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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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Contents

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 10928 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*.

This International Standard is technically identical to EN 705:1994.

Annex A of this International Standard is for information only.

Introduction

This standard has been prepared to describe 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 has been 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, deflection and creep.

The committee investigated a range of statistical techniques that could be used to analyse the test data produced by tests that were destructive. Many of these simple techniques required 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 has shown 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 for analysis of such data for this standard.

The results from non-destructive tests, such as creep or changes in deflection with time, often satisfy these three conditions and hence simpler procedures, using time as the independent variable, can also be used in accordance with this standard.

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

1 Scope

This 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 plastics pipes or fittings for the analysis of properties as a function of, usually, time. However it can be used for the analysis of any other data.

For use depending upon the nature of the data, three methods are specified. The extrapolation using these techniques typically extends the trend from data gathered over a period of approximately 10000 h, to a prediction of the property at 50 years.

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 and the applicability of a first order or a second order polynomial relationship.

The three methods of analysis used comprise 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;
- **method C:** least squares with time as the independent variable using a second order relationship.

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

3 Procedures for determining the functional relationships

3.1 Linear relationships - Methods A and B

3.1.1 Procedures common to methods A and B

Use method A (see 3.1.2) or method B (see 3.1.3) to fit a straight line of the form

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

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.

3.1.2 Method A - Covariance method

3.1.2.1 General

For method A calculate the following variables in accordance with 3.1.2.2 to 3.1.2.5:

$$Q_y = \frac{\Sigma(y_i - Y)^2}{n} \quad \ldots (2)$$

$$Q_x = \frac{\Sigma(x_i - X)^2}{n} \quad \ldots (3)$$

$$Q_{xy} = \frac{\Sigma\{(x_i - X) \times (y_i - Y)\}}{n} \quad \ldots (4)$$

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.

$$Y = \frac{\Sigma y_i}{n};$$

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

$$X = \frac{\Sigma x_i}{n};$$

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.

3.1.2.2 Suitability of data

Calculate the squared, r^2, and the linear coefficient of correlation, r, using the following equations:

$$r^2 = \frac{{Q_{xy}}^2}{Q_x \times Q_y} \qquad \ldots (5)$$

$$r = \left| (r^2)^{0,5} \right| \qquad \ldots (6)$$

If the value of r^2 or r is less than the applicable minimum value given in table 1 as a function of n, consider the data unsuitable for analysis.

Table 1: Minimum values for the squared, r^2, and linear coefficient of correlation, r, for acceptable data from n pairs of data

$(n - 2)$	Minimum values r^2	r	$(n - 2)$	Minimum values r^2	r
11	0,6416	0,8010	23	0,3816	0,6177
12	0,6084	0,7800	24	0,3689	0,6074
13	0,5781	0,7603	25	0,3569	0,5974
14	0,5506	0,7420	30	0,3070	0,5541
15	0,5250	0,7246	35	0,2693	0,5189
16	0,5018	0,7084	40	0,2397	0,4896
17	0,4805	0,6932	45	0,2160	0,4648
18	0,4606	0,6787	50	0,1965	0,4433
19	0,4425	0,6652	60	0,1663	0,4078
20	0,4256	0,6524	70	0,1443	0,3799
21	0,4099	0,6402	80	0,1273	0,3568
22	0,3953	0,6287	90	0,1139	0,3375
			100	0,1031	0,3211

NOTE: In table 1 and elsewhere in this standard, the equations and corresponding values for r^2 and r are given, for convenience of use in conjunction with reference data published elsewhere in terms of only r^2 or r.

3.1.2.3 Functional relationships

To find a and b for the functional relationship line

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

first set

$$\Gamma = \frac{Q_Y}{Q_X} \qquad \ldots (7)$$

then calculate a and b using the following equations:

$$b = -(\Gamma)^{0,5} \qquad \ldots (8)$$

$$a = Y - b \times X \qquad \ldots (9)$$

3.1.2.4 Calculation of variances

If t_u is the applicable time to failure, then set

$$x_u = lg\ t_u \qquad \ldots (10)$$

Using equations (11), (12) and (13) 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; and
- the error variance, σ_δ^2 for x.

$$x_i' = \frac{\Gamma \times x_i + b \times (y_i - a)}{2 \times \Gamma} \qquad \ldots (11)$$

$$y_i' = a + b \times x_i' \qquad \ldots (12)$$

$$\sigma_\delta^2 = \frac{\{\Sigma(y_i - y_i')^2 + \Gamma \times \Sigma(x_i - x_i')^2\}}{(n - 2) \times \Gamma} \qquad \ldots (13)$$

Calculate the following quantities:

$$E = \frac{b \times \sigma_\delta^2}{2 \times Q_{xy}} \qquad \ldots (14)$$

$$D = \frac{2 \times \Gamma \times b \times \sigma_\delta^2}{n \times Q_{xy}} \qquad \ldots (15)$$

Calculate the variance C of the slope b using the following equation:

$$C = D \times (1 + E) \qquad \ldots (16)$$

3.1.2.5 Check for the suitability of data for extrapolation

If it is intended to extrapolate the line, calculate T using the following equation:

$$T = \frac{b}{(\text{variance of } b)^{0,5}} = \frac{b}{C^{0,5}} \qquad \dots (17)$$

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.

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	12,7062	36	2,0281	71	1,9939
2	4,3027	37	2,0262	72	1,9935
3	3,1824	38	2,0244	73	1,9930
4	2,7764	39	2,0227	74	1,9925
5	2,5706	40	2,0211	75	1,9921
6	2,4469	41	2,0195	76	1,9917
7	2,3646	42	2,0181	77	1,9913
8	2,3060	43	2,0167	78	1,9908
9	2,2622	44	2,0154	79	1,9905
10	2,2281	45	2,0141	80	1,9901
11	2,2010	46	2,0129	81	1,9897
12	2,1788	47	2,0112	82	1,9893
13	2,1604	48	2,0106	83	1,9890
14	2,1448	49	2,0096	84	1,9886
15	2,1315	50	2,0086	85	1,9883
16	2,1199	51	2,0076	86	1,9879
17	2,1098	52	2,0066	87	1,9876
18	2,1009	53	2,0057	88	1,9873
19	2,0930	54	2,0049	89	1,9870
20	2,0860	55	2,0040	90	1,9867
21	2,0796	56	2,0032	91	1,9864
22	2,0739	57	2,0025	92	1,9861
23	2,0687	58	2,0017	93	1,9858
24	2,0639	59	2,0010	94	1,9855
25	2,0595	60	2,0003	95	1,9853
26	2,0555	61	1,9996	96	1,9850
27	2,0518	62	1,9990	97	1,9847
28	2,0484	63	1,9983	98	1,9845
29	2,0452	64	1,9977	99	1,9842
30	2,0423	65	1,9971	100	1,9840
31	2,0395	66	1,9966		
32	2,0369	67	1,9960		
33	2,0345	68	1,9955		
34	2,0322	69	1,9949		
35	2,0301	70	1,9944		

3.1.2.6 Validation of statistical procedures by an example calculation

The data given in table 3 together with the results given in this example are for use to verify that the other statistical procedures as adopted by users will produce results similar to those obtained from the equations given in this standard. For the purposes of 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 the calculation procedure to be acceptable, the results obtained for r, r^2, b, a, and the mean value of V, V_m, shall agree to within ± 0,1 % of the values given in this example, as applicable. The values of other statistics are provided to assist checking of the procedure.

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

n	V	y (lg V)	**time** h	x (lg time) (time in h)
1	30,8	1,4886	5184	3,7147
2	30,8	1,4886	2230	3,3483
3	31,5	1,4983	2220	3,3464
4	31,5	1,4983	12340	4,0913
5	31,5	1,4983	10900	4,0374
6	31,5	1,4983	12340	4,0913
7	31,5	1,4983	10920	4,0382
8	32,2	1,5079	8900	3,9494
9	32,2	1,5079	4173	3,6204
10	32,2	1,5079	8900	3,9494
11	32,2	1,5079	878	2,9435
12	32,9	1,5172	4110	3,6138
13	32,9	1,5172	1301	3,1143
14	32,9	1,5172	3816	3,5816
15	32,9	1,5172	669	2,8254
16	33,6	1,5263	1430	3,1553
17	33,6	1,5263	2103	3,3228
18	33,6	1,5263	589	2,7701
19	33,6	1,5263	1710	3,2330
20	33,6	1,5263	1299	3,1136
21	35,0	1,5441	272	2,4346
22	35,0	1,5441	446	2,6493
23	35,0	1,5441	466	2,6684
24	35,0	1,5441	684	2,8351
25	36,4	1,5611	104	2,0170
26	36,4	1,5611	142	2,1523
27	36,4	1,5611	204	2,3096
28	36,4	1,5611	209	2,3201
29	38,5	1,5855	9	0,9542
30	38,5	1,5855	13	1,1139
31	38,5	1,5855	17	1,2304
32	38,5	1,5855	17	1,2304
Means:		Y = 1,5301;		X = 2,9305

Sums of squares

Q_x = 0,79812;

Q_y = 0,00088;

Q_{xy} = -0,02484.

Coefficient of correlation

r^2 = 0,87999;

r = 0,93808.

Functional relationships

Γ = 0,00110;

b = -0,03317;

a = 1,62731.

Calculated variances (see 3.1.2.4)

E = $3,5202 \times 10^{-2}$;

D = $4,8422 \times 10^{-6}$;

C = $5,0127 \times 10^{-6}$ (the variance of b);

σ_δ^2 = $5,2711 \times 10^{-2}$ (the error variance for x).

Check of the suitability for extrapolation (see 3.1.2.5)

n = 32;

t_v = 2,0423;

T = $-0,03317/(5,0127 \times 10^{-6})^{0,5}$ = -14,8167;

$|T|$ = 14,8167 > 2,0423.

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
1,0	42,39
10,0	39,28
100,0	36,39
1000	33,71
10000	31,23
100000	28,94
438000	27,55

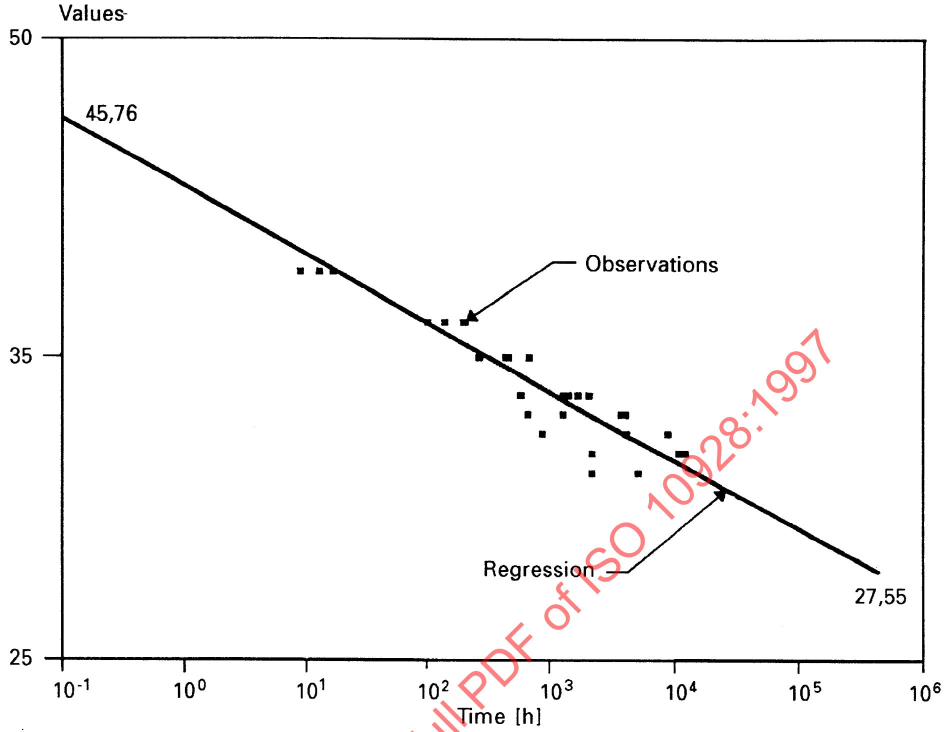

Figure 1: Regression line from the results in table 4

3.1.3 Method B - Regression with time as the independent variable

3.1.3.1 General

For method B calculate the following variables:

$$S_y = \Sigma(y_i - Y)^2 \quad \ldots (18)$$

(The sum of the squared residuals parallel to the y axis)

$$S_x = \Sigma(x_i - X)^2 \quad \ldots (19)$$

(The sum of the squared residuals parallel to the x axis)

$$S_{xy} = \Sigma\{(x_i - X) \times (y_i - Y)\} \quad \ldots (20)$$

(The sum of the squared residuals perpendicular to the line)

where:

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

$$Y = \frac{\Sigma y_i}{n};$$

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

$$X = \frac{\Sigma x_i}{n};$$

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 S_{xy} is greater than zero the slope of the line is positive and if the value of S_{xy} is less than zero then the slope is negative.

3.1.3.2 Suitability of data

Calculate the squared, r^2, and the linear coefficient of correlation, r, using the following equations:

$$r^2 = \frac{S_{xy}^2}{S_x \times S_y} \quad \ldots (21)$$

$$r = \left| (r^2)^{0,5} \right| \quad \ldots (22)$$

If the value of r^2, or r, is less than the applicable minimum value given in table 1 as a function of n, consider the data unsuitable for analysis.

3.1.3.3 Functional relationships

Calculate a and b for the functional relationship line [see equation (1)], using the following equations:

$$b = \frac{S_{xy}}{S_x} \quad \ldots (23)$$

$$a = Y - b \times X \quad \ldots (24)$$

3.1.3.4 Check for the suitability of data for extrapolation

If it is intended to extrapolate the line, calculate M using the following equation:

$$M = \frac{S_x^2}{S_{xy}^2} - \frac{t_v^2 \times (S_x \times S_y - S_{xy}^2)}{(n - 2) \times S_y^2} \quad \ldots (25)$$

where:

t_v is the applicable value for *Student's t* determined from table 2.

If M is equal to or less than zero consider the data unsuitable for extrapolation.

3.1.3.5 Validation of statistical procedures by an example calculation

Use the data given in table 5 for the calculation procedures described in 3.1.3.2 to 3.1.3.4 to ensure that the statistical procedures to be used in conjunction with this method will give results for r, r^2, a, b and V_m to within ± 0,1 % of the values given in this example.

Table 5: Basic data for example calculation and statistical validation

n	**Time** h	x (lg t) (t in h)	V	y (lg V)
1	0,10	-1,0000	7114	3,8521
2	0,27	-0,5686	6935	3,8410
3	0,50	-0,3010	6824	3,8341
4	1,00	0	6698	3,8259
5	3,28	0,5159	6533	3,8151
6	7,28	0,8621	6453	3,8098
7	20,0	1,3010	6307	3,7999
8	45,9	1,6618	6199	3,7923
9	72,0	1,8573	6133	3,7877
10	166	2,2201	5692	3,7552
11	219	2,3404	5508	3,7410
12	384	2,5843	5393	3,7318
13	504	2,7024	5364	3,7295
14	3000	3,4771	5200	3,7160
15	10520	4,0220	4975	3,6968
Means:		X = 1,4450		Y = 3,7819

Sums of squares

S_x = 31,6811;

S_y = 0,0347;

S_{xy} = -1,0242.

Coefficient of correlation

r^2 = 0,9556;

r = 0,9775.

Functional relationships (see 3.1.3.3)

a = 3,8286;

b = -0,0323.

Check of the suitability for extrapolation (see 3.1.3.4)

t_v = 2,1604;

M = 942,21.

The estimated mean values, V_m, for V at various times are given in table 6.

Table 6: Estimated mean values, V_m, for V

Time h	V_m
0,1	7259
1,0	6739
10,0	6256
100,0	5808
1000	5391
10000	5005
100000	4646
438000	4428

3.2 Second order polynomial relationships - Method C

3.2.1 General

This method fits a curved line of the form

$$y = c + d \times x + e \times x^2 \qquad \ldots (26)$$

where:

y is the logarithm (lg) of the property being investigated;

c is the intercept on the y axis;

d, e are the coefficients to the two orders of x;

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

3.2.2 Variables

For method C calculate the following variables:

Σx_i (sum of all individual x data);

Σx_i^2 (sum of all squared x data);

Σx_i^3 (sum of all x data to the third power);

Σx_i^4 (sum of all x data to the fourth power);

Σy_i (sum of all individual y data);

$(\Sigma y_i)^2$ (squared sum of all individual y data);

Σy_i^2 (sum of all squared y data);

$\Sigma(x_i \times y_i)$	(sum of all products $x_i y_i$);
$\Sigma(x_i^2 \times y_i)$	(sum of all products $x_i^2 y_i$);
$S_x = \Sigma(x_i - X)^2$	(sum of the squared residuals parallel to the x axis for the linear part);
$S_{xx} = \Sigma(x_i^2 - X^2)^2$	(sum of the squared residuals parallel to the x axis for the quadratic part);
$S_y = \Sigma(y_i - Y)^2$	(sum of the squared residuals parallel to the y axis);
$S_{xy} = \Sigma[(x_i - X)\times(y_i - Y)]$	(sum of the squared residuals perpendicular to the line for the linear part);
$S_{xxy} = \Sigma[(x_i^2 - X^2)\times(y_i - Y)]$	(sum of the squared residuals perpendicular to the line for the quadratic part).

where:

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

$$Y = \frac{\Sigma y_i}{n} ;$$

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

$$X = \frac{\Sigma x_i}{n} .$$

3.2.3 Solution system

Determine c, d and e (see 3.2.1) using the following matrix:

$$\Sigma y_i = c \times n + d \times \Sigma x_i + e \times \Sigma x_i^2 \quad \text{... (27a)}$$

$$\Sigma(x_i \times y_i) = c \times \Sigma x_i + d \times \Sigma x_i^2 + e \times \Sigma x_i^3 \quad \text{... (27b)}$$

$$\Sigma(x_i^2 \times y_i) = c \times \Sigma x_i^2 + d \times \Sigma x_i^3 + e \times \Sigma x_i^4 \quad \text{... (27c)}$$

NOTE: Examples showing the procedures that can be used are detailed in annex A.

3.2.4 Suitability of data

Calculate the squared, r^2, and the linear coefficient of correlation, r, using the following equations:

$$r^2 = \frac{c \times \Sigma y_i + d \times \Sigma(x_i \times y_i) + e \times \Sigma(x_i^2 \times y_i) - [(\Sigma y_i)^2/n]}{\Sigma y_i^2 - [(\Sigma y_i)^2/n]} \quad \ldots (28)$$

$$r = \left|(r^2)^{0,5}\right| \quad \ldots (29)$$

If the value of r^2, or r, is less than the applicable minimum value given in table 1 as a function of n, consider the data unsuitable for analysis.

3.2.5 Check for the suitability of data for extrapolation

If it is intended to extrapolate the line, calculate M using the following equation:

$$M = \frac{S_x^2}{S_{xy}^2} + \frac{S_{xx}^2}{S_{xxy}^2} - \frac{t_v^2 \times (S_x \times S_y - S_{xy}^2 + S_{xx} \times S_y - S_{xxy}^2)}{(n - 2) \times S_y^2} \quad \ldots (30)$$

If M is equal to or less than zero consider the data unsuitable for extrapolation.

3.2.6 Validation of statistical procedures by an example calculation

Use the data given in table 5 for the calculation procedures described in 3.2.2 to 3.2.5 to ensure that the statistical procedures to be used in conjunction with this method will give results for r, r^2, a, b and V_m to within ± 0,1 % of the values given in this example (n = 15).

Sums of squares and other variables

Σx_i = 21,671;

Σx_i^2 = 62,989;

Σx_i^3 = 180,623;

Σx_i^4 = 584,233;

Σy_i = 56,728;

$(\Sigma y_i)^2$ = 3218,09;

Σy_i^2 = 214,574;

$\Sigma x_i y_i$ = 80,932;

$\Sigma x_i^2 y_i$ = 235,175;

S_x = 31,681;

S_{xx} = 386,638;

S_y = 0,347;

S_{xy} = -1,0242;

S_{xxy} = -3,0418.

Solution system (see 3.2.3)

c = 3,8288;

d = -0,0262;

e = -0,0022.

Coefficient of correlation (see 3.2.4)

r^2 = 0,9647;

r = 0,9822.

Check of the suitability for extrapolation (see 3.2.5)

t_v = 2,1604;

M = 15859,6.

The estimated mean values, V_m, for V at various times are given in table 7 and shown in figure 2.

Table 7: Estimated mean values, V_m, for V

Time h	V_m
0,1	7125
1,0	6742
10,0	6315
100,0	5856
1000	5375
10000	4884
100000	4393
438000	4091

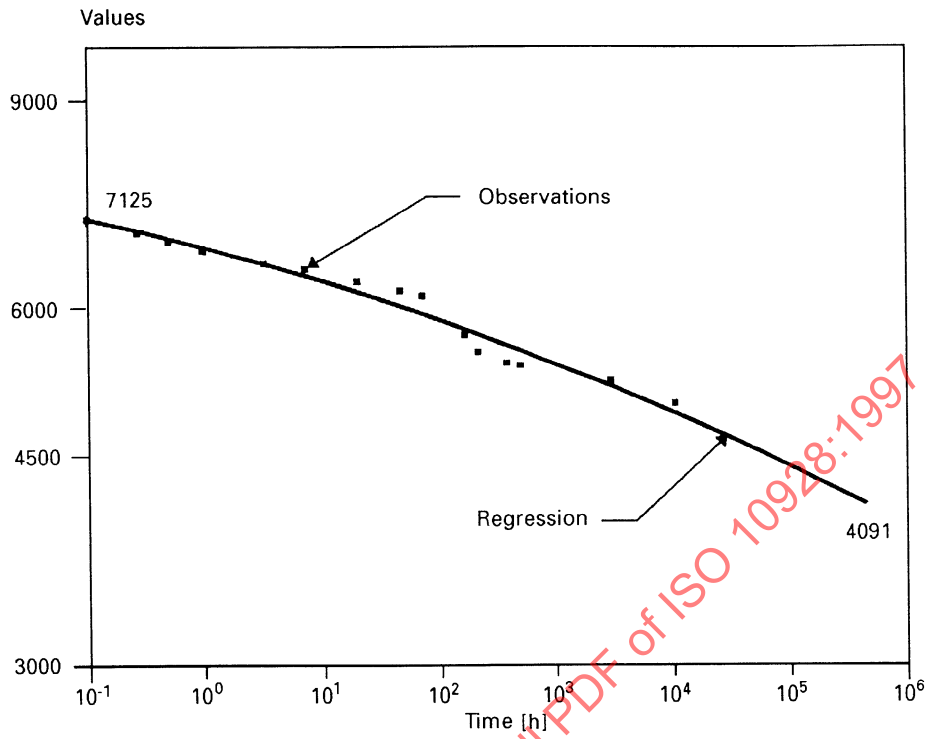

Figure 2: Regression line from the results in table 7

4 Application of methods to product design and testing

4.1 General

The referring standards specify limiting requirements for the properties and performance of a product. Some of these are based on destructive tests, for example hoop tensile strength, whilst others are based on actual or derived physical properties, such as stiffness.

Where the physical property being determined enables both method B and method C to be used then both procedures shall be performed. The value for r^2 and/or r determined for each procedure shall be compared and the value for the property determined using the procedure with the highest r^2 or r value shall be taken as the value for the property. If the referring standard specifies for such properties a method then only that procedure shall be performed.

In either case, many of these properties need an extrapolated long-term (e.g. 50 years) value for comparison with the requirement. This extrapolated value is determined by inserting, as necessary, the values for a, b, c, d and e, determined in accordance with 3.1 or 3.2 as appropriate, into equation (31) or (32) respectively.

$$\lg y = a + b \times t_L \quad \dots (31)$$

$$\lg y = c + d \times t_L + e \times t_L^2 \quad \dots (32)$$

where:

t_L is the logarithm (lg) of the long-term period, in hours, [for 50 years (438000 h), t_L = 5,64147].

Solving the equation, (31) or (32), for y gives the extrapolated value for comparison with the requirement specified in the referring standard.

For supplementary procedures, where relevant, for the application of the results to derive design requirements, see 4.2 and the worked examples given in 4.3 to enable validation of any calculation facilities used.

For their use for testing products, to predict and verify the ability of a product to conform to a specified requirement, see 4.4 and the examples given in 4.5 to enable validation of any calculation facilities used.

The wording of 4.2 to 4.5 is appropriate to specification limits in terms of minimum values, long-term performance at 50 years and short-term performance at 6 min. For limits comprising maximum values or other time periods, appropriate adjustments are necessary.

In conjunction with sampling requirements and limits on the acceptable levels, if any, on the quantity of non-conforming products to be specified by referring standards and in certification or quality plans, as appropriate, these methods can be used for quality control purposes.

4.2 Design

4.2.1 Regression values

4.2.1.1 Derived long-term values

Where it is assumed that, from initial short-term tests on pipe representative of such a design, the mean value of the property being investigated, $V_{0,m}$, and the estimated standard deviation, σ, of the initial test results are known, the procedures for designing a pipe to conform to a requirement of a referring standard are as follows.

If a safety factor, F_S, is specified, calculate the minimum long-term (50 years) value for the property, $V_{50,min.}$, (see figure 4), using the following equation:

$$V_{50,min.} = F_S \times V_{50,s,min.} \qquad \text{... (33)}$$

otherwise:

$$V_{50,min.} = V_{50,s,min.} \qquad \text{... (34)}$$

where:

$V_{50,s,min.}$ is the specified minimum long-term (50 years) requirement.

4.2.1.2 Regression ratio (see figure 3)

Calculate the regression ratio, R_R, using the following equation:

$$R_R = \frac{\text{extrapolated long-term (50 year) property value}}{\text{extrapolated short-term (6 min) property value}} \qquad \text{... (35)}$$

$$R_R = \frac{V_{50}}{V_6} \qquad \text{... (35)}$$

where both the 50 year and the 6 min extrapolated property values are calculated using equation (31) or (32), as applicable, except that for the 6 min value the logarithm of 0,1 h (6 min), i.e. -1, is used in place of 5,64147.

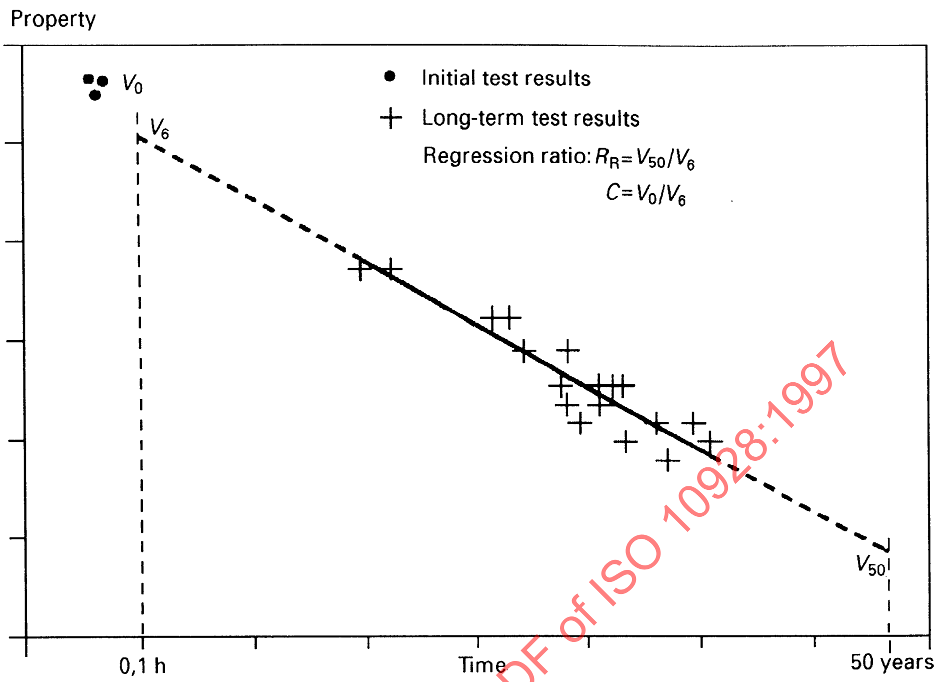

Figure 3: Extrapolated values

4.2.1.3 Factor C (see figure 3)

Calculate the factor C, which relates the extrapolated 6 min value to the test result for the initial tests on the pipes, using the following equation:

$$C = \frac{\text{initial property value}}{\text{extrapolated 6 min property value}} = \frac{V_0}{V_6} \quad \ldots (36)$$

4.2.2 Initial values

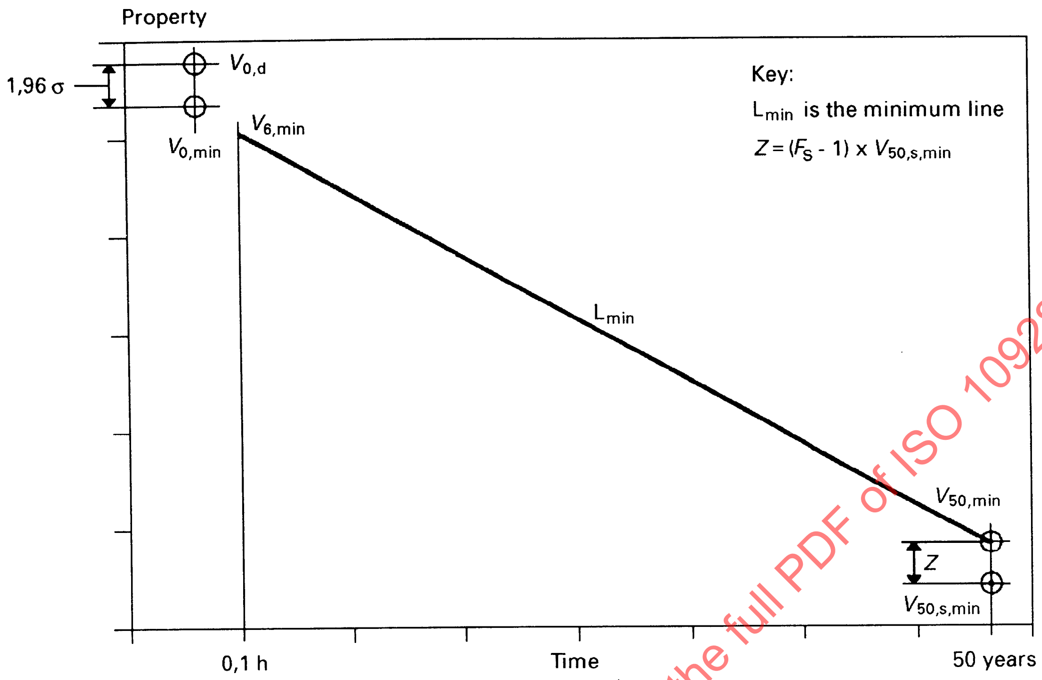

Figure 4: Derived values

4.2.2.1 Minimum initial property value ($V_{0,min.}$)

Derive the minimum initial property value, $V_{0,min.}$, using the following equation:

$$V_{0,min.} = \frac{C \times V_{50,min.}}{R_R} \qquad \dots (37)$$

where:

C is calculated using equation (36);

$V_{50,min.}$ is calculated using equation (33) or (34);

R_R is calculated using equation (35).

4.2.2.2 Property design values

Derive the design value for the initial property, $V_{0,d}$, using the following equation:

$$V_{0,d} = V_{0,min.} + 1,96 \times \sigma \qquad \dots (38)$$

where:

σ is the standard deviation of the short-term test results for this property.

The factor 1,96 assumes that a 2,5 % failure criteria is acceptable. Where other percentage failure criteria are specified in the referring standard then the relevant factor obtained from standard statistical references shall be substituted for 1,96.

NOTE: Where the standard deviation can be expected to increase with an increase in mean property values, and vice versa, then the design property values for different levels of the property can be obtained using a constant coefficient of variation.

Determine the short-term (6 min) and long-term (50 years) design property values, and hence the design line as follows:

- determine the estimated 6 min design property value, $V_{6,d}$, using the following equation:

$$V_{6,d} = \frac{V_{0,d}}{C} \qquad \text{... (39)}$$

where:

C is determined in accordance with 4.2.1.3;

- determine the estimated 50 years property value, $V_{50,d}$, using the following equation:

$$V_{50,d} = R_R \times V_{6,d} \qquad \text{... (40)}$$

where:

R_R is the regression ratio determined in accordance with 4.2.1.2;

- if applicable (see 4.1), determine the equation for the linear design line as follows:

$$\lg V_{t,d} = a_d + (b \times \lg t) \qquad \text{... (41)}$$

where:

$V_{t,d}$ is the design property value at a given time t;

b is the slope of both the minimum and the mean linear regression lines;

a_d is the constant of the linear design line;

where:

$$a_d = a + \delta_d \quad \dots (42)$$

where:

a is the constant of the property value mean linear line [see equation (1)];

$$\delta_d = \lg \frac{V_{0,d}}{V_{0,m}} \quad \dots (43)$$

- if applicable (see 4.1), determine the equation for the second order design curve as follows:

$$\lg V_{t,d} = c_d + (d \times \lg t) + \{e \times (\lg t)^2\} \quad \dots (44)$$

where:

$V_{t,d}$ is the design property value at a given time t;

d, e are the coefficients of both the design curve and the mean second order regression curve;

c_d is the constant of the second order design curve;

where:

$$c_d = c + \delta_d \quad \dots (45)$$

where:

c is the constant of the the second order mean regression curve [see equation (26)];

$$\delta_d = \lg \frac{V_{0,d}}{V_{0,m}} \quad \dots (43)$$

4.3 Examples for validation of calculation procedures for design

4.3.1 General

Use the data given in 4.3.2 and 4.3.3, as applicable, to verify that the calculation procedures used will give results for a, b, c, d, e, r^2, r, $V_{50,\text{min.}}$, $V_{6,\text{min.}}$, $V_{0,\text{min.}}$ and $V_{0,d}$ to within ± 0,1 % of the example values.

4.3.2 Example 1: Linear relationship; destructive test failure behaviour

4.3.2.1 The problem

Assuming that

a) the data given in table 3 are burst test pressure results, in bars;

b) table 4 comprises the results of the regression analysis of these burst test data for a pressure pipe;

c) initial burst test data are available in table 8 for a pipe with a comparable wall build-up, as given under a) and b),

determine the design values for a PN 10 (nominal pressure) pipe with a safety factor, F_S, of 1,8.

Table 8: Initial burst test results

Values in bars[1)]

52,0	44,5	49,0	50,3	46,7	51,1
47,3	49,7	53,3	51,1	46,0	50,3
45,9	49,1	48,8	46,7	49,8	53,6
Mean initial burst pressure				$p_{0,m}$	= 49,18
Standard deviation				σ	= 2,59

4.3.2.2 Calculations and final results

For the data in table 3 (see 3.1.2.6):

a = 1,62731;

b = -0,03317,

and hence (table 4):

p_6 = 45,76 bar;

p_{50} = 27,55 bar.

Using equation (35):

$$R_R = \frac{p_{50}}{p_6} = \frac{27,55}{45,76} = 0,6021.$$

Using equation (36):

$$C = \frac{p_{0,m}}{p_6} = \frac{49,18}{45,76} = 1,0747.$$

1) 1 bar = 10^5 N/m^2 = 0,1 MPa

The design values for the PN 10 pipe with a safety factor of 1,8 then become:

using equation (33):

$$p_{50,\text{min.}} = F_S \times p_{50,s,\text{min.}} = 1{,}8 \times 10 \text{ bar} = 18 \text{ bar};$$

$$p_{6,\text{min.}} = \frac{p_{50,\text{min.}}}{R_R} = \frac{18}{0{,}6021} \text{ bar} = 29{,}9 \text{ bar};$$

and using equation (35) and (37):

$$p_{0,\text{min.}} = C \times p_{6,\text{min.}} = 1{,}0747 \times 29{,}9 \text{ bar} = 32{,}1 \text{ bar};$$

using equation (38):

$$p_{0,d} = p_{0,\text{min.}} + 1{,}96 \times \sigma = 32{,}1 + 1{,}96 \times 2{,}59 = 37{,}18 \text{ bar}.$$

The 6 min and 50 years design values are derived using equations (39) and (40):

$$p_{6,d} = \frac{p_{0,d}}{C} = \frac{37{,}18}{1{,}0747} \text{ bar} = 34{,}6 \text{ bar}$$

$$p_{50,d} = R_R \times p_{6,d} = 0{,}6021 \times 34{,}6 \text{ bar} = 20{,}83 \text{ bar}$$

These equations give rise to the plots shown in figure 5.

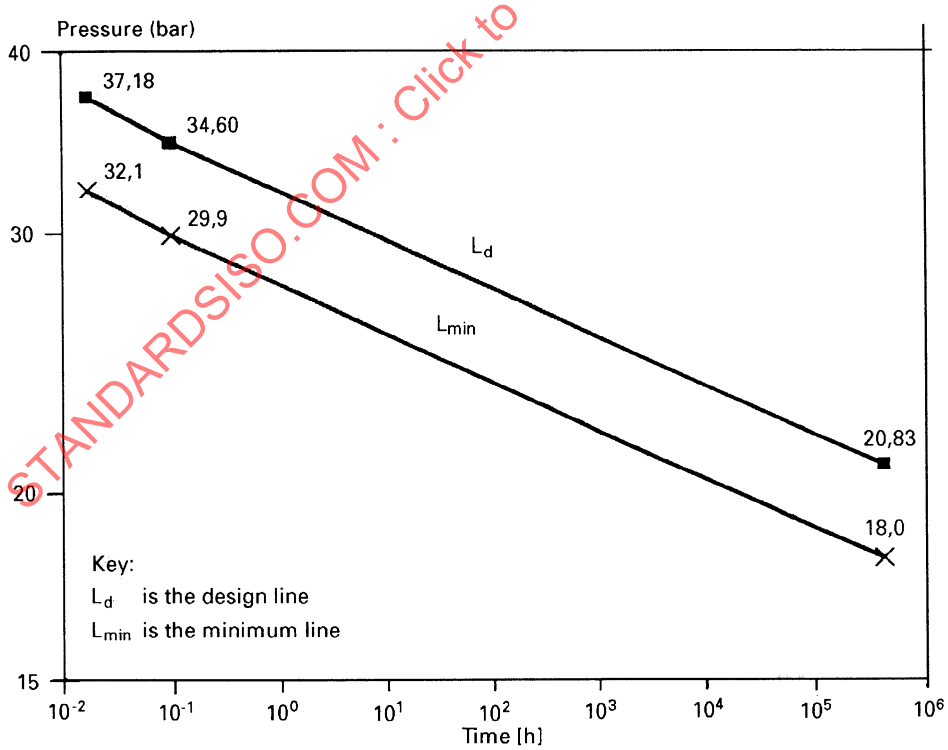

Figure 5: Example for pressure

4.3.3 Example 2: Second order relationship; non-destructive test (creep) behaviour

4.3.3.1 The problem

Assuming that

a) the data given in table 5 are ring stiffness test results, in newtons per square metre;

b) tables 6 and 7 comprise the results of the regression analysis of these ring stiffness test data;

c) initial ring stiffness test data are available in table 9 for pipes with a comparable wall build-up as for a) and b),

determine the design values for a SN 5000 pipe with a minimum long-term ring stiffness of 2000 N/m^2 and a safety factor, F_S, of 1,0.

Table 9: Initial ring stiffness test results

Values in newtons per square metre

7540	7200	6970	7190	7760
7170	7100	7310	6990	7180
Mean initial ring stiffness			$S_{0,m}$	= 7241
Standard deviation			σ	= 243

4.3.3.2 Calculations and definitive results

Using method B (linear relationship, see 3.1.3.2 and 3.1.3.5):

r^2 = 0,9556;

r = 0,9775.

Using method C (polynomial relationship, see 3.2.4 and 3.2.6):

r^2 = 0,9647;

r = 0,9822.

Because r^2, or r, obtained using method C is greater than that obtained using method B, the line derived using method C is the more appropriate and therefore the results given in 3.2.6, calculated from the data in table 5, are the following:

c = 3,8288;

d = -0,0262;

e = -0,0022,

and hence (table 7):

$S_6 = 7125$ N/m^2;

$S_{50} = 4091$ N/m^2.

From these results, it follows that:

using equation (35):

$$R_R = \frac{S_{50}}{S_6} = \frac{4091}{7125} = 0,5742;$$

using equation (36) and the results given in table 9:

$$C = \frac{S_{0,m}}{S_6} = \frac{7241}{7125} = 1,0163.$$

The design values for a SN 5000 pipe with minimum long-term ring stiffness of 2000 N/m^2 and a factor of safety of 1,0 then become:

using equation (34):

$$S_{50,min.} = S_{50,s,min.} = 2000 \text{ N/m}^2;$$

$$S_{6,min.} = \frac{S_{50,min.}}{R_R} = \frac{2000}{0,5742} = 3483 \text{ N/m}^2,$$

and using the equations (35) and (37):

$$S_{0,min.} = C \times S_{6,min.} = 1,0163 \times 3483 \text{ N/m}^2 = 3540 \text{ N/m}^2.$$

The value for $S_{0,min.}$ from the initial requirement (5000 N/m^2) is greater than the one from the long-term requirement (3540 N/m^2), therefore the relevant value is:

$$S_{0,min.} = 5000 \text{ N/m}^2.$$

Hence, using equation (38) and the results given in table 9:

$$S_{0,d} = S_{0,min.} + 1,96 \times \sigma = 5000 + 1,96 \times 243 = 5476 \text{ N/m}^2.$$

The 6 min and 50 years design values are derived using equations (39) and (40):

$$S_{6,d} = \frac{S_{0,d}}{C} = \frac{5476}{1,0163} \text{ N/m}^2 = 5388 \text{ N/m}^2$$

$$S_{50,d} = R_R \times S_{6,d} = 0,5742 \times 5388 \text{ N/m}^2 = 3094 \text{ N/m}^2$$

Based on the initial requirement (5000 N/m²) the 6 min and 50 years minimum values are also derived using equations (39) and (40):

$$S_{0,6,\mathrm{min.}} = \frac{S_{0,\mathrm{min.}}}{C} = \frac{5000}{1,0163} \mathrm{N/m^2} = 4920 \mathrm{N/m^2}$$

$$S_{0,50,\mathrm{min.}} = R_R \times S_{0,6,\mathrm{min.}} = 0,5742 \times 4920 \mathrm{N/m^2} = 2825 \mathrm{N/m^2}$$

These equations give rise to the plots shown in figure 6.

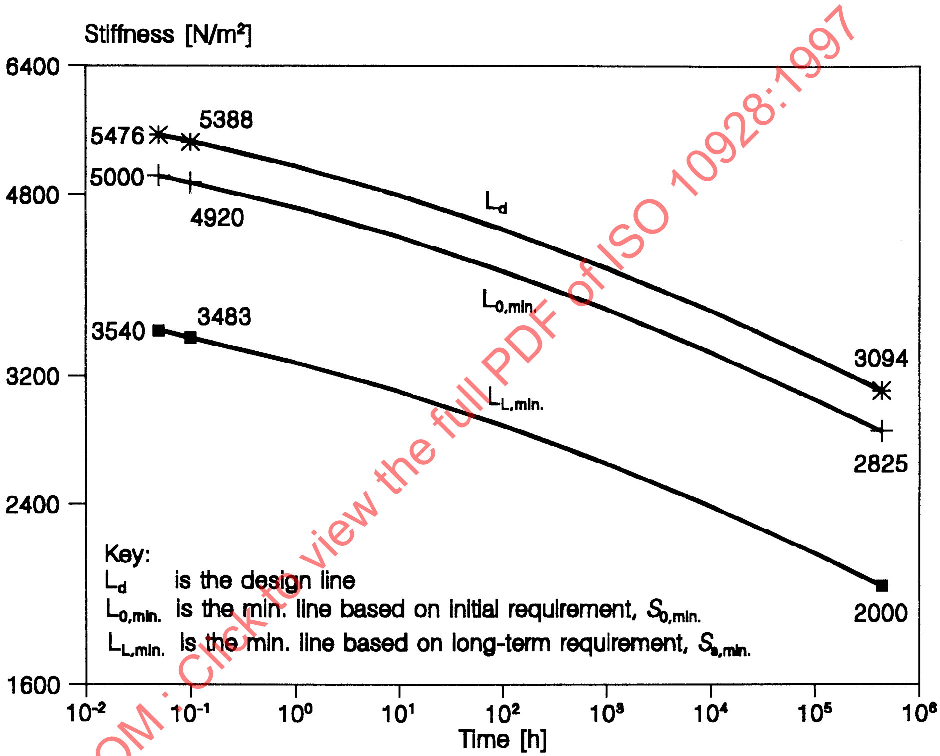

Figure 6: Example for ring stiffness

4.4 Procedures for verifying conformance to product design and performance values

4.4.1 General

Given the following assumptions:

a) a pipe design is to be verified by short-term tests or by both short-term and long-term tests on a product;

b) the design value, $V_{0,d}$, of the property being investigated has been determined in accordance with 4.2, use the following procedures as applicable to show that the product conforms to the design requirements, where:

- method 1 (see 4.4.2) is valid for destructive test behaviour;
- method 2 (see 4.4.3) is valid for non-destructive test behaviour.

4.4.2 Method 1 - Verification using destructive test data

4.4.2.1 Relationship between design value and/or minimum line and test results of products

Using the property design values determined in accordance with 4.2.2.2 unless otherwise specified in the referring standard the following requirements shall be used to assess conformity with the standard.

When a large group, i.e. more than 20 consecutive results, is being assessed then the following conditions shall be satisfied to show conformity with the referring standard:

a) the mean of the results shall be equal to or greater than the design value (see 4.2);

b) no individual result shall be less than 80 % of the minimum value (see 4.2).

When a small sample, i.e. up to and including five consecutive results, is being assessed then the following conditions shall be satisfied unless the referring standard specifies otherwise:

c) the mean of the sample shall not be less than the design value minus the standard deviation used to determine the design value (see 4.2);

d) no individual result shall be less than 80 % of the minimum value (see 4.2).

4.4.2.2 Relationship between design line and product data

Where times other than zero, 6 min or 50 years are specified in the referring standard then equation (41) (see 4.2.2.2) shall be used to determine the design value, $V_{t,d}$ (see figure 7).

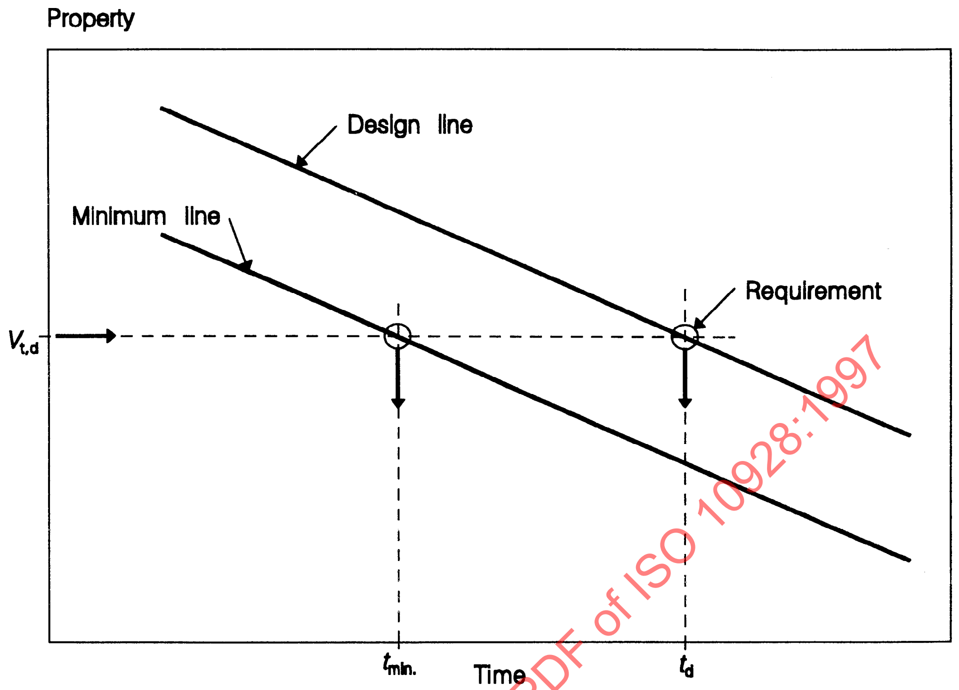

Figure 7: Property test values

4.4.2.3 Relationship between minimum line and product data (see figure 7)

Where times other than zero, 6 min or 50 years are specified in the referring standard then the following equation shall be used to determine the minimum required value, $V_{t,min.}$.

$$\lg V_{t,min.} = a_{min.} + (b \times \lg t) \qquad \dots (46)$$

where:

$V_{t,min.}$ is the minimum property value at a given time t;

b is the slope of both the minimum and the mean line;

$a_{min.}$ is the constant of the minimum line;

where:

$$a_{min.} = a + \delta_{min.} \qquad \dots (47)$$

where:

a is the constant of the mean property value line [see equation (1)];

$$\delta_{min.} = \lg \frac{V_{0,min.}}{V_{0,m}} \qquad \dots (48)$$

4.4.2.4 Conformance to a design property value, $V_{t,d}$, after a specified time t (see figure 7)

Where either the time to failure for the design line, t_d, or the time to failure for the minimum line, $t_{min.}$, is to be verified the appropriate one of the following equations shall be used:

$$\lg t_d = \frac{\lg V_{t,d} - a_d}{b} \quad \ldots (49)$$

$$\lg t_{min.} = \frac{\lg V_{t,min.} - a_{min.}}{b} \quad \ldots (50)$$

4.4.3 Method 2 - Verification using non-destructive test data

NOTE: Non-destructive tests for verification of long-term design or physical property behaviour are usually creep tests. It is assumed that the period of time for testing, t_c, and related property requirements are specified in the referring standard (see also 4.4.1).

4.4.3.1 Relationship between design and/or minimum line and test results of products

For these relationships the assumptions and requirements given in 4.4.2.1 are applicable.

4.4.3.2 Relationship between design line and product data

Where times other than zero, 6 min or 50 years are specified in the referring standard then equations (41) and (44) as well as equations (46), (47) and (48) (see 4.2.2.2) shall be used to determine the design value, $V_{t,d}$ (for principle see figure 7).

4.4.3.3 Relationship between minimum line and product data

4.4.3.3.1 Linear relationship (see figure 7)

For the linear relationship, the assumptions, procedures and equations given in 4.4.2.3 are applicable.

4.4.3.3.2 Second order polynomial relationship (for principle see figure 7)

Where times other than zero, 6 min or 50 years are specified in the referring standard then the following equation shall be used to determine the minimum required value, $V_{t,min.}$.

$$\lg V_{t,min.} = c_{min.} + (d \times \lg t) + \{e \times (\lg t)^2\} \qquad \ldots (51)$$

where:

$V_{t,min.}$ is the minimum property value at a given time t;

d, e are the coefficients of both the minimum and the mean regression line;

$c_{min.}$ is the constant of the minimum line;

where:

$$c_{min.} = c + \delta_{min.} \qquad \ldots (52)$$

where:

c is the constant of the mean property value line [see equation (26)];

$$\delta_{min.} = \lg \frac{V_{0,min.}}{V_{0,m}} \qquad \ldots (53)$$

4.4.3.4 Conformance to a design property value, $V_{t,d}$, after a specified time t (see figure 7)

To verify that a product conforms to a design value $V_{t,d}$, or a minimum value $V_{t,min.}$, after a time t_c specified in the referring standard the following equations shall be used to determine the relevant values where t is to be replaced with t_c:

for the linear relationship:

$$\lg V_{t,d} = a_d + (b \times \lg t) \qquad \ldots (41)$$

$$\lg V_{t,min.} = a_{min.} + (b \times \lg t) \qquad \ldots (46)$$

and for the second order polynomial relationship: