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Plastics piping systems — Glass-reinforced thermosetting plastics (GRP) pipes and fittings — Methods for regression analysis and their use

Systèmes de canalisation en matières plastiques — Tubes et raccords plastiques thermodurcissables renforcés de verre (PRV) — Méthodes pour une analyse de régression et leurs utilisations

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Foreword

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ISO 10928 was prepared by Technical Committee ISO/TC 138, *Plastics pipes, fittings and valves for the transport of fluids*, Subcommittee SC 06, *Reinforced plastics pipes and fittings for all applications*.

This second/third/... edition cancels and replaces the first/second/... edition (ISO 10928:2009), [clause(s) / subclause(s) / table(s) / figure(s) / annex(es)] of which [has / have] been technically revised.

Introduction

This International Standard describes the procedures intended for analysing the regression of test data, usually with respect to time and the use of the results in design and assessment of conformity with performance requirements. Its applicability is limited to use with data obtained from tests carried out on samples. The referring standards require estimates to be made of the long-term properties of the pipe for such parameters as circumferential tensile strength, long-term ring deflection, strain-corrosion and creep or relaxation stiffness.

A range of statistical techniques that could be used to analyse the test data produced by destructive tests was investigated. Many of these simple techniques require the logarithms of the data to

a) be normally distributed,

b) produce a regression line having a negative slope, and

c) have a sufficiently high regression correlation (see Table 1).

Whilst the last two conditions can be satisfied, analysis shows that there is a skew to the distribution and hence this primary condition is not satisfied. Further investigation into techniques that can handle skewed distributions resulted in the adoption of the covariance method of analysis of such data for this International Standard.

However, the results from non-destructive tests, such as long-term creep or relaxation stiffness, often satisfy all three conditions and hence a simpler procedure, using time as the independent variable, can also be used in accordance with this International Standard.

These data analysis procedures are limited to analysis methods specified in ISO product standards or test methods. However, other analysis procedures can be useful for the extrapolation and prediction of long-term behaviour of some properties of glass-reinforced thermosetting plastics (GRP) piping products. For example, a second-order polynomial analysis is sometimes useful in the extrapolation of creep and relaxation data. This is particularly the case for analysing shorter term data, where the shape of the creep or relaxation curve can deviate considerably from linear. A second-order polynomial analysis is included in Annex A. In Annex B there is an alternative non-linear analysis method. These non-linear methods are provided only for information and the possible use in investigating the behaviour of a particular piping product or material, therefore they might not be generally applicable to other piping products.

Plastics piping systems — Glass-reinforced thermosetting plastics (GRP) pipes and fittings — Methods for regression analysis and their use

1 Scope

This International Standard specifies procedures suitable for the analysis of data which, when converted into logarithms of the values, have either a normal or a skewed distribution. It is intended for use with the test methods and referring standards for glass-reinforced thermosetting plastics (GRP) pipes or fittings for the analysis of properties as a function of time. However, it can be used for the analysis of other data.

Depending upon the nature of the data, two methods are specified. The extrapolation using these techniques typically extends the trend from data gathered over a period of approximately 10 000 h, to a prediction of the property at 50 years, which is the typical maximum extrapolation time.

This International Standard only addresses the analysis of data. The test procedures to collect the data, the number of samples required and the time period over which data is collected, are covered by the referring standards and/or test methods. Clause 4 discusses how the data analysis methods are applied to product testing and design.

2 Principle

Data are analysed for regression using methods based on least squares analysis which can accommodate the incidence of a skew and/or a normal distribution. The two methods of analysis used are the following:

— method A: covariance using a first-order relationship;

— method B: least squares, with time as the independent variable using a first-order relationship.

The methods include statistical tests for the correlation of the data and the suitability for extrapolation.

3 Procedures for determining the linear relationships – Methods A and B

3.1 Procedures common to methods A and B

Use method A (see 3.2) or method B (see 3.3) to fit a straight line of the form given in Equation (1):

$$y = a + b \times x \quad (1)$$

where

y is the logarithm, lg, of the property being investigated;

a is the intercept on the Y-axis;

b is the slope;

x is the logarithm, lg, of the time, in hours.

3.2 Method A – Covariance method

3.2.1 General

For method A, calculate the following variables in accordance with 3.2.2 to 3.2.5, using Equations (2), (3) and (4):

$$Q_y = \frac{\sum (y_i - Y)^2}{n} \tag{2}$$

$$Q_x = \frac{\sum (x_i - X)^2}{n} \tag{3}$$

$$Q_{xy} = \frac{\sum [(x_i - X) \times (y_i - Y)]}{n} \tag{4}$$

where

Q_y is the sum of the squared residuals parallel to the Y-axis, divided by n;

Q_x is the sum of the squared residuals parallel to the X-axis, divided by n;

Q_{xy} is the sum of the squared residuals perpendicular to the line, divided by n;

Y is the arithmetic mean of the y data, i.e. given as Equation (5):

$$Y = \frac{\sum y_i}{n} \tag{5}$$

X is the arithmetic mean of the x data, i.e. given as Equation (6):

$$X = \frac{\sum x_i}{n} \tag{6}$$

x_i, y_i are individual values;

n is the total number of results (pairs of readings for x_i, y_i).

NOTE If the value of Q_{xy} is greater than zero, the slope of the line is positive and if the value of Q_{xy} is less than zero, then the slope is negative.

3.2.2 Suitability of data

Calculate the linear coefficient of correlation, r, using Equations (7) and (8):

$$r^2 = \frac{Q_{xy}^2}{Q_x \times Q_y} \tag{7}$$

$$r = \left| (r^2)^{0,5} \right| \tag{8}$$

If the value of r is less than: $\frac{\text{Student's } t(f)}{\sqrt{n-2+\left[\text{Student's } t(f)\right]^2}}$

then the data are unsuitable for analysis.

Table 1 gives the minimum acceptable values of the correlation coefficient, r, as a function of the number of variables, n. The Student's t value is based on a two-sided 0,01 level of significance.

Table 1 — Minimum values of the correlation coefficient, r, for acceptable data from n pairs of data

Number of variables n	Degrees of freedom $n-2$	Student's $t(0{,}01)$	Minimum r	Number of variables n	Degrees of freedom $n-2$	Student's $t(0{,}01)$	Minimum r
13	11	3,106	0,683 5	26	24	2,797	0,495 8
14	12	3,055	0,661 4	27	25	2,787	0,486 9
15	13	3,012	0,641 1	32	30	2,750	0,448 7
16	14	2,977	0,622 6	37	35	2,724	0,418 2
17	15	2,947	0,605 5	42	40	2,704	0,393 2
18	16	2,921	0,589 7	47	45	2,690	0,372 1
19	17	2,898	0,575 1	52	50	2,678	0,354 2
20	18	2,878	0,561 4	62	60	2,660	0,324 8
21	19	2,861	0,548 7	72	70	2,648	0,301 7
22	20	2,845	0,536 8	82	80	2,639	0,283 0
23	21	2,831	0,525 6	92	90	2,632	0,267 3
24	22	2,819	0,515 1	102	100	2,626	0,254 0
25	23	2,807	0,505 2				

3.2.3 Functional relationships

To find a and b for the functional relationship line:

$$y = a + b \times x \tag{1}$$

First set Γ as given in Equation (9):

$$\Gamma = \frac{Q_y}{Q_x} \tag{9}$$

then calculate a and b using Equations (10) and (11):

$$b = -(\Gamma)^{0{,}5} \tag{10}$$

$$a = Y - b \times X \tag{11}$$

3.2.4 Calculation of variances

If t_u is the applicable time to failure, then set x_u as given in Equation (12):

$$x_u = \lg t_u \tag{12}$$

Using Equations (13), (14) and (15) respectively, calculate for $i = 1$ to n, the following sequence of statistics:

— the best fit x_i' for true x_i;

— the best fit y_i' for true y_i;

— the error variance, $\sigma_\delta{}^2$ for x.

$$x_i' = \frac{\Gamma \times x_i + b \times (y_i - a)}{2 \times \Gamma} \tag{13}$$

$$y_i' = a + b \times x_i' \tag{14}$$

$$\sigma_\delta{}^2 = \frac{\left[\sum (y_i - y_i')^2 + \Gamma \times \sum (x_i - x_i')^2\right]}{(n-2) \times \Gamma} \tag{15}$$

Calculate quantities E and D using Equations (16) and (17):

$$E = \frac{b \times \sigma_\delta{}^2}{2 \times Q_{xy}} \tag{16}$$

$$D = \frac{2 \times \Gamma \times b \times \sigma_\delta{}^2}{n \times Q_{xy}} \tag{17}$$

Calculate the variance, C, of the slope b, using Equation (18):

$$C = D \times (1 + E) \tag{18}$$

3.2.5 Check for the suitability of data for extrapolation

If it is intended to extrapolate the line, calculate T using Equation (19):

$$T = \frac{b}{(\text{var } b)^{0,5}} = \frac{b}{C^{0,5}} \tag{19}$$

If the absolute value, $|T|$ (i.e. ignoring signs), of T is equal to or greater than the applicable value for Student's t, t_v, shown in Table 2 for $(n - 2)$ degrees of freedom, then consider the data suitable for extrapolation.

Calculation of confidence limits is not required by the test methods or referring standards, however, the calculation of lower confidence limit, LCL, and lower prediction limit, LPL, are given in Annex C.

Table 2 — Percentage points of Student's t distribution (upper 2,5 % points; two-sided 5 % level of confidence; t_v for 97,5 %)

Degree of freedom $(n-2)$	Student's t value t_v	Degree of freedom $(n-2)$	Student's t value t_v	Degree of freedom $(n-2)$	Student's t value t_v
1	12,706 2	36	2,028 1	71	1,993 9
2	4,302 7	37	2,026 2	72	1,993 5
3	3,182 4	38	2,024 4	73	1,993 0
4	2,776 4	39	2,022 7	74	1,992 5
5	2,570 6	40	2,021 1	75	1,992 1
6	2,446 9	41	2,019 5	76	1,991 7
7	2,364 6	42	2,018 1	77	1,991 3
8	2,306 0	43	2,016 7	78	1,990 8
9	2,262 2	44	2,015 4	79	1,990 5
10	2,228 1	45	2,014 1	80	1,990 1
11	2,201 0	46	2,012 9	81	1,989 7
12	2,178 8	47	2,011 2	82	1,989 3
13	2,160 4	48	2,010 6	83	1,989 0
14	2,144 8	49	2,009 6	84	1,988 6
15	2,131 5	50	2,008 6	85	1,988 3
16	2,119 9	51	2,007 6	86	1,987 9
17	2,109 8	52	2,006 6	87	1,987 6
18	2,100 9	53	2,005 7	88	1,987 3
19	2,093 0	54	2,004 9	89	1,987 0
20	2,086 0	55	2,004 0	90	1,986 7
21	2,079 6	56	2,003 2	91	1,986 4
22	2,073 9	57	2,002 5	92	1,986 1
23	2,068 7	58	2,001 7	93	1,985 8
24	2,063 9	59	2,001 0	94	1,985 5
25	2,059 5	60	2,000 3	95	1,985 3
26	2,055 5	61	1,999 6	96	1,985 0
27	2,051 8	62	1,999 0	97	1,984 7
28	2,048 4	63	1,998 3	98	1,984 5
29	2,045 2	64	1,997 7	99	1,984 2
30	2,042 3	65	1,997 1	100	1,984 0
31	2,039 5	66	1,996 6		
32	2,036 9	67	1,996 0		
33	2,034 5	68	1,995 5		
34	2,032 2	69	1,994 9		
35	2,030 1	70	1,994 4		

3.2.6 Validation of statistical procedures by an example calculation

The data given in Table 3 are used in the following example to aid in verifying that statistical procedures, as well as computer programs and spreadsheets adopted by users, will produce results similar to those obtained from the equations given in this International Standard. For the purposes of the example, the property in question is represented by V, the values for which are of a typical magnitude and in no particular units. Because of rounding errors, it is unlikely that the results will agree exactly, so for a calculation procedure to be acceptable, the results obtained for r, r^2, b, a, and the mean value of V, and V_m, shall agree to within ± 0,1 % of the values given in this example. The values of other statistics are provided to assist the checking of the procedure.

Sums of squares:

Q_x = 0,798 12;

Q_y = 0,000 88;

Q_{xy} = −0,024 84.

Coefficient of correlation:

r^2 = 0,879 99;

r = 0,938 08.

Functional relationships:

Γ = 0,001 10;

b = −0,033 17;

a = 1,627 31.

Table 3 — Basic data for example calculation and statistical analysis validation

n	V	Y lg V	Time h	X lg h
1	30,8	1,488 6	5 184	3,714 7
2	30,8	1,488 6	2 230	3,348 3
3	31,5	1,498 3	2 220	3,346 4
4	31,5	1,498 3	12 340	4,091 3
5	31,5	1,498 3	10 900	4,037 4
6	31,5	1,498 3	12 340	4,091 3
7	31,5	1,498 3	10 920	4,038 2
8	32,2	1,507 9	8 900	3,949 4
9	32,2	1,507 9	4 173	3,620 4
10	32,2	1,507 9	8 900	3,949 4
11	32,2	1,507 9	878	2,943 5
12	32,9	1,517 2	4 110	3,613 8
13	32,9	1,517 2	1 301	3,114 3
14	32,9	1,517 2	3 816	3,581 6
15	32,9	1,517 2	669	2,825 4
16	33,6	1,526 3	1 430	3,155 3
17	33,6	1,526 3	2 103	3,322 8
18	33,6	1,526 3	589	2,770 1
19	33,6	1,526 3	1 710	3,233 0
20	33,6	1,526 3	1 299	3,113 6
21	35,0	1,544 1	272	2,434 6
22	35,0	1,544 1	446	2,649 3
23	35,0	1,544 1	466	2,668 4
24	35,0	1,544 1	684	2,835 1
25	36,4	1,561 1	104	2,017 0
26	36,4	1,561 1	142	2,152 3
27	36,4	1,561 1	204	2,309 6
28	36,4	1,561 1	209	2,320 1
29	38,5	1,585 5	9	0,954 2
30	38,5	1,585 5	13	1,113 9
31	38,5	1,585 5	17	1,230 4
32	38,5	1,585 5	17	1,230 4
Means:		Y = 1,530 1		X = 2, 930 5

Calculated variances (see 3.2.4):

$E = 3{,}520\ 2 \times 10^{-2}$;

$D = 4{,}842\ 2 \times 10^{-6}$;

$C = 5{,}012\ 7 \times 10^{-6}$ (the variance of b);

$\sigma_{\delta}^{2} = 5{,}271\ 1 \times 10^{-2}$ (the error variance of x).

Check for the suitability for extrapolation (see 3.2.5):

$n = 32$;

$t_{v} = 2{,}042\ 3$;

$T = -0{,}033\ 17 / (5{,}012\ 7 \times 10^{-6})^{0{,}5} = -14{,}816\ 7$;

$|T| = 14{,}816\ 7 > 2{,}042\ 3$.

The estimated mean values for V at various times are given in Table 4 and shown in Figure 1.

Table 4 — Estimated mean values, V_m, for V

Time h	V_m
0,1	45,76
1	42,39
10	39,28
100	36,39
1 000	33,71
10 000	31,23
100 000	28,94
438 000	27,55