BRITISH STANDARD

BS EN 1227:1998
BS 2782-12:
Method 1214F:
1998

Plastics piping systems — Glass-reinforced thermosetting plastics (GRP) pipes — Determination of the long-term ultimate relative ring deflection under wet conditions

The European Standard EN 1227:1997 has the status of a British Standard

ICS 23.040.20

National foreword

This British Standard is the English language version of EN 1227:1997.

The UK participation in its preparation was entrusted to Technical Committee PRI/61, Plastics piping systems and components, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this committee can be obtained on request to its secretary.

This European Standard is also incorporated into BS 2782-12 *Methods of testing plastics — Part 12: Reinforced plastics pipes, fittings and valves*, as Method 1214F:1998, for association with related test methods for plastics materials and plastics piping systems.

It may be used for the revision or amendment of other national standards, but it should not be presumed to apply to any existing standard or specification which contains or makes reference to a different test method until that standard/specification has been amended or revised to make reference to this method and adjust any requirements as appropriate.

NOTE In Table A.3 of this English language version, the value of LCL given for test piece #18, shown in the ratified text of EN 1227 as "−2,9.5", has been corrected to read "−2,905"; and the value of Z_u given for test piece #9, shown in the ratified text as "0,11", has been corrected to read "1,11".

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the BSI Standards Catalogue under the section entitled "International Standards Correspondence Index", or by using the "Find" facility of the BSI Standards Electronic Catalogue.

WARNING. This British Standard, which is identical with EN 1227:1997, does not necessarily detail all the precautions necessary to meet the requirements of the Health and Safety at Work etc. Act 1974. Attention should be paid to any appropriate safety precautions and the method should be performed only by trained personnel.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, the EN title page, pages 2 to 14, an inside back cover and a back cover.

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English version

Plastics piping systems — Glass-reinforced thermosetting plastics (GRP) pipes — Determination of the long-term ultimate relative ring deflection under wet conditions

Systèmes de canalisations en plastique — Tubes en plastique thermodurcissable renforcé de verre (PRV) — Détermination de la déflexion annulaire relative ultime, à long terme, en conditions mouillées

Kunststoff-Rohrleitungssysteme — Rohre aus glasfaserverstärkten duroplastischen Kunststoffen (GFK) — Ermittlung der relativen Langzeit-Ringverformbarkeit unter Feuchteeinfluß

This European Standard was approved by CEN on 16 August 1997.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

CEN
European Committee for Standardization
Comité Européen de Normalisation
Europäisches Komitee für Normung

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Ref. No. EN 1227:1997 E

Foreword

This European Standard has been prepared by Technical Committee CEN/TC 155, Plastics piping systems and ducting systems, the secretariat of which is held by NNI.

This standard is based on the draft proposal for an International Standard ISO/DP 10471.2 *Glass-reinforced thermosetting plastics (GRP) pipes and fittings — Determination of the long-term ultimate ring deflection of pipes under wet conditions*, prepared by the International Organization for Standardization (ISO). It is a modification of ISO/DP 10471.2 for reasons of possible applicability to other test conditions and alignment with texts of other standards on test methods.

The modifications are:

- the slope of the logarithm (lg) of the vertical deflection versus lg [time] is not used as a failure criterion;
- test parameters are not specified;
- material-dependent or performance requirements are not given;
- editorial changes have been introduced.

The material-dependent test parameters and/or performance requirements are incorporated in the referring standard.

Annex A, which is normative, is an example using the procedures described in **8.5**.

This standard is one of a series of standards on test methods which support system standards for plastics piping systems and ducting systems.

This European standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by June 1998, and conflicting national standards shall be withdrawn at the latest by June 1998.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

Contents

1 Scope

This standard specifies a method for determining by extrapolation the long-term ultimate relative ring deflection of glass-reinforced thermosetting plastics (GRP) pipes under wet conditions.

Two methods of loading are given, depending upon the use of plates or beam bars.

NOTE Either method may be used for measurements of relative deflection up to 28 %. When it is expected that this level is exceeded, then the procedure is limited to the use of beam bars.

2 Normative references

This standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter.

For dated references, subsequent amendments to, or revisions of, any of these publications apply to this standard only when incorporated in it by amendment or revision.

For undated references, the latest edition of the publication referred to applies.

EN 705:1994, *Plastics piping systems — Glass-reinforced thermosetting plastics (GRP) pipes and fittings — Methods for regression analyses and their use*

3 Definitions

For the purposes of this standard, the following definitions apply.

3.1

vertical compressive load *(F)*

the vertical load applied to a horizontal pipe to cause a vertical deflection

it is expressed in newtons

3.2

vertical deflection *(y)*

the vertical change in diameter of a horizontal pipe in response to a vertical compressive load

it is expressed in metres

3.3

mean diameter (d_m)

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

it is given, in metres, by either of the following equations:

$$d_m = d_i + e_A$$

$$d_m = d_e - e_A$$

where

d_i is the average of the measured internal diameters (see **6.3.3**), in metres;

d_e is the average of the measured external diameters (see **6.3.3**), in metres;

e_A is the average of the measured wall thicknesses of the pipe (see **6.3.2**), in metres

NOTE For the purpose of this definition and to avoid confusion, the symbol "e_A" is used to represent the wall thickness of the pipe. Elsewhere in this standard (for consistency with EN 705), the symbol "e" is used for one of a series of coefficients used in polynomial equations.

3.4

relative vertical deflection (y/d_m)

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

3.5

ultimate vertical deflection under wet conditions ($y_{u,wet}$)

the vertical deflection (see **3.2**) under wet conditions when a failure occurs (see **8.5** and clause **4**)

it is expressed in metres

3.6

ultimate relative vertical deflection under wet conditions ($y_{u,wet}/d_m$)

the ratio of the ultimate vertical deflection under wet conditions (see **3.5**) to the mean diameter, d_m, of the pipe (see **3.3**)

3.7

long-term ultimate ring deflection under wet conditions ($y_{u,wet,x}$)

the value of the extrapolated ultimate vertical deflection under wet conditions (see **3.5**) at a time, x, specified in the referring standard

it is expressed in metres

3.8

long-term ultimate relative ring deflection under wet conditions ($y_{u,wet,x}/d_m$)

the ratio of the long-term ultimate ring deflection under wet conditions (see **3.7**) to the mean diameter, d_m, of the pipe (see **3.3**)

3.9

rate of vertical deflection (r)

the rate of change in diameter in the vertical direction caused by the vertical compressive load (see **3.1**)

it is expressed in metres per hour

3.10

rate of vertical deflection at failure (r_u)

the value of r (see **3.9**) when failure occurs (see **8.5** and clause **4**)

It is expressed in metres per hour.

3.11

failure

loss of the structural integrity of the test piece as defined by either of the following conditions:

a) rupture of the pipe wall;

b) if applicable (see **8.5.2**), estimated rupture of the pipe wall derived from the intersection of:

1) the line described by the logarithm of the rate of deflection, lg r, versus the logarithm of time, lg t, as obtained from a series of vertical deflection/time points of an individual test piece, not yet ruptured [see equation (1)]; and

2) the line as described by the logarithm of the rate of vertical deflection at rupture, lg r_u, versus the logarithm of time, lg t_u, derived from a series of test pieces [see equation (2)],

whereby the equations are the following:

$$\lg r = w - z + \lg w' \qquad (1)$$

where

$$w = a + (b \times z) + (c \times z^2) + (d \times z^3) + (e \times z^4);$$
$$w' = b + (2 \times c \times z) + (3 \times d \times z^2) + (4 \times e \times z^3);$$
$$z = \lg t;$$

where

a, b, c, d, e	are coefficients;
t	is the time, in hours.

$$\lg r_u = f + (g \times \lg t_u) - (t_v \times \sigma_u) \qquad (2)$$

where

f, g	are coefficients;
t_v	is Student's t;
σ_u	is the standard deviation of the values of lg r_u.

3.12

time to failure (t_u)

the time elapsed until a failure occurs (see **8.5** and **3.11**)

It is expressed in hours.

3.13

deflection regression ratio ($R_{R,def}$)

the ratio between the extrapolated long-term (50 years) property and the extrapolated short-term (6 min) property based on deflection

3.14

strain regression ratio ($R_{R,str}$)

the ratio between the extrapolated long-term (50 years) property and the extrapolated short-term (6 min) property based on strain

3.15

strain factor (D_g)

the factor used to transform a deflection value into a strain value at a certain point in time

4 Principle

Each of several cut lengths of pipe, supported horizontally and under water, is subjected to a vertical load throughout its length such that each test piece is subject to a load which is different from that applied to any of the others. The resulting vertical deflections are recorded at given times.

Depending upon the level of deflection and the time elapsed, cracks will be initiated and propagate to failure.

The long-term ultimate ring deflection under wet conditions is obtained by extrapolation of the data in accordance with EN 705.

A regression ratio for deflection is calculated relative to a specific short-term deflection, and this can be converted, if required, to a regression ratio based on strain.

NOTE It is assumed that the following test parameters are set by the standard making reference to this standard:

a) the time, x, to which the values are to be extrapolated (see **3.7** and clauses **8** and **9**);

b) the length and number of test pieces (see clause **6**);

c) the test temperature (see **8.1**);

d) if necessary, the distribution of the times to failure (see note to **8.5**).

5 Apparatus

5.1 *Compressive loading machine*, comprising a system capable of applying a load without shock, through two parallel load application surfaces conforming to **5.2**, so that a horizontally orientated test piece of pipe, conforming to clause **6** and immersed in water in accordance with **8.3**, can be compressed vertically and maintained under constant load in accordance with **8.3**.

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

5.2 *Load application surfaces*, as described in **5.2.1** to **5.2.3**.

5.2.1 *General arrangement*

The surfaces shall be provided by a pair of 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. Their major axes shall be perpendicular to, and centred on, the direction of application of load F 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*

Each plate shall have a length at least equal to the length of the test piece (see **6.1**), a width of at least 100 mm and a thickness such that no visible bending or deformation of the plate shall occur during the test.

5.2.3 *Beam bars*

Each beam bar shall be rigid and shall have a length at least equal to the length of the test piece (see **6.1**), and shall have a flat face (see Figure 1) without sharp edges and with a width dependent upon the pipe size as follows:

a) for pipes with a nominal size not greater than DN 300, the width shall be (20 ± 2) mm;

b) for pipes with a nominal size greater than DN 300, the width shall be (50 ± 5) mm.

The beam bar(s) shall be so constructed and supported that no other surface of the beam bar structure shall come into contact with the test piece during the test.

5.3 *Water container*, large enough to accommodate and, if necessary, support submerged test pieces, in accordance with clause **6** and **8.3**, while they are subject to a compressive load in accordance with **8.4** and **8.5**.

The liquid shall be tap water, having a pH of 7 ± 2 and kept at a specified temperature (see **8.1**).

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

5.4 *Dimensional measuring devices*, capable of determining the following:

- the necessary dimensions (length, 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.

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.

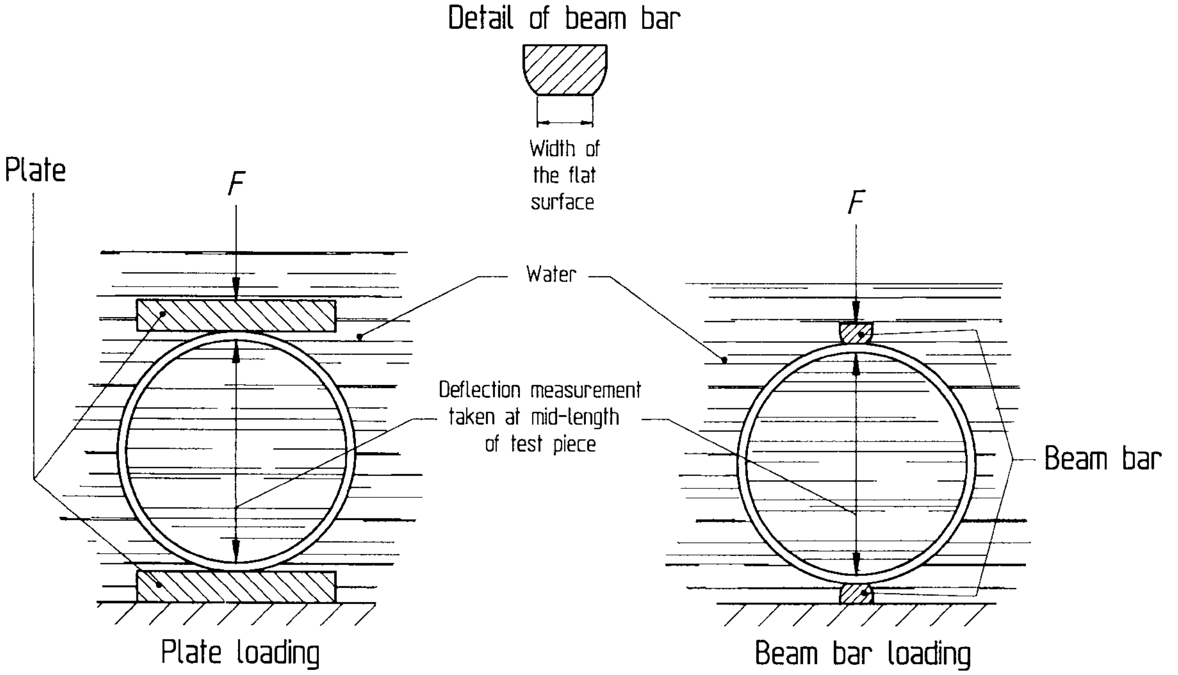

Figure 1 — Schematic diagram of the test arrangement

6 Test pieces

6.1 Preparation

The test piece shall be a complete ring cut from the pipe to be tested. The length of the test piece shall be as specified in the referring standard, with permissible deviations of ± 5 %.

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

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

6.2 Number

The number of test pieces shall be as specified in the referring standard.

6.3 Determination of the dimensions

6.3.1 *Length*

Measure the length of the test piece along each reference line to an accuracy of 1,0 %.

Calculate the average length, L, of the test piece, in metres.

6.3.2 *Wall thickness*

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

Calculate the average wall thickness, e_A, as the average of the four measured values, in metres.

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 test piece between the reference lines at their mid-length, e.g. by means of a calliper;

b) the external diameter, d_e, of the test piece, which includes the mid-points of the reference lines, 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 and either the internal or the external diameter (see **3.3**).

7 Conditioning

Unless otherwise specified by the referring standard, store the test pieces under water for at least 1 000 h at the test temperature (see **8.1**) prior to testing.

8 Procedure

8.1 Test temperature

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

8.2 Selection of the load

Choose a load to deflect the test piece, so that the resulting time to failure, together with those produced from other test pieces, conforms to the distribution of the times to failure specified in the referring standard.

When choosing the load, take into account, as necessary, the weight of the upper plate or beam bar.

8.3 Positioning of the test piece

If the applied load is expected to cause a relative deflection in excess of 28 %, use beam bars; otherwise use either plate(s) and/or beam bar(s) (see **5.2**).

Place the test piece in the apparatus with the pair of diametrically opposed reference lines in contact with the upper and lower plate(s) or bar(s).

Ensure that the contact between the test piece and each plate or beam bar is as uniform as possible and that the plate(s) and/or bar(s) are not tilted laterally.

Place the apparatus in the water container and fill the container with water (see **5.3**) to a level such that the test piece is completely immersed.

8.4 Application of load

Load the test piece so that the predetermined load (see **8.2**) is obtained in (3 ± 0,5) min.

Hold this load constant until the test is completed in accordance with **8.5**.

8.5 Determination of time/deflection data

Where the term "relative ring deflection" is used in the following clauses, the term "ring deflection" may be substituted, if required.

NOTE The various times specified in this subclause are based on an extrapolation to 50 years (438 000 h). In cases of other extrapolation periods, these times should be adjusted accordingly.

When the series of tests in accordance with **8.5.1** and/or **8.5.2** has been completed, the procedures in clause **9** shall be followed.

8.5.1 *Measured data*

From the deflections measured, calculate and record the relative ring deflections at mid-length of the test piece. Take at least three readings for each decade of logarithm of time, where the time is expressed in hours.

Unless otherwise specified by the referring standard, the test is completed when either of the following conditions is fulfilled.

a) Rupture of the test piece occurs (see **3.11**), in which case record the relative ring deflection and the time to failure.

b) The test has continued for at least 10 000 h without rupture, and both the following conditions are fulfilled:

  1) pipe wall rupture has been detected in at least 16 other test pieces; and

  2) for at least two of those 16 test pieces, the time to failure exceeded 6 000 h.

When the conditions in b) have been satisfied, either the procedure in **8.5.2** shall be used or the test shall be continued until rupture.

8.5.2 *Predicted data*

8.5.2.1 For the calculations which follow, use any calculation method or package which conforms to the second paragraph of **A.1**.

8.5.2.2 To predict the time to failure and the relative ring deflection, y/d_m, at failure for test pieces which have not ruptured after 10 000 h, use least squares analysis to solve the following fourth order polynomial for each time/deflection series of data:

$$w = a + (b \times z) + (c \times z^2) + (d \times z^3) + (e \times z^4) \qquad (3)$$

where

$w = \lg y$, or $w = \lg (y/d_m)$;

$z = \lg t$.

8.5.2.3 For each test piece, where rupture has occurred, calculate $\lg r_u$, using the following equation:

$$\lg r_u = w_u - z_u + \lg w_u' \qquad (4)$$

where

$z_u = \lg t_u$;

$w_u = a + (b \times z_u) + (c \times z_u^2) + (d \times z_u^3) + (e \times z_u^4)$;

$w_u' = b + (2 \times c \times z_u) + (3 \times d \times z_u^2) + (4 \times e \times z_u^3)$.

NOTE w_u' is the first derivative of w_u.

8.5.2.4 To determine a linear regression for the logarithmic values of the rates of relative ring deflections at failure, r_u, and the corresponding times to failure, t_u, take $\lg r_u$ as the ordinate and $\lg t_u$ as the abscissa. Perform the linear regression analysis using a lower one-sided confidence limit of 97,5 % in conjunction with the following equation:

$$\lg r_u = f + (g \times \lg t_u) - (t_v \times \sigma_u) \qquad (2)$$

where

t_v is Student's t for a one-sided 0,025 level of significance and $(n - 2)$ degrees of freedom, where n is the number of ruptured test pieces;

σ_u is the standard deviation of the values of $\lg r_u$. The standard deviation shall be calculated using the following equations:

$$\sigma_u = (\sigma_u^2)^{0,5}$$

$$\sigma_u^2 = \frac{(S_x \times S_y) - S_{xy}^2}{(n - 2) \times S_x}$$

where

S_x is the sum of the squared residuals parallel to the x axis (see also EN 705):

$$S_x = \Sigma(x_i - X)^2$$

where

X is the arithmetic mean of the x data, i.e.

$X = (\Sigma x_i)/n$

x_i are individual x values;

n is the total number of readings for x_i;

S_y is the sum of the squared residuals parallel to the y axis (see also EN 705):

$$S_y = \Sigma(y_i - Y)^2$$

where

Y is the arithmetic mean of the y data, i.e.

$Y = (\Sigma y_i)/n$

y_i are individual y values;

n is the total number of readings for y_i;

S_{xy} is the sum of the squared residuals perpendicular to the line (see also EN 705):

$$S_{xy} = \Sigma\{(x_i - X) \times (y_i - Y)\}.$$

Plot the straight line for the 16 or more failure points, using equation (2), taking $\lg t$ as the abscissa and $\lg r$ as the ordinate.

8.5.2.5 On the same graph, plot the curve for the test pieces that have been on test for more than 10 000 h and have not ruptured, using equation (1).

Use a, b, c, d and e determined from equation (3).

8.5.2.6 Determine the value of z_u at the intersection of the straight line and the curve. Choose the scales for the graph so that z_u can be determined with an error of less than 0,5 %. Calculate the corresponding logarithmic value of the relative ring deflection at failure, w_u, using equation (5):

$$w_u = a + (b \times z_u) + (c \times z_u^2) + (d \times z_u^3) + (e \times z_u^4) \qquad (5)$$

where

$w_u = \lg (y_{u,wet}/d_m)$, if calculating the ultimate relative ring deflection under wet conditions; or

$w_u = \lg y_{u,wet}$, if calculating the ultimate ring deflection under wet conditions.

NOTE An example calculation is given in annex A.

9 Calculation

9.1 For results relating to deflection, carry out calculations in accordance with **9.2**. If a regression ratio related to strain is required, carry out calculations in accordance with **9.2** and **9.3**.

9.2 Using all the data obtained in accordance with **8.5.1** and, if applicable, **8.5.2**, plot lg [ultimate relative ring deflection] as a function of lg [time].

From the series of ultimate relative ring deflections and corresponding times to failure, determine the equation of the straight line in accordance with method A of EN 705:1994.

Calculate the extrapolated ultimate relative ring deflection, $y_{u,wet,x}/d_m$, for the time x specified in the referring standard.

Calculate the deflection regression ratio $R_{R,def}$ (see **3.13**) using the following equation:

$$R_{R,def} = \frac{y_{u,wet,50}/d_m}{y_{u,wet,6}/d_m} \qquad (7)$$

where

$y_{u,wet,50}/d_m$ is the extrapolated ultimate relative ring deflection at 50 years;

$y_{u,wet,6}/d_m$ is the extrapolated ultimate relative ring deflection at 6 min.

9.3 Where it is required to determine the strain regression ratio, $R_{R,str}$, (see **3.14**), use the following equation:

$$R_{R,str} = \frac{D_{g,50}}{D_{g,6}} \times R_{R,def} \qquad (8)$$

where

$D_{g,50}$ is the strain factor at 50 years determined using the following equation:

$$D_{g,50} = \frac{4{,}28}{\{1 + (0{,}5 \times y_{u,wet,50}/d_m)\}^2}$$

$D_{g,6}$ is the strain factor at 6 min determined using the following equation:

$$D_{g,6} = \frac{4{,}28}{\{1 + (0{,}5 \times y_{u,wet,6}/d_m)\}^2}$$

NOTE These strain factors can be used as long as the pipe remains elliptical during the test. With the beam bar surface, this condition may not always be satisfied.

10 Test report

The test report shall include the following information:

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

b) the full identification of the pipes tested;

c) the dimensions of each test piece, in metres;

d) the number of test pieces;

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

f) the equipment details, including whether beam bars and/or plates were used;

g) the temperature, in degrees Celsius, and the pH of the water during the test;

h) for each test piece, the plot of relative ring deflection versus time;

i) for each test piece, the ultimate relative ring deflection, or the ultimate ring deflection, and the corresponding time to failure and the method of failure determination (see **8.5.1** and **8.5.2**);

j) the calculated long-term ultimate relative ring deflection under wet conditions, $y_{u,wet,x}/d_m$;

k) the calculated value of $R_{R,def}$ or $R_{R,str}$, as applicable;

l) the calculated long-term ultimate strain level, if applicable (see clause **9**);

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

n) the dates of the testing periods.

Annex A (normative)

Example calculation for validation of procedures

A.1 The following example demonstrates the way the procedures described in this standard are used.

In addition, the example, together with the calculation procedures described in this standard, can be used as a validation of any statistical procedure used in conjunction with this standard to verify that the results given in this annex are met within ± 0,1 %.

Figure A.1 shows the recorded data of 18 test pieces plotted in a lg–lg diagram, where lg [time] is the abscissa and lg [relative ring deflection] is the ordinate.

Table A.1 gives the values for test piece #14. These are used in the example which describes, for test pieces which have failed (see **8.5.2**), the procedure to determine the long-term ultimate relative ring deflection under wet conditions and the time to failure.

Using standard mathematical procedures incorporating least squares analysis to derive the fourth order polynomial equation, the following coefficients were obtained for test piece #14.

$a = 1{,}0500;$
$b = 0{,}0226;$
$c = -0{,}0182;$
$d = 0{,}0012;$
$e = 0{,}0050.$

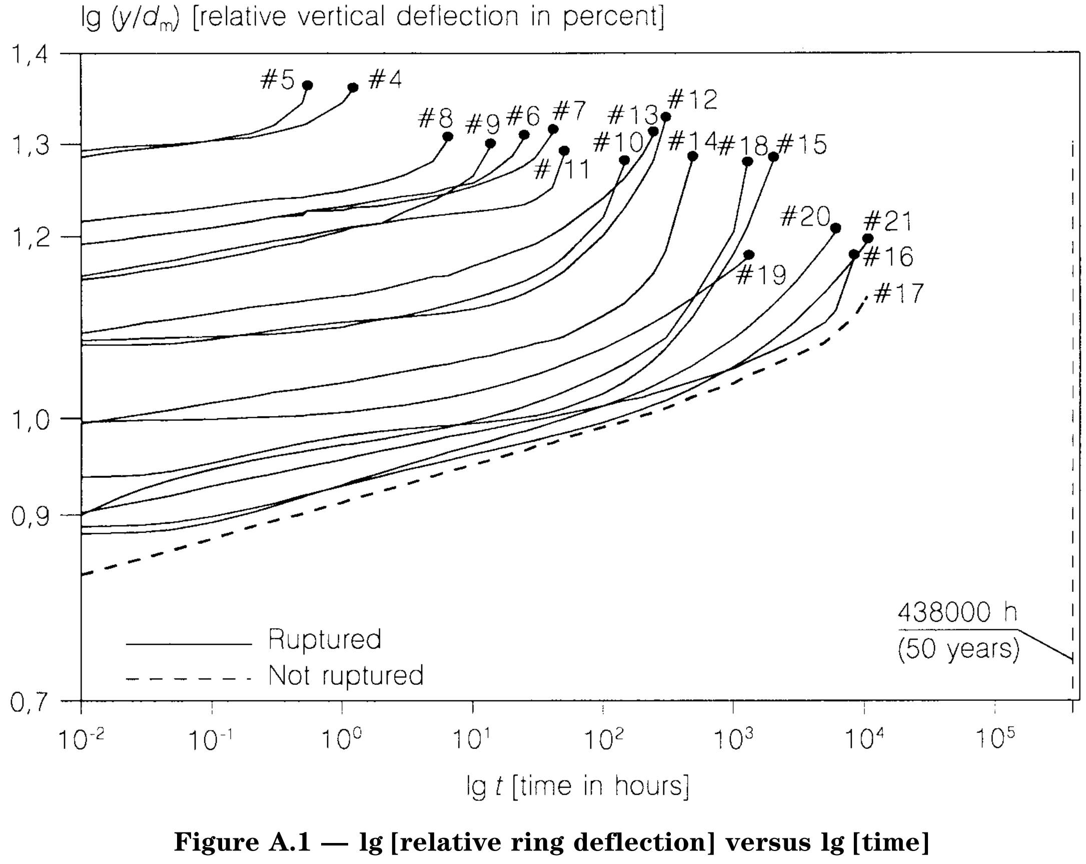

Figure A.1 — lg [relative ring deflection] versus lg [time]

Table A.1 — Values of time and relative ring deflection for test piece #14

t h	$z = \lg t$	y/d_m %	$w = \lg (y/d_m)$
0,01	−2,000	9,95	0,998
0,02	−1,699	10,10	1,004
0,03	−1,523	10,18	1,008
0,05	−1,301	10,29	1,013
0,10	−1,000	10,47	1,020
0,20	−0,699	10,63	1,027
0,30	−0,523	10,75	1,031
0,50	−0,301	10,84	1,035
0,54	−0,268	10,87	1,036
1,00	0,000	11,01	1,042
1,19	0,076	11,05	1,044
2,00	0,301	11,20	1,049
3,00	0,477	11,32	1,054
5,00	0,699	11,47	1,059
6,40	0,806	11,52	1,061
10,00	1,000	11,69	1,068
13,47	1,129	11,77	1,071
20,00	1,301	11,95	1,077
24,45	1,388	12,03	1,080
30,00	1,477	12,13	1,084
40,90	1,612	12,24	1,088
50,00	1,699	12,34	1,091
100,00	2,000	13,00	1,114
144,15	2,159	13,40	1,127
200,00	2,301	14,02	1,147
241,19	2,382	14,45	1,160
300,00	2,477	15,25	1,183
480,00	2,681	19,30	1,286

In Table A.2 are listed for each test piece the coefficients of the fourth order polynomial

$$w = a + (b \times z) + (c \times z^2) + (d \times z^3) + (e \times z^4) \qquad (3)$$

calculated using the same procedures as for test piece #14.

From Table A.2, for test piece #14, the value for z_u can be calculated by:

$$z_u = \lg t_u = \lg 480 = 2{,}68$$

Using the following equations, for test piece #14, the values for w_u and for w_u' can be calculated [(see also equation (4)]:

$$w_u = 1{,}05 + (0{,}0226 \times 2{,}68) - (0{,}0182 \times 2{,}68^2) + (0{,}0012 \times 2{,}68^3) + (0{,}005 \times 2{,}68^{4)}$$

$$w_u = 1{,}261$$

$$w_u' = 0{,}0226 - (2 \times 0{,}0182 \times 2{,}68) + (3 \times 0{,}0012 \times 2{,}68^2) + (4 \times 0{,}005 \times 2{,}68^3)$$

$$w_u' = 0{,}336$$

$$\lg w_u' = -0{,}473$$

$$\lg r_u = 1{,}261 - 2{,}68 + (-0{,}473)$$

$$\lg r_u = -1{,}893$$

This procedure is repeated for each test piece where rupture occurred. Hence the logarithm of the rate of relative ring deflection at failure can be calculated for each test piece where rupture occurred (see Table A.3), using equation (4), i.e.:

$$\lg r_u = w_u - z_u + \lg w_u'$$

Table A.2 — Coefficients of the fourth order polynomial

	#4	**#5**	**#6**	**#7**	**#8**	**#9**
a	1,3380	1,4400	1,2270	1,2300	1,2450	1,2020
b	0,1368	0,4682	0,0114	0,0103	0,0193	0,0259
c	0,1690	0,5610	−0,0001	−0,0004	0,0265	0,0150
d	0,0954	0,2945	0,0089	0,0141	0,0284	0,0208
e	0,0194	0,0556	0,0037	0,0061	0,0081	0,0069
t_u [h]	1,2	0,5	40,0	24,0	6,6	13,0
$\frac{y_{u,wet}}{d_m}$ [%]	22,4	22,5	20,6	20,4	20,1	19,9
	#10	**#11**	**#12**	**#13**	**#14**	**#15**
a	1,1050	1,2090	1,1070	1,1380	1,0500	0,9841
b	0,0126	0,0126	0,0130	0,0207	0,0226	0,0212
c	−0,0013	−0,0120	−0,0061	−0,0001	−0,0182	−0,0104
d	0,0056	0,0074	0,0034	0,0039	0,0012	0,0000
e	0,0039	0,0052	0,0041	0,0021	0,0050	0,0028
t_u [h]	142,0	48,0	280,0	243,0	480,0	1982,0
$\frac{y_{u,wet}}{d_m}$ [%]	19,2	19,6	21,1	20,5	19,3	19,1
	#16	**#18**	**#19**	**#20**	**#21**	**#17**
a	0,9616	0,9749	1,0102	0,9323	0,9310	0,9134
b	0,0329	0,0215	0,0129	0,0438	0,0353	0,0420
c	−0,0048	0,0001	0,0069	−0,0005	−0,0006	−0,0019
d	−0,0016	0,0022	0,0017	−0,0028	−0,0020	−0,0009
e	0,0010	0,0018	0,0001	0,0013	0,0010	0,0005
t_u [h]	8760,0	1259,0	1202,0	6026,0	10391,0	—
$\frac{y_{u,wet}}{d_m}$ [%]	15,2	18,9	17,3	16,5	16,0	—

Table A.3 — Rate of ultimate relative ring deflection/time to failure

Test piece	z_u	w_u	w_u'	lg w_u'	lg r_u[1]	lg r_u[2] Regression	LCL[3] 97,5 %
#5	−0,26	1,351	0,231	−0,636	0,977	0,843	0,481
#4	0,08	1,350	0,165	−0,781	0,489	0,500	0,138
#8	0,82	1,298	0,138	−0,861	−0,382	−0,246	−0,608
#9	1,11	1,289	0,175	−0,757	−0,582	−0,543	−0,904
#7	1,38	1,303	0,154	−0,813	−0,890	−0,811	−1,173
#6	1,60	1,306	0,140	−0,852	−1,149	−1,035	−1,396
#11	1,68	1,273	0,134	−0,873	−1,282	−1,114	−1,476
#10	2,15	1,266	0,240	−0,619	−1,506	−1,589	−1,950
#13	2,39	1,308	0,201	−0,697	−1,775	−1,824	−2,186
#12	2,45	1,299	0,285	−0,546	−1,694	−1,886	−2,248
#14	2,68	1,261	0,336	−0,473	−1,893	−2,122	−2,483
#19	3,08	1,174	0,115	−0,938	−2,843	−2,524	−2,885
#18	3,10	1,274	0,300	−0,523	−2,349	−2,544	−2,905
#15	3,30	1,272	0,354	−0,451	−2,476	−2,743	−3,104
#20	3,78	1,205	0,201	−0,697	−3,272	−3,229	−3,591
#16	3,94	1,160	0,166	−0,781	−3,563	−3,393	−3,754
#21	4,02	1,194	0,193	−0,715	−3,538	−3,468	−3,829

[1] See equation (4).

[2] See equation (2).

[3] LCL is the lower 97,5 % confidence limit of lg r_u, derived as a prediction from equation (2).

The last two columns of Table A.3 give the results of a linear regression analysis on this data.

Figure A.2 shows two lines as follows:

a) a line determined in accordance with **8.5.2.4**:

$$\lg r_u = f + (g \times z_u) - (t_v \times \sigma_u)$$

where

f = 0,5795;
g = −1,0076;
t_v = 2,1315;
σ_u = 0,1696.

b) a curve for test piece #17 determined in accordance with **8.5.2.5**:

$$\lg r = w + \lg w' - z$$

where

$z = \lg t$;
$w = a + (b \times z) + (c \times z^2) + (d \times z^3) + (e \times z^4)$;
$w' = b + (2 \times c \times z) + (3 \times d \times z^2) + (4 \times e \times z^3)$

The values of the coefficients a, b, c, d and e are taken from Table A.2 for test piece #17.

For Figure A.2 the values for the time t were chosen as shown in Table A.4 together with the results for lg r_u and lg r.

The intersection of the two lines is the logarithmic value of the time to failure of test piece #17.

$$z_u = \lg t_u = 4{,}047$$

Hence:

$$t_u = 11\,153 \text{ h}$$

The logarithm of the ultimate relative ring deflection is calculated using equation (2):

$$w_u = a + (b \times z_u) + (c \times z_u^2) + (d \times z_u^3) + (e \times z_u^4)$$

$$w_u = 1{,}1268$$

or

$$\frac{y_{u,wet}}{d_m} = 13{,}4 \ \%$$

Then, with the results of this calculation and the values given in Table A.2 for time to failure and corresponding ultimate relative ring deflection, a regression analysis and an extrapolation in accordance with EN 705 can be made (see Table A.5).

Table A.4 — Data for Figure A.2

z	t	$\lg r_u$	r_u	$\lg r$	r
3,90	7943	−3,711	0,000194	−3,769	0,000170
3,95	8913	−3,762	0,000173	−3,800	0,000158
4,00	10000	−3,812	0,000154	−3,831	0,000148
4,05	11220	−3,863	0,000137	−3,862	0,000138
4,10	12589	−3,913	0,000122	−3,892	0,000128
4,15	14125	−3,963	0,000109	−3,922	0,000120

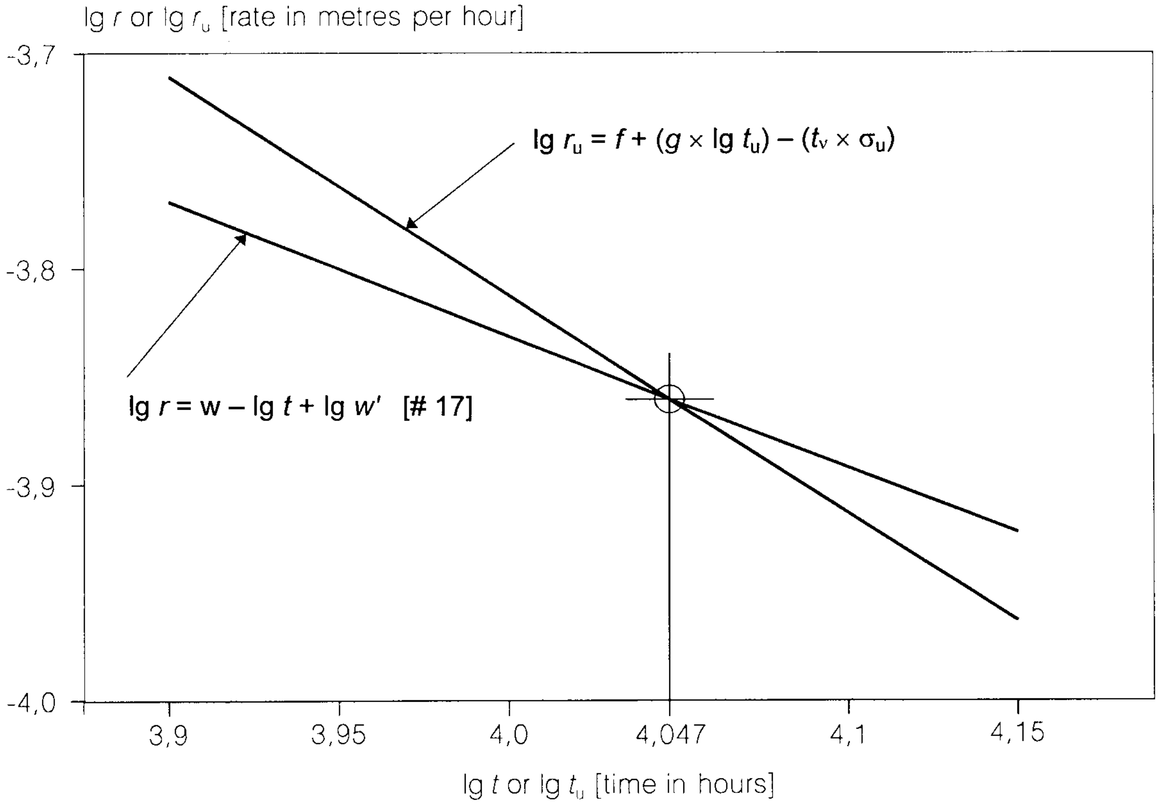

Figure A.2 — lg [time] versus lg [rate]

Table A.5 — Data to be used for analysis according to EN 705

t	lg t	$y_{u,wet}/d_m$	lg $(y_{u,wet}/d_m)$
0,5	−0,261	22,5	1,352
1,2	0,079	22,4	1,350
6,6	0,820	20,1	1,303
13,0	1,114	19,9	1,299
24,0	1,380	20,4	1,310
40,0	1,602	20,6	1,314
48,0	1,681	19,6	1,292
142	2,152	19,2	1,283
243	2,386	20,5	1,312
280	2,447	21,1	1,324
480	2,681	19,3	1,286
1202	3,080	17,3	1,238
1259	3,100	18,9	1,276
1982	3,297	19,1	1,281
6026	3,780	16,5	1,217
8760	3,943	15,2	1,182
10391	4,017	16,0	1,204
11153	4,047	13,4	1,127

NOTE When using method A of EN 705:1994, $r^2 = 0{,}704\,9 > 0{,}501\,8$, i.e. the data are suitable for the analysis, and the absolute value for $T = 19{,}737\,8 > 2{,}119\,9$, i.e. the data are suitable for extrapolation. The extrapolated 50 years value for the ultimate relative ring deflection under wet conditions is 13,35 %.

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