PRESTRESSING WIRE RELAXATION VALUES EXPECTED AT 20 TO 80 °C

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1. Introduction

The presented approximation method of relaxation excess due to temperatures slightly over the ambient one (up to $+80$ °C) is likely to be of use for the estimation of the relatively short temperature effect in concrete steam curing.

There are recommendations specifying the expected relaxation of prestressing wire as a function of manufacture (drawn and stress relieved, stabilized, alloyed, oil quenched etc.) and of initial prestress [1], [2].

According to FIP Recommendations [1], relaxation loss R_{rel} depends on the initial prestress level R_0/R_{prk} according to a parabola of second order, and for $R_0 = 0.5\ R_{prk}$ there is no relaxation (relaxation threshold); the Skandinavian formula is right in lowering the relaxation threshold ($0.4\ R_B$) but the loss is only linearly related to the initial prestress level — contrarily to several test results. It should be noticed that both rheological models (e.g. [3]) and tests (e.g. [4]; for $R_0 = 0.1\ R_B$) show relaxation at any non-zero stress — the quoted relaxation threshold of $0.5\ R_{prk}$ cannot be considered as valid but at marked practical neglects.

In case of non-normal temperatures, even specifications recommend tests to be made. [1]

As testified by some tests (e.g. [5] through [9]), and in conformity with a statement by the FIP Symposium in Madrid [10], the elevated temperature effect can be estimated by superposing on the normal temperature effect a thermal excess ΔR_{rel}, linearily dependent on the temperature difference:

$$R_{rel,t^\circ} = R_{rel\,25^\circ} + A. \ (t^\circ - 25^\circ). \tag{1}$$

It is apparent, however, from a more comprehensive analysis of data (especially of those of the 10.000 h tests [6]) that this assumption is only approximate and even so, valid only for certain wire types and in their range for a certain initial prestress level. Also our test results reject the general validity of Eq. (1), a hint to find another approximate calculation method by superposition [11].

2. Records and evaluation

Tests were started at an initial prestress R_0 amounting to 70 per cent of the real tensile strength at normal temperature, and relaxation was expressed as its percentage (Table 1).

Two specimens of $\varnothing$ 5 mm wire made by Felten (Austria) were tested at about $+25$ °C, at exactly $+40$ °C and $+80$ °C each, and one specimen of $\varnothing$ 7 mm at about $+20$ °C, at exactly $+50$ °C and $+80$ °C each, by means of a lever-

Table 1

Relaxation test data on a wire $\varnothing$ 7 mm made in Austria					
20 °C		50 °C		80 °C	
Time h	Prestress loss %	Time h	Prestress loss %	Time h	Prestress loss %
0.4	0	0.1	3.95	0.1	3.96
0.5	0.28	0.2	4.54	0.25	5.33
0.7	0.28	0.4	4.92	0.4	6.61
1.—	0.49	0.7	5.73	0.5	7.60
2.—	0.95	2.0	6.90	0.7	8.21
4.—	2.04	4.0	8.10	1.—	8.50
7.—	2.75	6.0	8.40	2.—	10.61
24.—	2.75	24.0	11.10	4.—	12.20
48.—	4.20	48.0	11.60	7.—	13.40
120.—	4.20	72.0	12.00	24.—	15.80
288.—	4.54	100.0	12.40	48.—	16.90
504.—	5.56	168.0	14.20	96.—	16.90
720.—	6.10	334.0	15.20	192.—	18.00
1056.—	6.52	504.0	15.90	394.—	19.20
1512.—	7.70	696.0	17.00	576.—	20.15
2000.—	9.20	864.0	17.80	788.—	20.80
		1008.0	18.50	984.—	21.3

type relaxation tester of manual weight reduction. Wires have been loaded after heating, and then fixed. Stress R_0 being obtained in 2 minutes, a few seconds later the measuring length had been fixed and relaxation measurement started. Mechanical data of wires and the deduced indices are shown in Table 2.

Notice that — according to a statement on p. 69 in [10] — stepwise load reduction produces a higher measured relaxation than does a perfectly continuous one, hence the generally applied method by freely suspended lever arm involves an error on the safe side.

A relaxation that is constant during a given period (Table 1) is otherwise assumed not to be due to a measurement error: in fact, in a real material, phenomena occur periodically (e.g. displacements of dislocations); this is only approached by functions derived for ideal materials.

Curves plotted from best fitting approximation and extrapolation functions calculated from 1000 h data are shown in Fig. 1.

Table 2

A) Mechanical data of wires

Specimen		Permanent set stress		Tensile strength	Modulus of elasticity	Total elongation
		$R_{0,02}$	$R_{0,2}$	R_B	E	δ_{10}
$\varnothing$ mm	No.		kp/mm²			%
6	1	158	174	186	19 100	5
	2	166	171	186	18 900	4.8
7	1	140	155	171	20 000	5.7
	2	143	156	171	20 300	6.7

B) Relaxation quality indices of prestressing wire

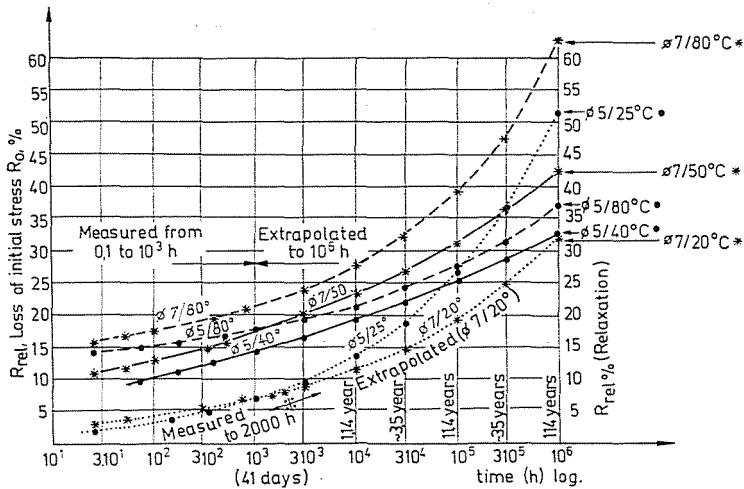| Wire	$R_{0,02}/R_B$	$R_{0,2}/R_B$	$R_0 = 0.7\, R_B$	$R_v/R_{0,02}$	$R_v/R_{0,2}$
$\varnothing$ mm 5	0.87	0.926	130	0.803	0.754
$\varnothing$ mm 7	0.823	0.91	119.5	0.845	0.769

Fig. 1

Qualitative evaluation of the really measured curve sections

Parameters in part B of Table 1 suggest that at an identical stress level R_0/R_B the $\varnothing 7$ mm wire will relax more than the $\varnothing 5$ mm wire — at least during a prolonged initial period, since its technical elastic limit and 0.2 % permanent set stress is more exploited.
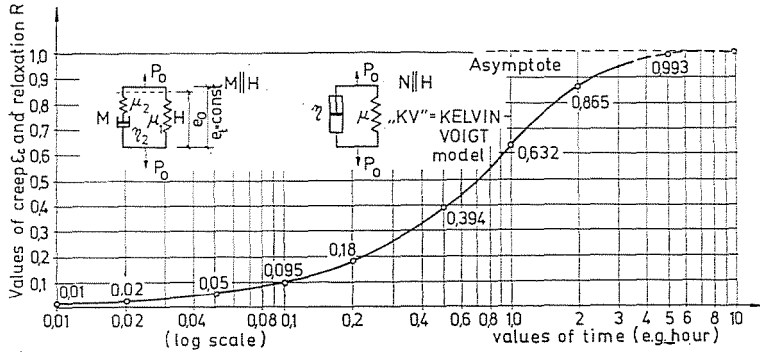

Fig. 2 Simplest rheological models and the typical "S"-shaped functions

$$R = R_1 (1 - e^{-t/tr}) \qquad \varepsilon_c = \frac{p_0}{\mu} (1 - e^{-t/tr}) \qquad y = 1 - e^{-x}$$

$$R = 1 - e^{-t} \qquad\qquad \varepsilon_c = 1 - e^{-t}$$

20 to 25 °C curves plotted to lin-log scale are typically within the first section of the "S"-shaped function in [12], and the relaxation will long increase. Our "hotter" curves are about lying between the first (so-called parabolic) and the second (so-called logarithmic) section. Remark that in 10,000 h iso-thermal tests at 20, 40, 60, 100 °C no variation of the creep rate according to a "S"-shaped curve was observed in case of stabilized strands and wires [13]. Materials of shorter relaxation times t_r, hence poorer from this aspect, are likely to exhibit sections characteristic to the "S" curve. Fig. 2 shows rheologi-cal model of the "S" curve, together with its peculiar function $y = 1 - e^{-x}$.

It is interesting to see the relaxation increment not to be directly pro-portional to the temperature increase: a rather slight deviation from 20 °C or 25 °C causes an abrupt relaxation increase.

Calculated values of term 2 in Eq. (1), i.e., ΔR_{rel} due to temperature incre-ments referred to 20 °C or 25 °C, for different periods (Table 3) show relaxation increments of the material of the $\varnothing 5$ mm wire ΔR_{rel} to about stabilize after 10 h, or for $t = 40$ °C, after 100 h, hence for the given case, recorded data permit to deduce an approximate formula in the form of (1): For $\varnothing 5$ mm wire, $T \geqslant 10$ h and $R_0 = 0.7\ R_B$:

$$R_{rel,80°} \approx R_{rel,25°} + 11.8\ \% \tag{2}$$

for $T \geq 100$ h:

$$R_{\text{rel},40°} \simeq R_{\text{rel},25°} + 7.5\,\% \tag{3}$$

For the $\varnothing 7$ mm wire (see in Table 3) no kind of superposition formula can be deduced from the data, since temperature increments ΔR_{rel} are far from stabilized at 1000 h, even they increase: relaxation rates do not converge.

Table 3

Recorded and linearly extrapolated relaxation increments ΔR_{rel} due to a temperature increment Δt and their ratios for wires $\varnothing$ 5 and 7 mm

$\varnothing$ mm	Time h	Increment $\Delta R_{\text{rel}}\%$ over $t = 25$ °C for			$\dfrac{\text{Recorded}}{\text{Calculated}}\,\%$
		$t = 80$ °C rec.	$t = 40$ °C rec.	$t = 40$ °C calc.	$t = 40$ °C
	0.25	7.87	2.63	2.15	122
	1	8.90	3.50	2.43	144
5	10	11.2	5.1	3.05	167
	100	12.9	7.25	3.52	206
	1000	11.3	7.45	3.08	242

$\varnothing$ mm	Time h	Increment $\Delta R_{\text{rel}}\%$ over $t = 20$ °C for			$\dfrac{\text{Recorded}}{\text{Calculated}}\,\%$
		$t = 80$ °C rec.	$t = 50$ °C rec.	$t = 50$ °C calc.	$t = 50$ °C
	0.1	3.9	3.9	1.95	200
	1	8.0	5.6	4.0	140
7	10	11.4	6.9	5.7	121
	100	12.75	8.15	6.38	127
	1000	14.8	12.00	7.4	162

40 °C (50 °C) data calculated by linear interpolation between 20 °C (25 °C) and 80 °C remain throughout below the recorded ones, "recorded/calculated" mid-temperature indices exhibit 50 to 100 per cent errors to the detriment of safety for the case if the relaxation value expected for $t \neq 20$ °C (25 °C) is to be estimated by means of the linear interpolation formula (1).

Exponential interpolation

If the relaxation $R_{\text{rel},t}$ expected at a higher temperature is likely to be approximable by a superposition formula based on recorded data (such as for the $\varnothing 5$ mm wire) then the relaxation at a higher temperature is to be estimated by means of the exponential formula we proposed, instead of Eq. (1):

$$R_{\text{rel},t} = R_{\text{rel},t_0} + A\left(\frac{\Delta t}{B}\right)^c \tag{4}$$

where $\varDelta t = (t - t_0)$; A and c being constants determinable trom recorded data, from a relaxation curve for at least two temperatures different from t_0; and B an arbitrary initial temperature [11]. Eq. (4) is the generalized form of the superposition formula (1), coincident with it for $c = 1$. Namely, in log-log scale, term 2 of function (4) i.e. temperature increment curve $\varDelta R_{\text{rel}}$ straightens:

$$\log \varDelta R_{\text{rel}} = \log A + c \cdot \log \frac{\varDelta t}{B} \ . \tag{5}$$

Thus, A, B and c can be determined by construction and calculation on log-log paper. (See the procedure on e.g. p. 28 in [14] and p. 733 in [17].)

Exponentially interpolating formula of superposition based on 1000 h tests on wire $\varnothing$ 5 mm at $t > 25$ °C ($\varDelta t = t - 25$ °C):

$$R_{\text{rel},t^\circ} = R_{\text{rel},25^\circ} + 6.3 \left(\frac{\varDelta t}{10}\right)^{0,362} \ . \tag{6}$$

This formula cannot be interpreted for $t < 25$ °C since it leads to imaginary numbers, but towards $t > 80$ °C a *minor* temperature extrapolation seems feasible.

Constants A and c are more safe to construct by checking for three relaxation value pairs recorded at four different temperatures (e.g. 20—40—60—80 °C) whether in fact, plots in log-log scale are rectilinear or not. Remark that curves in [6] obtained upon delayed rather than isothermal heating would yield $c > 1$ for certain cases; and $c < 1$ for others like ours. Thus, formula (4) is not bound to a test method; on the other hand, c is a constant depending on the initial prestress and the wire type, that can only be determined by tests for certain narrow temperature ranges.

A formula like (6) is meaningless for the 1000 h data series of the $\varnothing$ 7 mm wire in our case, increments varying continuously even after 1000 h. Then extrapolation of recorded data has to be attempted first, although extrapolated values of functions fitted to recorded divergent data series will again be divergent, little promising for the parallelism "after a while" of relaxation curves.

3. Extrapolation of recorded data

Functions seeming appropriate

Previously, ([11], [14]) some functions had been analysed for suitability to *estimation* (extrapolation) and *fitting* to recorded data (approximation).

(Here and in the following, R means relaxation [%], v_R its rate, t the time and T the temperature.)

Table 4

Adopted extrapolation values

Time h	Time days, years	Wire ø 5 mm			Wire ø 7 mm		
		+25°	+40°	+80°	+20°	+50°	+80°
$3 \cdot 10^3$	123 d	9.4	16.35	19.4	8.8	20.0	23.8
10^4	1.14 y	13.6	19.10	21.1	11.5	23.3	27.6
$3 \cdot 10^4$	3.42 y	18.7	22.0	24.2	14.7	26.8	32.1
10^5	11.4 y	*26,6	25.1	27.6	19.3	31.3	39.0
$3 \cdot 10^5$	34.2 y	*36.6	28.5	31.6	24.7	*36.1	*47.6
10^6	114 y	*51.5	32.6	37.0	*32.5	*42.1	*61
Considered time h		24 1008	72 1008	24 1008	24 2000	24 504	24 984
Adopted extra-polation function		Mean from two D	Mean from C 1st and 2nd deg.	Mean from D and C 2nd deg.	Linear C	Linear C	Mean from C 1st and 2nd deg.

* Improbably high

Type "A": $R = c_1 \cdot t^a$ corresponding to point rows exponentially bent up in log t scale. This function is straightened in log R — log t scale (cf. first-degree form type "C").

Type "B": $R = a + b \log t + c \log^2 t + \dots$ is a higher-order polynomial, rather fairly describing the diagram curved in lin R — log t (semilog.) scale. A simple linear approximation is detrimental to safety as a rule — in prolonged measurements, relaxation curves of high-grade materials at normal temperature always deviate from the initial straight line in R — log t scale.

Type "C": $\log R = a + b \log t + c \log^2 t + \dots$ (log-log scale). Omitting the first 24 to 120 hours, the in fact parabolic point rows — exponential on semi-logarithmic paper — may closely be approximated by a linear function (a straight line) at a neglect on the safe side. The same is recommended by the Concrete Research Institute of Holland (CUR) and by FIP [15], [1]. This solution is felt to be the happiest if a polynomial of second degree fits recorded data so that coefficient b of the square term is negative and the extreme value is far beyond the expected life.

Type "D": $\log v_R = -C_1 \cdot \log t + C_2$.

Relaxation is obtained by integrating a relaxation rate function rectilinear in log-log scale. Several authors (e.g. [7], [26] and [13]) point to the approximate straightness in log-log scale of the creep rate v_c. We apply the same assumption to the relaxation rate v_R, although creep and relaxation rates are known to *decrease more than calculated beyond 10,000 h*, hence, such an extrapolation would deliver excessively pessimistic values [11].

First-degree log R — log t approximation is mathematically identical to the first-degree log v_r — log t approximation.

Type "E": $R = A(1 - e^{-Bt})$ or $R = A(1 - e^{-Bt-c})$ yields a curve of "S" shape in log t scale, hence tending to a limiting value, correct according to [12], [16] but wrong according to [13]. This function is correct in conformity with the simplest (idealizing) rheological models, hence, from phenomenology aspects (see Fig. 2), and in constructional practice it is often used to describe slow processes tending to a final value, although to now, it has not been proved for metals by methods of metal physics. (The new Hungarian Standards for Prestressed Concrete involve this function for calculating the relaxation procedure.)

Instead of the expected $A \leq 100\%$, *type "E"* in its quoted simple forms yields also $A > 100\%$ values, hence, for actual estimation it is not superior to the previous functions. Notice that the three-parameter rheological model M ‖ H (Fig. 2) suits to simulate the instantaneous elastic elongation upon loading, the relaxation after setting the basis length, but fails to indicate the residual plastic strain after unloading (see e.g. [3]).

Extrapolation results

Available experience [11], [14], [17] gave a hint not to test but functions type C and D, although sometimes also type B may be of use after finding by trial the optimum degree. (For comparison of functions without and with rheological meaning see [25].)

Acceptable results of functions type "C" and "D" fitted to 24 to 1000 h data are compiled in Table 4. Extrapolated data are means of two or three possible solutions.

Evaluation of results and contradictions

Curves extrapolated from records $\varnothing\, 5/25 - 40 - 80$ (Fig. 1) lead partly to impossibilities: $\varnothing\, 5$ mm wires tested at higher temperature were lower in relaxation already after 10^4 h than those tested at normal temperature.

Contradictions are less conspicuous for wires $\varnothing\, 7$ mm, although the curve $7/80°$ would intersect that of $7/50°$ *within* the life of 114 years if both were extrapolated by pure *first-degree polynomial* type "C" (cf. FIP recommendation). With our extrapolating function (mean of the first and the better fitting second-degree one) intersection occurs later.

By now, the contradictory result can be attributed to four facts:

1. For high-grade wires at normal temperature, 1000 h tests are insufficient (as pointed out earlier). The semi-logarithmic diagram of the first thousand hours or so is abruptly ascending, thereby either the corresponding func-

tion type "*D*", or the similarly exponential construction according to [17], or even function type "*C*": $\log R = a + b \log t$ recommended by CUR and FIP yield excessive values [18], [19]. Extrapolation even at room temperature from at least 5000 h but still better from 10^4 h tests is more reliable if it is based on the second stage of measurements (after 3000 h). [19]

2. All the selected substitution functions are ascending in log scale (save type "*C*" in a single case, with negative square coefficient) and for $t \to \infty$, $R \to \infty$, hence they do not agree with the curve of "S" shape in log-log scale, considered rheologically correct, tending to a limiting value (Fig. 2, [12], [16]).

3. In heat relaxation tests, wires were heated to $+40$ °C, $+80$ °C etc., isothermally loaded and fixed in that condition, hence part of possible creep strain — affecting curve shape and position but escaping measurement — took place during loading.

4. The first (manual) load reduction was carried out 6 to 15 minutes after the reference length has been fixed, hence during this period pure creep rather than relaxation took place. This effect is markedly greater for wires tested at higher temperatures. The higher the temperature, the greater the error involved in the measured initial relaxation, the error being always on the safe side.

Conclusions: deficiencies of the isothermal method

Relaxation during loading can only be determined by more complex measurements started at the instant of loading, and by calculation using a model responsive to the entire process of loading (e.g. plastic, irreversible deformations).

Deficiencies of the already initially isothermal test method are eliminated by a delay in heating the wire tested for relaxation, determined on its turn by a frequency-type rather than a lever-type instrument. (See e.g. [6]).

Thus, prestress losses expected in curing are more reliably predicted from relaxation tests involving heating and cooling down than from isothermal tests. [7] states the *difference:* Relaxation of a wire heated from 20 °C to 80 °C at 15 days exceeds that of a wire tested from the beginning at 80 °C.

Isothermal relaxation error may be reduced also by recording isothermal *creep* as a process coherent with loading, and *calculating* relaxation therefrom, applying simple or intricate assumptions [13], [20], [21].

4. The Larson-Miller extrapolation

With reference to earlier authors, [23] states rates of creep, tempering and diffusion to obey the law:

$$\Theta = A \cdot e^{-Q/RT} \tag{7}$$

others derive from (7):

$$T(C + \log t) = \text{const} = LM \tag{8}$$

Plotting ultimate creep stresses in log scale and invariant (8) (often called Larson—Miller parameter and marked LM) in linear scale, for a given metal a single master curve (many overlapping ones) is obtained, yielding for arbitrary correlated t (h) and $T°$ (K) values the instantaneous strength, creep or relaxation [22], [24].

LM-type extrapolation consists essentially in an early generation of dislocation displacements by raising the temperature.

Processing of test results

From records and accepted extrapolations, wire relaxation curves vs. parameter $LM = T (C + \log t)$ have been plotted (Figs 3 and 4).

Curves in Fig. 3 are not coincident enough to unite in a master curve — but an equalizing curve can be traced. Values measured and extrapolated at
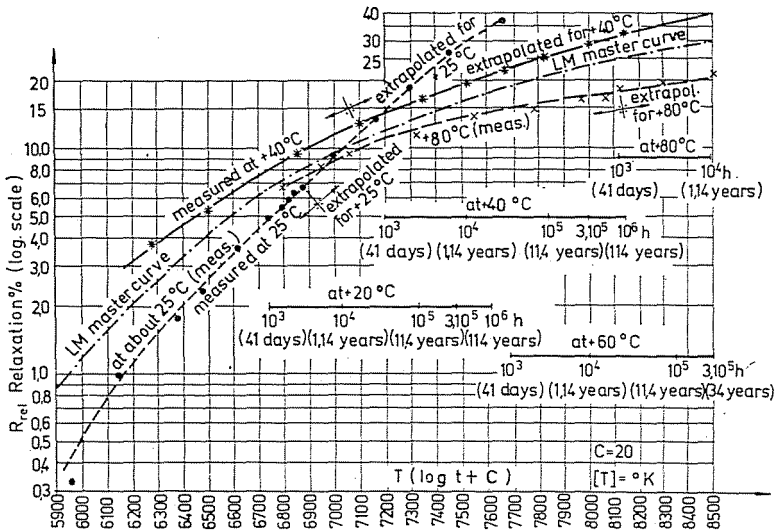

Fig. 3

+40 °C show the greatest scatter; relaxations being much higher than would follow from those measured either at 25 °C or at 80 °C, as already mentioned. Curve 5/25 °C, hardly extrapolable from 1000 h tests, intersects the scattered set of curves, proving its relaxation value set to be excessive. Also the test at "room temperature" of 25 °C might in fact be lower than that, hence the 25 °C curve ought to be shifted to the left, towards lower temperatures and LM values,

improving its fitting to both other curves. One condition of constructing a good master curve is to have a thermostated test room.

No better fitting is obtained with the constants of either $C = 11$ in [25] or $C = 16$ in [9]. A somewhat better fitting is seen in Fig. 4, as expected from Fig. 1.
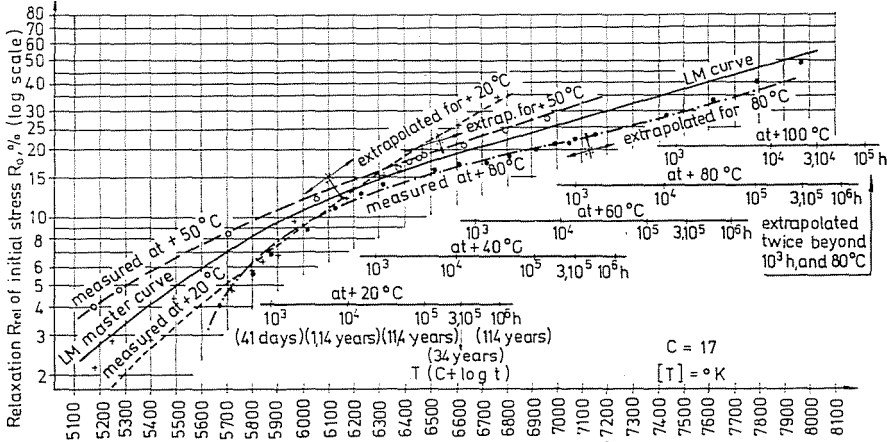

Fig. 4

Criticism of extrapolation

From a 1000 to 10,000 h data set of stabilized wires and strands (10, 5, 6 and 2 different types of materials at 20 °C, 40°, 60 °C and 100 °C, respectively), a creep rate function type *"D"* and its integrated had been established, then the complete creep functions were supplied also with relaxation scale, applying the simplified conversion $R = E \cdot \varepsilon_C$ [13]. Recorded and calculated curve sections are affin, creep increases about linearly with temperature. Though, this kind of curve set may better fit a *LM* master curve, also the values in [13] show a deviation between values extrapolated by the creep rate function and by the *LM* master curve, the former yielding excessive, by 20 to 40 per cent higher estimations, shown also by our previous $2 \cdot 10^4$ h tests [11]. Thus, *LM* extrapolation may be more reliable than to apply a *"D"*-type function.

5. Relaxation excess due to steam curing

Time-table of steam curing

Steam curing produces a temperature gradient in the concrete unit according or similar to the known stepped pattern. In case of a moderate concrete coverage or of steam curing in heated mould, wire temperature lags but slightly behind the theoretical curing temperature. The wire may even be overheated by about 5 to 10 °C due to exothermy. The cooling rate depends on the circumstances.

Superposition of thermal effects

Until there are no more reliable test data or theoretical values available, the effect of temperature time-table can only be approximated by superposition, as follows:

a) Let the wire begin to warm up e. g. 6 h after prestressing. Up to then, it is relaxing according to a +20 °C (+ 25 °C) diagram (T_2°).

b) Let the wire be warmed to e.g. +80 °C during 3 h. Its relaxation will then exceed the isothermal relaxation at 80 °C [7]. Here only the test data will be reckoned with, to the detriment of safety, relaxation passing to the isothermal curve for 80 °C (T_1°).

c) Then the relaxation will follow the 80 °C curve during e.g. 6 h of isothermal curing.

d) From 15 to 20 h the wire will cool down to +25 °C, while the relaxation rate will slow down or even stop for a while, but of course, the relaxation that occurred will not recede.

To correct part of the error to the detriment of safety, the wire is assumed to relax according to the higher temperature during cooling, e.g. according to the 80 °C diagram.

e) After cooling, the wire is assumed to relax further according to the +25 °C curve (or slower, to be cleared by further experiments).

If the curing process takes 24 hours, at an arbitrary time t, expected max loss in the prestressing wire in the concrete steam cured at T_1° and stored at T_2° after 24 h of cooling:

$$R \lesssim R_{24}^{(T_1)} + R_t^{(T_2)} - R_{24}^{(T_2)}$$

where $R_{24}^{(T_1)}$ = 24-h relaxation of a wire exposed to T_1 from 0 to 24 h;

$R_t^{(T_2)}$ = relaxation from 0 to t hours at temperature T_2; and

$R_{24}^{(T_2)}$ = relaxation from 0 to 24 hours at the same temperature T_2.

$R^{(T_1)}$ and $R^{(T_2)}$ values should possibly be taken from measurements, or else, from the extrapolating master curve LM.

If relaxation curves for different temperatures tend to become parallel after 24 (100, 200 etc.) hours, then another slight error on the safe side is committed by adopting throughout the curing temperature curve T_1.

6. Conclusions, suggestions

These isothermal curves show the relaxation to much increase upon warming by as little as 15 to 25 °C over normal temperature (e.g. in prestressed concrete reservoirs, bridge slabs, roof decks exposed to sunshine).

Relaxation rates are not absolutely equal, hence, superposition formulae

for intermediate temperatures are of casual validity, or even if valid, expo-
nential, rather than linear, interpolation has to be applied:

$$R_{\text{rel},t} = R_{\text{rel},t_0} + A \left(\frac{\Delta t}{B} \right)^c .$$

In our case $c < 1$, hence thermal increment is significant even for low Δt values.

Extrapolation functions fitted to 1000 to 2000 h data yield irrealistic
high values for normal temperature, requiring at least 5000 h or even 10,000 h
tests and improved extrapolation functions based on rheology models.
Recorded (or recorded and extrapolated) data permit only informative lower
and upper sections of the LM master curve to be constructed. Even so, this
diagram is more suitable for extrapolation or checking than arbitrary lengthen-
ing of measured data rows.

Relaxation after steam curing can be obtained from isothermal test
results by superposition. Informative, approximative value for $R_{g,t}$ being:

$$R_{g,t} \gtrless R_{24}^{(T_1)} + R_t^{(T_2)} - R_{24}^{(T_2)}$$

i.e. the relaxation loss is nearly as high as if the wire were constantly exposed
to heat.

Acknowledgement

Summary

1000 h relaxation data rows obtained at 20 . . . 80 °C show relaxation excess to depend
else than linearly on temperature increase.

Time-independent superposition formulae are only valid if relaxation rates become
equal still during measurements, a rather infrequent case.

Usual simplifying assumptions permit no reliable extrapolation, thus, rheological model-
based functions tending to a limiting value are imperative. Extrapolation by a Larson-Miller
parameter is acceptable even if only extreme values of the master curve are available.

Steam curing much increases relaxation. In lack of test data on relaxation rates during
and after cooling, the loss may be estimated by the superposition of isothermal curves. Upper
limit of the expected loss corresponds to the isothermal relaxation curve at the steam curing
temperature.

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* In Russian.
** In Hungarian.