,\,wet}$, in percent), either calculated using Equation (5) or determined from a strain-deflection calibration curve (see 10.3).

NOTE The strain may also be measured directly by the use of waterproofed strain gauges.

$$\varepsilon_{u,\,wet} = D_g \times \frac{e}{d_m} \times \frac{y_{u,\,wet}}{d_m} \times 100 \quad (5)$$

where

$D_g$ is calculated using Equation (6):

$$D_g = \frac{4,28}{\left(1 + \frac{y_{u,\,wet}}{2 \times d_m}\right)^2} \quad (6)$$

$y_{u,\,wet}$ being the ultimate vertical deflection under wet conditions, in metres;

$d_m$ is the mean diameter of the pipe (see 3.2), in metres;

$e$ is the mean wall thickness of the pipe, obtained from several measurements around the pipe circumference, in metres.

These values of ultimate bending strain and the applicable times, $t_u$ (see 3.10), are used in the procedures described in method A of ISO 10928:1997 to determine the long-term ultimate bending strain under wet conditions, $\varepsilon_{u,\ wet,\ x}$. If it is required to determine the long-term ultimate relative ring deflection under wet conditions, $y_{u,\ wet,\ x}/d_m$ (see 3.8), expressed in percent, then the long-term ultimate bending strain is converted to deflection using Equation (7):

$$\frac{y_{u,\ wet,\ x}}{d_m} = \frac{\varepsilon_{u,\ wet,\ x}}{D_g \times \dfrac{e}{d_m}} \tag{7}$$

NOTE It is assumed that values for the following test parameters will be set by the standard making reference to this International Standard:

a) the time, $x$, to which the values are to be extrapolated (see 3.7 and 3.8);

b) the test temperature (see 5.3 and 10.1);

c) the length and number of test pieces (see Clauses 6 and 7);

d) the distribution of the times to failure (see 10.8);

e) the pH of the test water.

The standard test procedure is to determine and analyse the bending strains induced by the vertical deflections. This procedure accommodates sample to sample variation and results in a strain versus time expression applicable to a range of pipe classifications.

## 5 Apparatus

### 5.1 Compressive loading machine

The machine shall comprise a system capable of applying a force, without shock, through two parallel force application surfaces conforming to 5.2 so that a horizontally orientated test piece of pipe conforming to Clause 6 and immersed in water can be compressed vertically and maintained under a constant force for the duration of the test in accordance with 10.7.

Equipment shall be available for determining the force applied to within ± 1 % of the total force.

Ensure that the applied force is not affected by buoyancy effects or friction.

NOTE For test pieces subjected to high predetermined forces, for which failure is expected to occur within 100 h, an automatic recording device will help in recording failure times and deflections accurately.

### 5.2 Force application surfaces

NOTE The method allows the use of either bearing plates or beam bars for loading the test piece, subject to reporting the choice used. Either method may be used for measurements of relative vertical deflection up to 28 %. When it is expected that 28 % deflection is going to be exceeded then the procedure is limited to the use of at least one beam bar.

#### 5.2.1 General arrangement

The surfaces shall be provided by a pair of bearing plates, conforming to 5.2.2, or a pair of beam bars, conforming to 5.2.3, or a combination of one such plate and one such bar. However, if the applied force is expected to cause a relative deflection in excess of 28 %, at least one of the surfaces shall be a beam bar. The surface's major axes shall be perpendicular to and centred on the direction of application of force $F$ by the compressive loading machine, as shown in Figure 1. The surfaces to be in contact with the test piece shall be flat, smooth, clean and parallel.



### 5.2.2 Plates

The plate(s) shall have a width of at least 100 mm and a length at least equal to the length of the test piece (see Clause 6). They shall be sufficiently stiff so that they do not visibly bend or otherwise deform during the test.

### 5.2.3 Beam bars

Each beam bar shall be sufficiently stiff that it does not visibly bend or otherwise deform during the test. Each beam bar shall have a length at least equal to the length of the test piece (see Clause 6) and a flat face (see Figure 1) without sharp edges. The width of the flat face shall be 15 mm to 55 mm.

The beam bars shall be so constructed and supported that no other surface of the beam bar structure comes into contact with the test piece during the test.

## 5.3 Water container

Required is a container large enough to accommodate submerged test pieces conforming to Clause 6 whilst they are subject to the compressive force in accordance with 10.6 and containing test water maintained at the specified temperature (see Clause 4).

The water level shall be maintained sufficiently constant to avoid any significant effect on the value of the vertical force applied to the test piece.

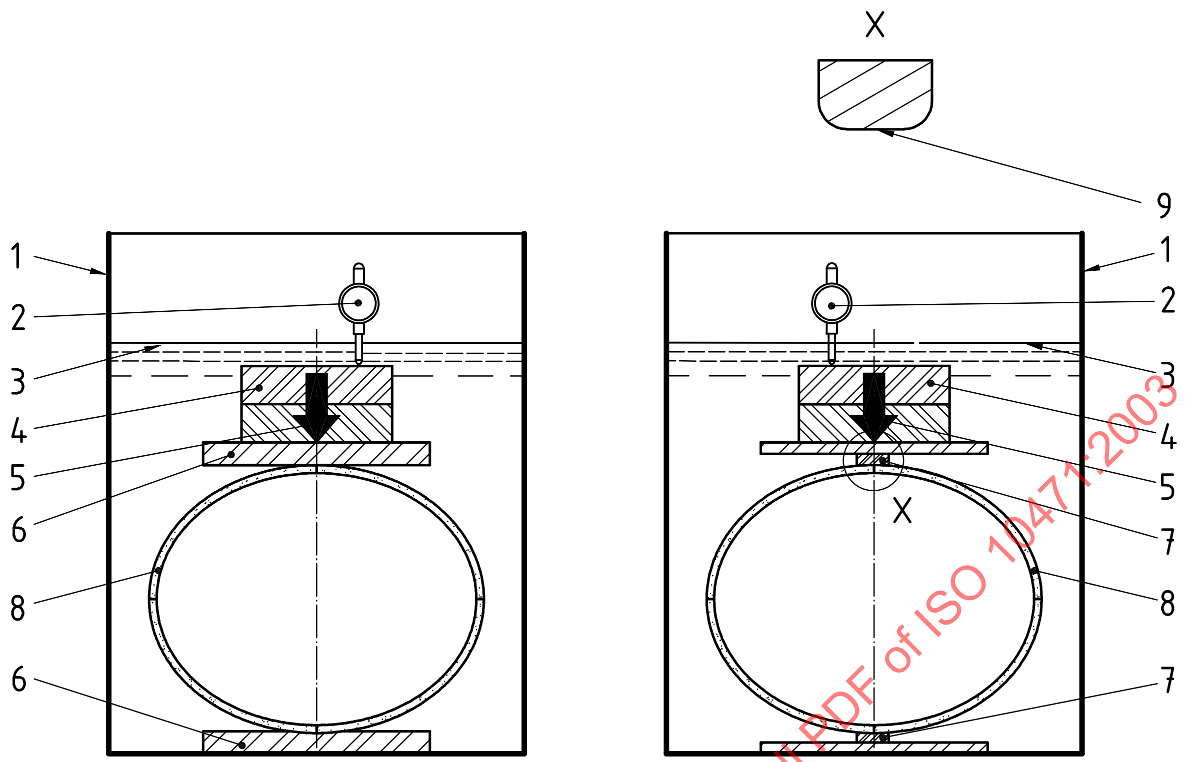
## 5.4 Measuring devices

Required are devices capable of determining:

a) the necessary dimensions (length, diameters, wall thickness) to an accuracy within ± 1,0 mm;

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

NOTE When selecting the device to measure the change in diameter of the test piece, consideration should be given to the potentially corrosive environment in which the device is to be used.




a) **Plate loading** b) **Beam bar loading**

**Key**

1 water container
2 deflection-measuring device
3 water level
4 deadweights
5 direction of compressive force, $F$
6 bearing plate
7 beam bar
8 test piece
9 flat face

**Figure 1 — Typical test arrangements**

## 6 Test piece

The test piece shall be a complete ring. The length, $L$, in metres, of the test piece shall be as specified in the referring standard, subject to permissible deviations of ± 5 %. If not specified in the referring standard, the length of the test piece shall be (300 ± 15) mm.

The ends shall be smooth, shall be cut perpendicular to the axis of the pipe and may be sealed.

Two straight lines shall be drawn on either the inside or the outside along the length of the test piece and at 180° to each other, to serve as reference lines.

## 7 Number of test pieces

Unless otherwise specified in the referring standard at least 18 test pieces shall be used to obtain the distribution of failure times specified in the referring standard (see Note to Clause 4).

## 8 Determination of the dimensions of the test piece

### 8.1 Length

Measure the length of each test piece along each reference line with an accuracy within ± 1,0 % to determine whether or not the test piece conforms to Clause 6. Trim or replace, as applicable, the test piece if it does not conform.

Calculate the mean length, $L$, in metres, of each test piece from the six measured values.

### 8.2 Wall thickness

Measure to within ± 0,2 mm the wall thickness of each test piece at each end of each reference line.

Calculate the mean wall thickness, $e$, in metres, of the four measured values.

### 8.3 Mean diameter

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

a) the internal diameter, $d_i$, of the test piece between the diametrically opposed pair of reference lines at their mid-length, e.g. by means of calipers, subsequently calculating the internal diameter, $d_i$, in metres;

b) the external diameter, $d_e$, in metres, of the test piece by means of a circumferential wrap steel tape.

Using either Equation (1) or Equation (2), calculate the mean diameter, $d_m$ (see 3.2), of the test piece using the value obtained for the mean wall thickness, $e$, in 8.2 and either the internal or external diameter.

## 9 Conditioning

If applicable, condition the test pieces in accordance with the referring standard.

## 10 Procedure

**10.1** For each test piece conduct the following procedure at the temperature specified in the referring standard (see Clause 4).

**10.2** To assess the uniformity of the test pieces, for at least six of the test pieces determine and record in accordance with the procedures in ISO 7685 the initial specific ring stiffness, $S_0$, of the test piece. The measured value of $S_0$ at the pair of reference lines (see Clause 6) may also be used to estimate the force required to compress the test piece to the necessary deflection to achieve a time to failure, together with those produced from other test pieces, that conforms to the distribution of times to failure specified in the referring standard.

**10.3** Deflections in excess of 28 % of the diameter may cause local flattening of the pipe and lead to erratic test results. For deflections approaching 28 %, improved accuracy is obtained by use of strain gauges to establish, for each pipe product, a calibration scale of deflection versus measured strain. This calibration technique is useful at all deflection levels. If such a calibration procedure is established then it shall be used to determine the strains for all test pieces in the test series.

**10.4** Place a test piece in the apparatus in contact with the upper and lower plate or beam bar with the pair of diametrically opposed reference lines vertically aligned. However, if the applied force is expected to result in relative deflections that may be in excess of 28 %, use at least one beam bar. Ensure that the contact between the test piece and each bearing plate or beam bar is as uniform as possible and the plates and/or beam bars are not tilted laterally. Place the apparatus in the water container.

**10.5** Fill the container with water so that the test piece is fully immersed.

**10.6** When the test piece is fully immersed in the water and taking account, as necessary, of the weight of the upper plate or beam bar, and of any spacer, apply the vertical compressive force, $F$, so that the corresponding vertical deflection is reached within 3 min and record the actual force applied and deflection achieved.

**10.7** Whilst maintaining the force applied in 10.6, measure and record at predetermined intervals of time the elapsed time and the deflection of the test piece, using either suitable manual devices or automatic recording equipment capable of the accuracy specified in 5.4. When failure (see 3.9) occurs, the time to failure, $t_\text{u}$, and the deflection at failure, $y_\text{u, wet}$, shall be taken as:

a) either the elapsed time and its associated deflection recorded on the automatic device;

b) or the last recorded readings, prior to failure occurring, of deflection and its associated time.

NOTE Table A.1 in Annex A gives values of equal lg(time in h) increments which may be useful to the operator.

**10.8** Continue the procedure detailed in 10.2 to 10.7 inclusive until at least 18 test pieces have failed with the distribution of times to failure specified in the referring specification. However, if 16 test pieces have failed and two others have been on test for more than 10 000 h without failing then these two test pieces may be included in the data at their current elapsed time and deflection if it provides sufficient data for extrapolation and the distribution of failure times required by the referring standard will be satisfied.

**10.9** Convert the relative vertical deflection at failure [ultimate relative vertical deflection, $y_\text{u, wet}/d_\text{m}$ (see 3.6)] determined in accordance with 10.7 and 10.8 into a bending strain at failure (ultimate bending strain), $\varepsilon_\text{u, wet}$, in percent, using Equation (5) or determined by deflection-strain calibration.

## 11 Calculation

### 11.1 Extrapolation of the strain data to obtain the $x$-year value, $\varepsilon_{x,\text{ wet}}$

Determine lg(time to failure in h), $t_\text{u}$ (see 3.10), and lg(bending strain at failure in percent) from the series of calculated bending strains at failure and their associated times obtained in accordance with 10.9.

From this data, determine, in accordance with method A of ISO 10928:1997, the equation of the strain regression line. Using this equation, calculate the extrapolated logarithm of the long-term ultimate bending strain under wet conditions at $x$ years, lg($\varepsilon_{\text{u, wet, }x}$) and then the long-term ultimate bending strain, $\varepsilon_{\text{u, wet, }x}$, in percent.

If required by the referring standard, use the data obtained in accordance with 10.9 and plot lg(bending strain at failure) as a function of lg(time in h), i.e. the strain regression line.

### 11.2 Calculation of the long-term ultimate relative ring deflection under wet conditions, $y_{\text{u, wet, }x}/d_\text{m}$

Where it is required to determine the long-term ultimate relative ring deflection under wet conditions, expressed in percent, $y_{\text{u, wet, }x}/d_\text{m}$ (see 3.8), convert the long-term ultimate bending strain, $\varepsilon_{\text{u, wet, }x}$, determined in 11.1 to a deflection, in percent, using Equation (7).

## 12 Test report

The test report shall include the following information:

a) a reference to this International Standard and the referring standard;

b) full identification of the pipe tested;

c) the number of test pieces;