CIB -W18A / 22-9-1

INTERNATIONAL COUNCIL FOR BUILDING RESEARCH STUDIES AND DOCUMENTATION

WORKING COMMISSION W18A - TIMBER STRUCTURES

LONG-TERM TESTS WITH GLUED LAMINATED TIMBER GIRDERS

by

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MEETING TWENTY - TWO

BERLIN

GERMAN DEMOCRATIC REPUBLIC

SEPTEMBER 1989

1. Introduction

The present report is dealing with the preparation and implementation of long-term investigations and tests with glued laminated timber girders subjected to bending. The layers of the "BSH M3"-type glued laminated timber have been sorted mechanically to obtain strength grades. The tests are being carried out under an outdoor roofed storage facility and will be continued for a minimum period of 10 years. In this connection, the girders are being exposed to a variable long-term loading.

The objective of the tests and investigations is the measurement of time-dependent deformations and the determination of the residual loadbearing capacity after a loading period of at least ten years.
From the results and findings, the creep factor K_{creep} and the modification factor as to "load action period" $K_{mod,1}$ will be obtained.

They are being compared with those factors indicated in the Eurocode 5 /1/ and will possibly be applied in the new TGL 33 135/04 GDR Industrial Code Specification /2/.

2. Determination of the variable long-term stressing

In addition and as a supplement to the factors
- creep factor K_{creep}, and
- "load action period" modification factor $K_{mod,1}$

as used in the specifications mentioned under /1/and /2/, long-term tests with a loading being variable in terms of the time are required which shall be accomplished with a climate (environment) of "outdoors under a roof".

Timber is an elastoplastic material creeping until failure when subjected to a constant long-term load, with the strength decreasing with an increasing period of loading.

Similar properties are being found in the glue (adhesive) with glued laminated timber. Therefore, the tests and investigations are being performed by means of glued laminated timber girders.

The evaluation of publications as included in /3/ shows that mainly the individual influence of constant long-term loads with different periods of loading on the long-term strength of structural timber has been investigated.

However, it is necessary indeed to study and investigate the complex influence of variable long-term loads together with the action and effect of the air temperature, relative air humidity and timber moisture on structural timber and glued laminated timber.

The load combination of "dead load + snow" is being allocated to the variable long-term load.

Based on /4/, a timber roof frame (truss) is being selected the loading of which includes a large portion of dead load with a small portion of snow load. Thus, an insignificant rebound is occurring when relieving from "dead load + snow" to "dead load". The loading of the selected roof frame being supported by steel members D 24.5 (see /4/, page 34) is as follows:

dead load of roof:			$0.27\ kN/m^2$
dead load of floor:			$0.45\ kN/m^2$
dead load of installation:			$0.29\ kN/m^2$
total dead load:	g_K	=	$1.01\ kN/m^2$
snow load:	s_K	=	$0.5\ kN/m^2$

dead load portion:

$$\frac{g_K}{g_K + s_K} = \frac{1.01}{1.01 + 0.5} = 0.67$$

The long-term tests are being accomplished by using glued laminated timber girders of the grade BSH M3 (see Figure 1).
Short-term tests carried out by means of BSH M3 specimens demonstrated that the flexural strength $f_{m,K}$ and the modulus of

elasticity $E_{o,mean}$ of grade BSH M3 timber are almost coinciding with strength grade C 5 as indicated in the Eurocode 5, 10/87 (see /1/, page 109). The characteristic value of the flexural strength is as follows:

$$f_{m,K} = 24 \text{ N/mm}^2.$$

The "load action period" modification factor being selected according to /1/, page 42, due to the large portion of dead load for the "long/medium" load action period grade and the moisture grade 1 or 2 amounts to

$$K_{mod,1} = 0.85.$$

The material factor being selected according to /1/, page 31, for glued laminated timber with regard to the adoption of a neutral foreign supervision in the manufacture of glued laminated timber (in German, abbreviated: BSH) amounts to

$$\gamma_M = 1.3.$$

This results in a design value of the flexural strength amounting to:

$$f_{m,d} = \frac{f_{m,K} \cdot K_{mod,1}}{\gamma_M} = \frac{24 \cdot 0.85}{1.3} = 15.7 \text{ N/mm}^2.$$

The design value is for the

- top stress:

$$\sigma_{m,1,d} = f_{m,d} = 15.7 \text{ N/mm}^2$$

- bottom stress:

$$\sigma_{m,2,d} = \frac{g_K}{g_K + s_K} \cdot \sigma_{m,1,d} = 0.67 \cdot 15.7 = 10.5 \text{ N/mm}^2.$$

The action periods for snow loads per annum are indicated as follows:

- 1 week to 6 months according to /1/, page 40
- 1.8 months according to /5/, page 217
- 2 months according to /6/, page 70
- 2.5 months according to /7/.

With regard to possible locations at a higher altitude above sea level, the action period being selected for the snow load is 2.5 months.
Now, this results in a variable long-term stressing (see Figure 2) amounting to:

$$\sigma_{m,1,d} = 15.7\ N/mm^2, \text{ action period of 75 d (days)}$$
$$\sigma_{m,2,d} = 10.5\ N/mm^2, \text{ action period of 285 d.}$$

3. Description of the test specimens

12 test specimens consisting of BSH M3 grade glued laminated timber (see Figure 1) are being used for the long-term tests.

The specimens are girders subjected to bending with a width of b = 97 mm, a height (depth) of h = 192 mm, an effective span of l_1 = 2880 mm and a length of l = 3080 mm.

The layers of boards of the glued laminated timber girders are consisting of sawn coniferous timber (pine) and are being sorted mechanically into strength grades according to the flexural modulus of elasticity and to the knottiness as follows:

- The 1st and 6th layer (see Figure 1) are belonging to the F II strength grade
  ($E \geq 9500\ N/mm^2$, individual knots according to Figure 3, accumulations of knots according to Figure 4, /8/)
- The 2nd to 5th layers (see Figure 1) are belonging to the F III strength grade
  ($E \geq 7000\ N/mm^2$, individual knots acc. to Fig, 3, accumulations of knots acc. to Fig. 4, /8/).

Decisive for the allocation to a strength grade is the unfavourable value of one sorting parameter.

The glueing (bonding) of the layers of boards with one another as well as of the key-dovetail connections is being performed by using a "Plastasol L47 N"-type phenolic resin bonding adhesive.

As a general principle, a key-dovetail connection is being arranged in layer 1 (being the lowest layer - tension layer -; see Figure 1) within the test zone (see Figure 5). In our instance, the key-dovetailing length amounts to 50 mm.

The distance of the key-dovetail connections (key-dovetail staggering; in German abbreviated as KZV) between the 1st and 2nd layer is being guaranteed with an amount of KZV $\geq$ 250 mm.

The equilibrium moisture of the layers of boards after the manufacture amounts to $\omega \approx 12$ %.

4. Test arrangement

With a view to achieving a zone being free from transverse forces, a four-point loading is being selected for the test arrangement of the glued laminated timber girders (see Figure 5).

The results and findings from studies and investigations performed by using structural timber /9/ are showing that - in order to avoid shear failures - the ratio of the flexural stress $\sigma_{m,d}$ to the shear stress τ_d shall be 22 whereas for a shear influence of about 6 % the ratio of the effective span l_1 to the specimen height h shall be 15. With these prerequisites prevailing, the length of the test zone l_2 is being designed as l_2 = 4 h /9/ (see Figure 5).

The values of the variable long-term load resulting from the long-term stresses are as follows:

- for dead load + snow: $F_{1,d}$ = 17.74 kN; t = 75 d
- for dead load: $F_{2,d}$ = 11.89 kN; t = 285 d

The force $F_{i,d}$ (see Figure 5) is being introduced by means of a mass piece (weight) M through a lifting rack-type facility.
The hinge G is vertically movable in order to ensure a horizontal position of the load lever also with an increasing deflection U_z.

The long-term tests are being accomplished under the cover of a roofed-over outdoor facility. With such a climatic test condition, the test specimens are freely exposed to the air temperature, air humidity and air motion of the external climate. However, the specimens are protected from precipitations and sunshine.

The maximum equilibrium moisture to be expected amounts to $\omega \leqq 18$ % according to /10/ and corresponds to the moisture grade 2 in compliance with /1/.

5. Measurements

The measurements to be performed during the long-term tests with regard to the time are as follows:

(a) Girder deflection U_z

It is being determined at the central position of the effective span (see Figure 5) by means of a dial gauge with a reading accuracy of 0.1 mm and in addition - for control purposes - by means of a gauge stick (measuring rod) and a level with a reading accuracy of 0.5 mm.

(b) Strains ε_x

Within the layers of boards 1 and 6 (see Figure 1), respectively, at the central position of the effective span the strains of the timber $\varepsilon_{x,1}$ and $\varepsilon_{x,6}$ are being measured by means of a mechanical strain gauge (stress-probing extensometer; manufacturer: Messrs. Holle, Magdeburg/GDR).

(c) Timber moisture ω

It is being determined through a pair of electrodes being permanently inserted into the girder - with a depth of penetration of about 20 mm - by means of measuring the electrical resistance (type of unit: "Hydromette H 65"; manufacturer: Messrs. Gann, Stuttgart/FRG).

(d) Air temperature T and relative air humidity φ

They are being recorded continuously by means of thermo-hygrographs (type 406; manufacturer: VEB Feingerätebau Drebach/GDR).

6. Initial results and findings

The long-term tests and investigations with the 12 girders have been started for test-engineering reasons only on April 15, 1988, instead of January 1, 1988, with the load stage $F_{1,d}$. The load stage $F_{2,d}$ was effective from June 29 until December 31, 1988. On January 1, 1989, the load stage $F_{1,d}$ of the 2nd year of loading has been applied.

The values and data of the measurements accomplished concerning T, φ, ω, ε_x and U_z are plotted and shown in the Figures 6 to 10 for the period from April 15 until December 31, 1988. /11/

The graphical representations of the measured quantities X are comprising X_{mean}, X_{max} and X_{min}.

With a view to increasing and improving the lucidity, the graphical representations are being drawn up on semilogarithmic paper.

Due to the fact that the time ranges immediately after the loading or relief, respectively, are of a particular interest, the time scales (units) of minutes (min) and days (d) are being used in the graphical representations (Figures 6 to 10).

The most significant measured quantities are the girder deflections U_z and the creep deformations occurring in the course of time.

The mean deflections $U_{z,mean}$ amount to

- $U_{z,mean,0}$ = 12.5 mm

  with t = 0 for $F_{1,d}$ according to Figure 6;

- $U_{z,mean,75\,d}$ = 18.5 mm

  with t = 75 d for $F_{1,d}$ according to Figure 7;

  the creep factor corresponding to this is as follows:

$$K_{creep,1} = \frac{U_{z,mean,75\ d}}{U_{z,mean,0}} = \frac{18.5}{12.5} = 1.5$$

- $U_{z,mean,186\ d} = 14.1$

  with $t = 186$ d for $F_{2,d}$ according to Figure 10;

  the creep factor corresponding to this is as follows:

$$K_{creep,2} = \frac{U_{z,mean,186\ d}}{U_{z,mean,0}} = \frac{14.1}{12.5} = 1.1$$

The measured deflections provide for an initial comparison with the data included in the Eurocode 5 /1/.

The mean values of the measured relative air humidity φ_{mean} and timber moisture ω_{mean} (see the Figures 7, 9 and 10) are within the ranges of

$\varphi_{mean} = 65$ to 95 % ; $\omega_{mean} = 12$ to 18 %.

Thus, according to /1/, para 2.5.4., the moisture grade 2 is prevailing.

As for the load portions being applied during the tests -"dead load" $\frac{g_K}{g_K + s_K} = 0.67$; "snow" $\frac{s_K}{g_K + s_K} = 0.33$ -, the creep factor $K_{creep,1}$ resulting according to /1/, table 4.1, for moisture grade 2 and $F_{1,d}$ "dead load + snow" amounts to $K_{creep,1} = 0.67 \cdot 1.8 + 0.33 \cdot 1.3 = 1.64$.

This value is exceeding that of $K_{creep,1} = 1.5$ as determined during the test for $F_{1,d}$ at $t = 75$ d.

According to /1/, table 4.1, the creep factor $K_{creep,2}$ resulting for moisture grade 2 and $F_{2,d}$ "dead load" amounts to $K_{creep,2} = 1.8$.

This value is exceeding that of $K_{creep,2} = 1.1$ as determined during the test for $F_{2,d}$ at $t = 75 + 186 = 261$ d.

However, a final statement concerning the creep factors can be provided only after a period of about 10 years upon the completion of the long-term tests and investigations.

In compliance with /1/, page 48, the deflection in the final state shall not exceed $\frac{l_1}{250}$.

In the hitherto accomplished tests and investigations, the largest mean deflection for $F_{1,d}$ "dead load + snow" at t = 75 d is as follows:

$$U_{z,mean,75\ d} = 18.5\ mm > \frac{l_1}{250} = \frac{2880}{250} = 11.5\ mm.$$

The exceeding in the limit state of the usability does not mean that the loading $F_{1,d}$ as selected was too high.

This finds its expression by fixing $K_{mod,1}$ and γ_M for the determination of $\sigma_{m,1,d} = f_{m,d}$ in chapter 2 as follows:

$K_{mod,1}$ = 0.85 instead of 0.9 according to /1/, page 42;
γ_M = 1.3 instead of 1.25 according to /1/, page 31.

A consideration of the values of $K_{mod,1}$ and γ_M as indicated in /1/ would result in even higher loads and thus even larger deflections.

The development (curve) of the mean timber moisture ω_{mean} is following that of the mean relative air humidity φ_{mean} (see the Figures 7 and 9).

One can see that in the case of autumn weather lasting for a longer period with a high relative air humidity of $\varphi_{mean} \approx 93$ % the timber moisture will reach the value of ω_{mean} = 18 % (see Figure 9).

However, connections between timber moisture changes and deflection changes cannot be discerned (see the Figures 9 and 10). Similar observations apply to the strain change as well.

The developments (curves) of $U_{z,mean}$ within the load range of $F_{1,d}$ (see the Figures 6 and 7)are showing that immediately after the load application a very large increase in deflection ΔU_z can be observed (amounting to 2.2 mm/d on an average) which, however, is increasingly decaying with an amount of 0.1 mm/d.

Considerably less distinct are the creep deformations after the partial load relief to $F_{2,d}$ (see the Figures 8 and 10). Initially the decrease in deformation is only 0.1 mm/d on an average. The backcreep processes can be regarded as decayed already after a period of 5 days.

7. Regression equations

The mathematical description of the time-dependent deflections is possible by means of simple regression equations.

The influence factor is the time t whereas the objective (target) factor is the mean deflection $U_{z,mean}$ of 12 test specimens.

The regression analysis is being performed by means of both exponential functions ($y = a \cdot \exp(bx)$) and logarithmic functions ($y = a + b \cdot \ln x$).

The regression equations with the highest correlation coefficients r are indicated in Figure 11.

8. Summary

Long-term tests and investigations are being carried out using glued laminated timber girders subjected to bending with the action of a variable long-term load at a climate (environment) of "outdoors under a roof".

Initial results and findings of the measurements are providing information on the magnitude of the creep factors to be expected.

Final values concerning the creep factors K_{creep} and the "load action period" modification factor $K_{mod,1}$ for the moisture grade 2 will be available after a period of about 10 years.

9. References (Publications)

/1/ Eurocode 5 "Holzbauwerke" - Deutsche Entwurfsfassung; Oktober 1987
(Eurocode 5 "Timber Structures" - German draft wording; October 1987)

/2/ DDR-Fachbereichsstandard TGL 33 135/04 E 89
"Holzbau, Tragwerke, Berechnung, Bauliche Durchbildung"
(Industrial GDR Code Specification TGL ...:
"Timber construction; Loadbearing structures; Calculation; Structural design")
Draft, September 1989

/3/ Forschungsbericht G 2: "Langzeituntersuchungen an maschinell sortiertem Brettschichtholz unter Biegebeanspruchung"
(Research Report G 2: "Long-term investigations with mechanically sorted glued laminated timber subjected to bending")
Academy of Building of the GDR, Institute for Industrial Buildings; Berlin, December 1988

/4/ "Dach- und Hallenkonstruktionen in Holzbauweise"
Informationen und Systemübersichten 1986
("Roof and hall structures built by adopting the timber construction method" - Information and system abstracts of 1986)
"Baufa" Research Institute, Leipzig

/5/ Spaethe, G.:
"Die Sicherheit tragender Baukonstruktionen"
("The safety of loadbearing building constructions")
Published by: VEB Verlag für Bauwesen; Berlin 1987

/6/ Steck, G.:
"Die Zuverlässigkeit des Vollholzbalkens unter reiner Biegung"
("The reliability of the solid timber beam subjected to pure bending")
Fridericiana University, Karlsruhe 1982

/7/ Glos, P.:
"Was darf der Holzbau von dem neuen probabilistischen Sicherheitskonzept erwarten?"
("What may timber construction expect of the new probabilistic safety concept?")
Published in: Bauen mit Holz (1983) 1, pp. 26 - 31

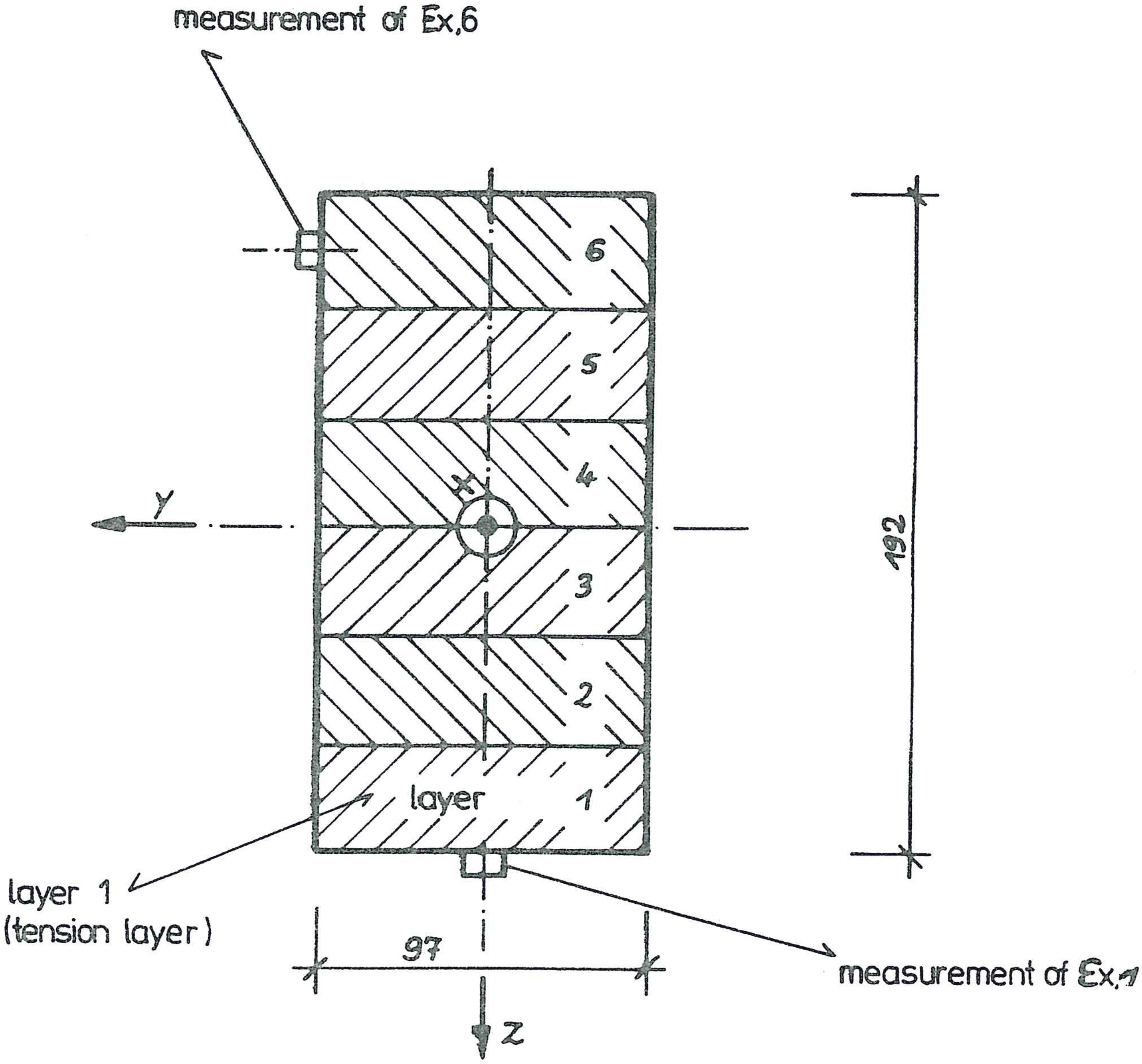
References: (continued)

/8/ DDR-Fachbereichsstandard TGL 33 135/03 E 88
"Holzbau, Tragwerke, Gütebedingungen, Bauschnittholz"
(Industrial GDR Code Specification TGL ...:
"Timber construction; Loadbearing systems; Quality specifications; Sawn structural timber")
Draft; March 1988

/9/ Apitz, R.:
"Ermittlung von Festigkeitskennwerten für Vollholz bei der Beanspruchung Biegung durch Versuche"
("Determination of strength characteristics for solid timber subjected to bending by tests")
Wismar Engineering College; Progress Report dated 1982-11-27

/10/ DDR-Fachbereichsstandard TGL 33 135/01
"Holzbau, Tragwerke, Berechnung, Bauliche Durchbildung"
(Industrial GDR Code Specification TGL ...:
"Timber construction; Loadbearing systems; Calculation; Structural design")
1st Modification dated 1986-06-24

/11/ Prüfbericht Nr. 329 4005/88
"Langzeituntersuchung an festigkeitssortiertem Brettschichtholz"
(Test Report No. ...: "Long-term investigation with strength-sorted glued laminated timber")
Researcher: W. Schöne; VEB Kombinat Bauelemente und Faserbaustoffe, Forschungsinstitut (Trust for Building Units and Fibre Building Materials; Research Institute)
Leipzig, 1988-11-14



grade : BSH M3
layers 1 and 6 : NSH F II
layers 2 to 5 : NSH F III

designations :

a) glued laminated timber *BSH*
b) sawn coniferous timber *NSH*
c) strength grade *F*

Figure 1: Girder cross section

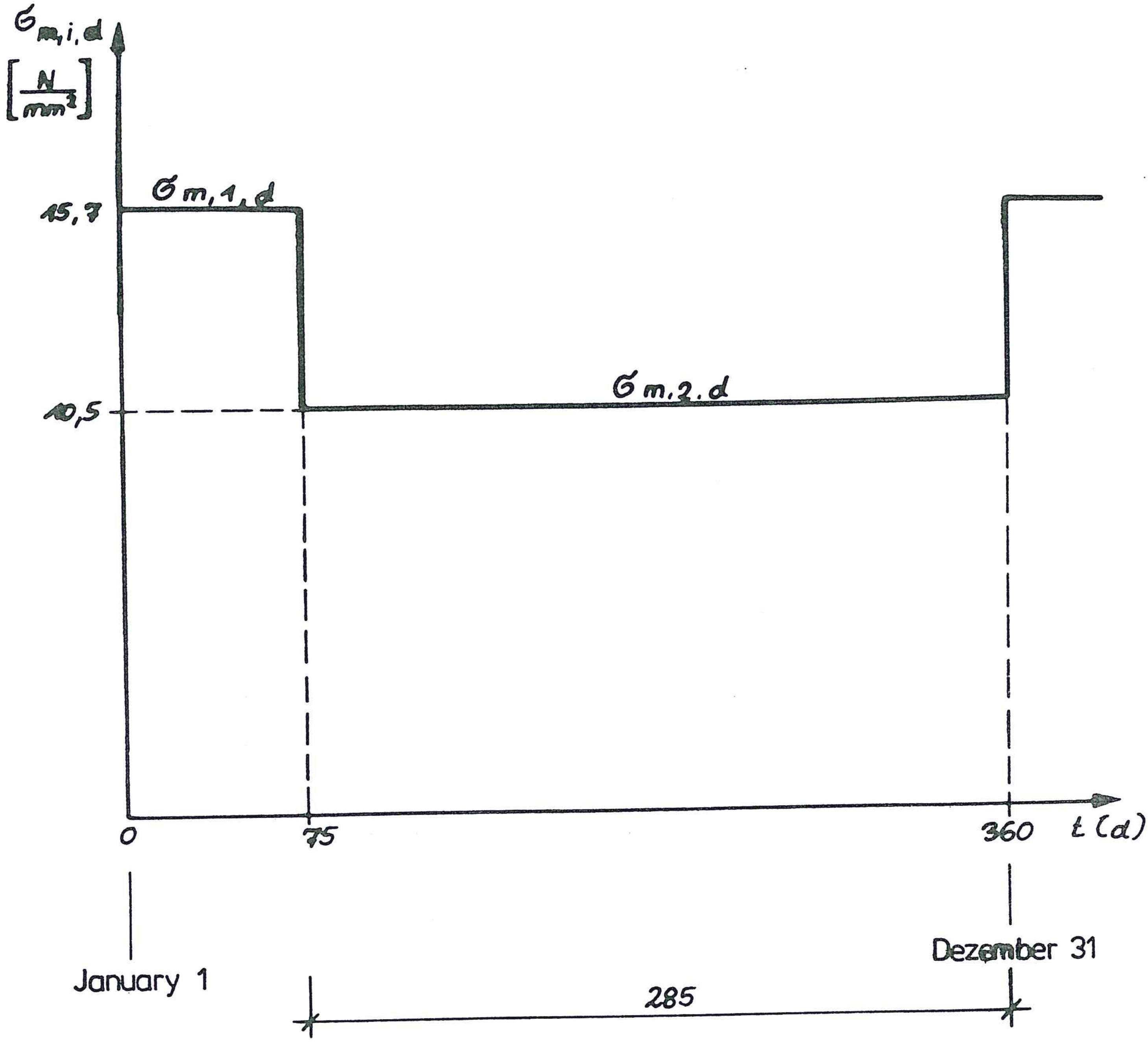
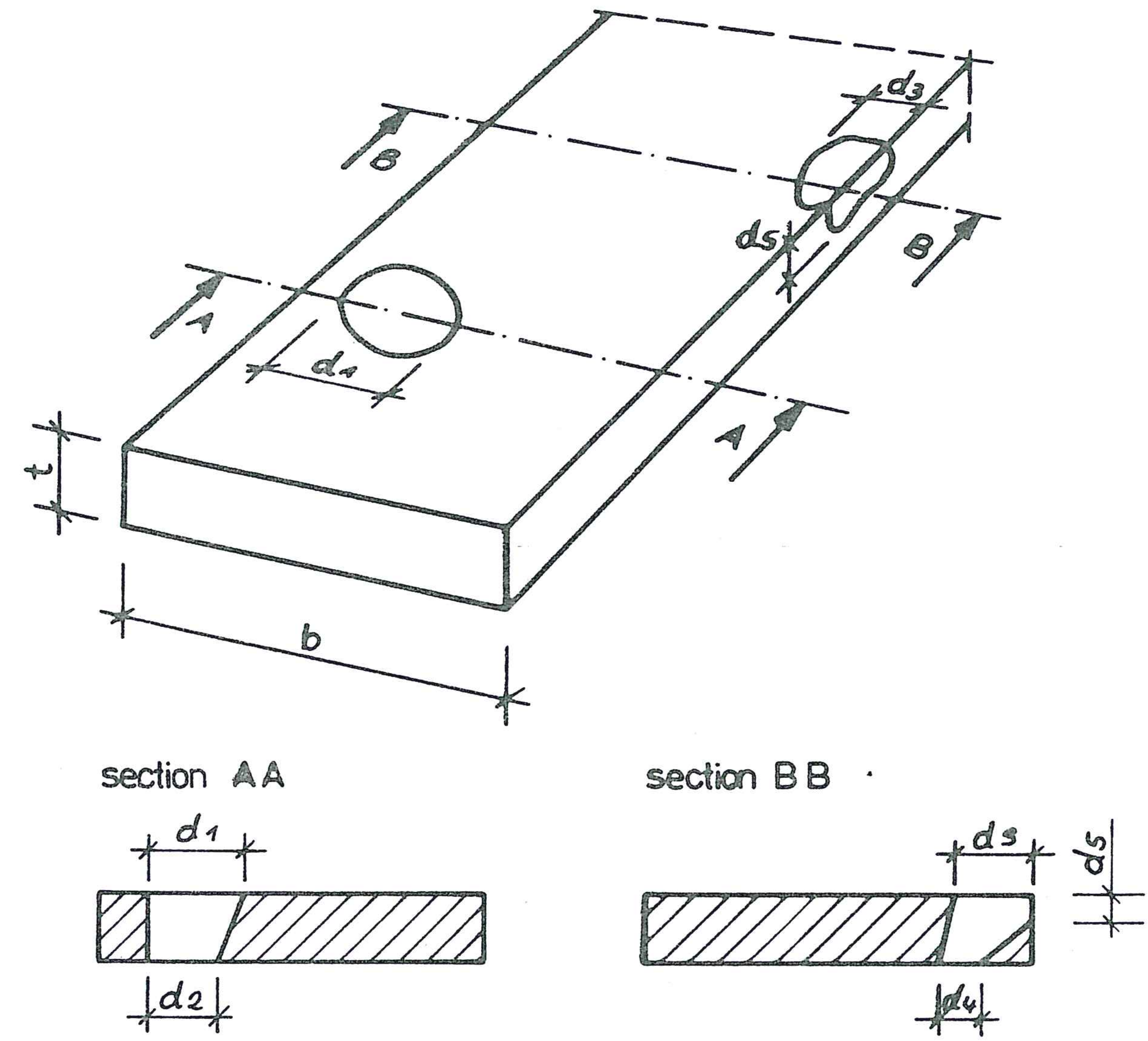


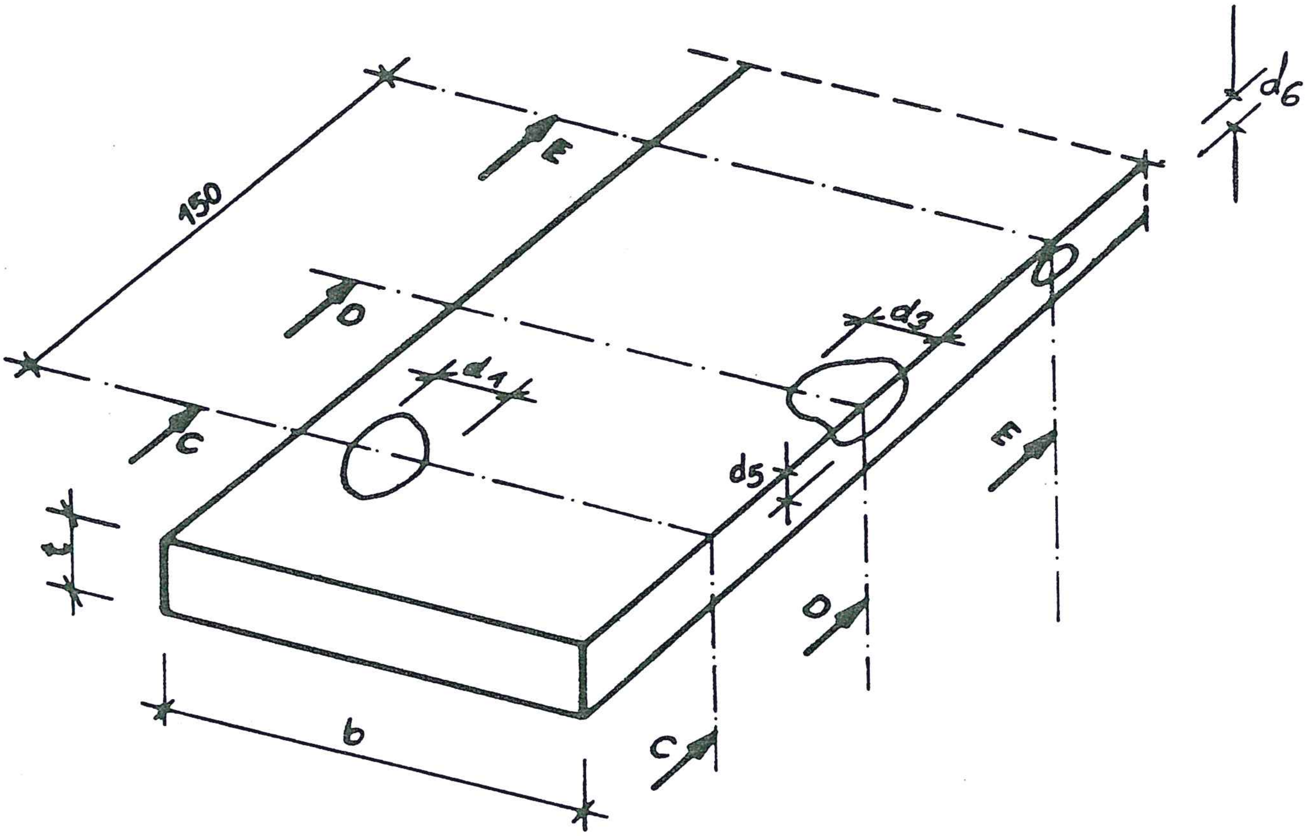
Figure 2: Variable long-term stressing



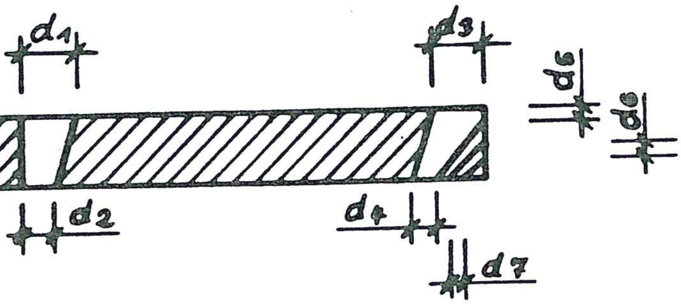
$$k = \frac{d_1 + d_2}{2b} \quad ; \quad \frac{d_3 + d_4 + d_5}{2b}$$

k	strength grade
$\leq \frac{1}{3}$	F I
$\leq \frac{1}{2}$	F II

Figure 3: Sorting by individual knots



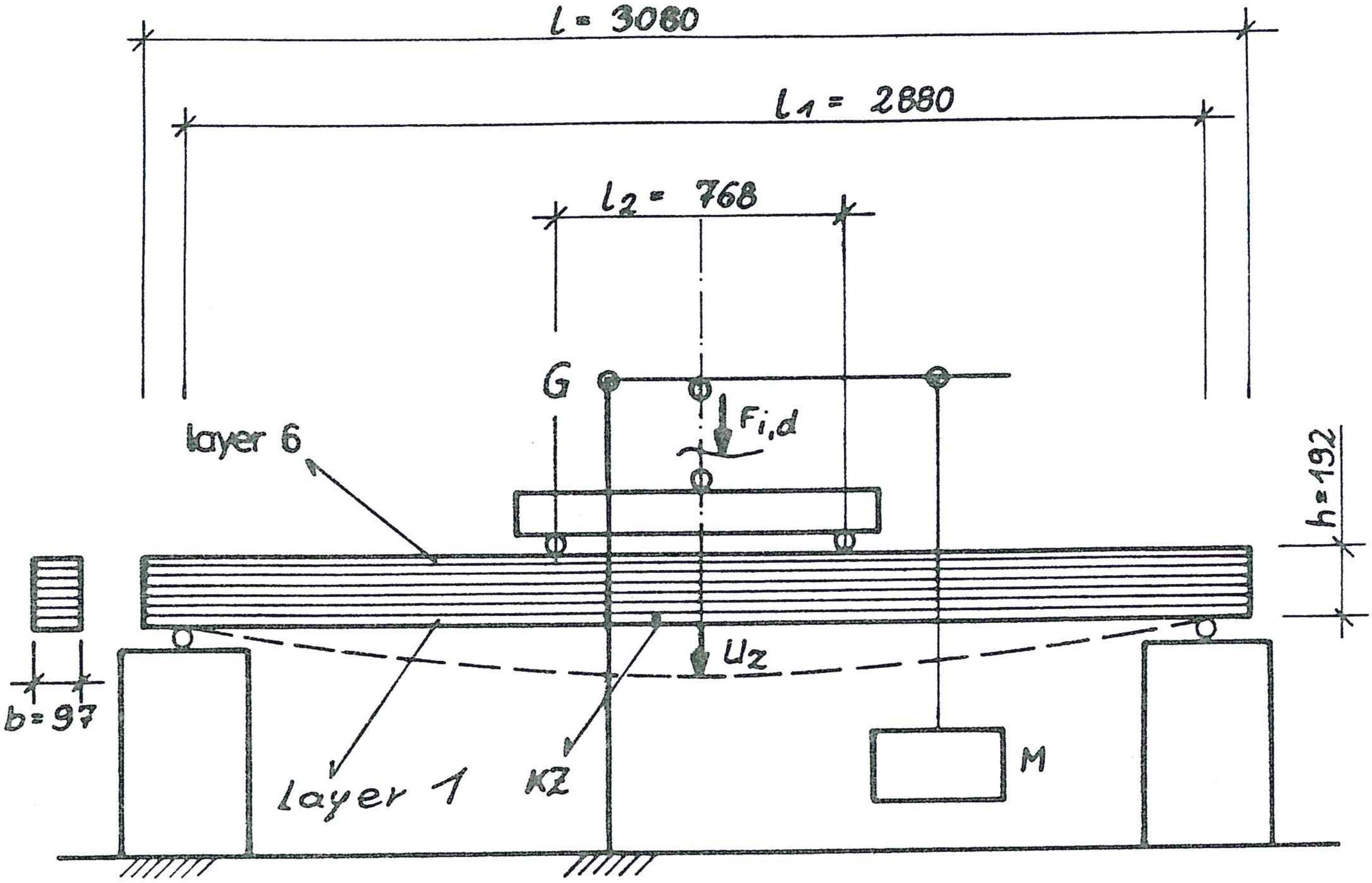
sections CC, DD, EE shown in one sectional drawing



$$K = \frac{d_1 + d_2 + d_3 + d_4 + d_5 + d_6 + d_7}{2b}$$

K	strength grade
$\leq \frac{1}{2}$	F II
$\leq \frac{2}{3}$	F III

Figure 4 : Sorting by accumulations of knots



designations:

a) F -with i=1,2 - variable long-term load
b) U -maximum deflection
c) h -test specimen heigth
d) l -test specimen length
e) l -effective span l_1= 15h
f) l -test zone length l_2= 4h
g) G -vertically adjustable hinge
h) M -mass piece (weight)
i) KZ - key-dovetail connection, always located within the test zone l , layer 1

Figure 5 : Test arrangement

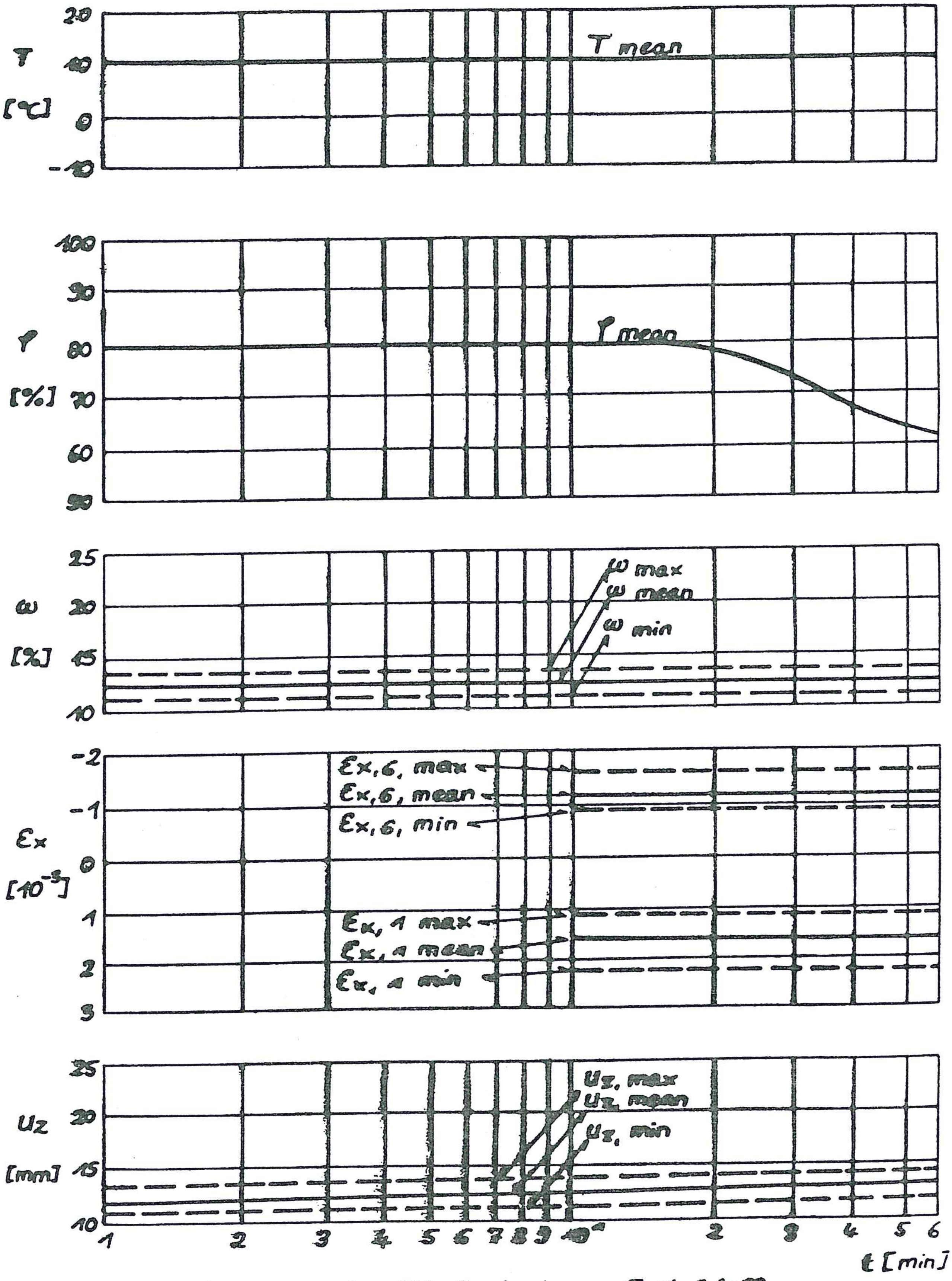


Figure 6: Measurements within the load range $F_{4,d}$; t = 1 to 60 minutes; 1st year of loading; from April 15 until June 29 1988

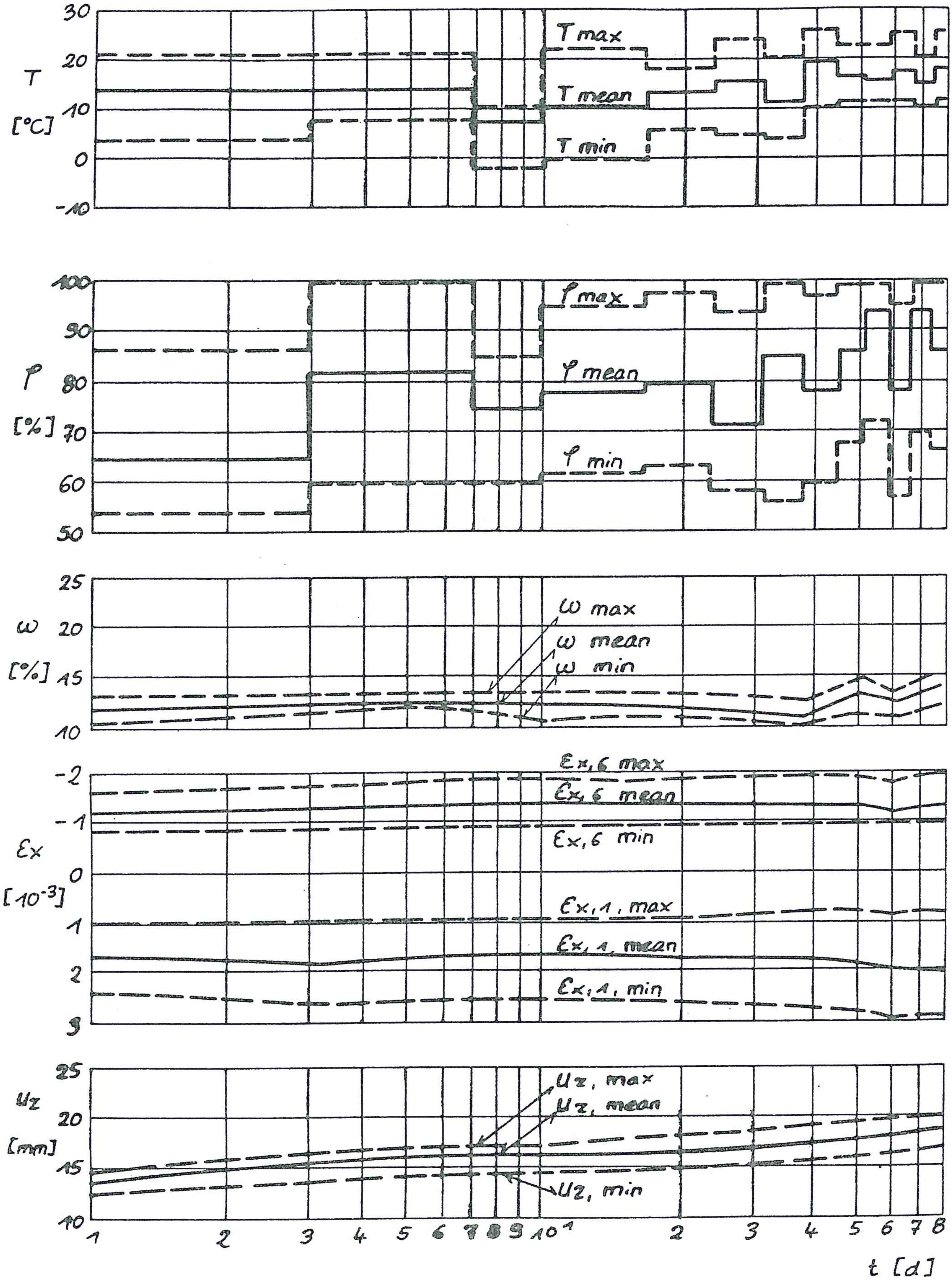


Figure 7: Measurements within the load range $F_{1,d}$; t = 1 to 75 days; 1st year of loading; from April 15 until June 29, 1988

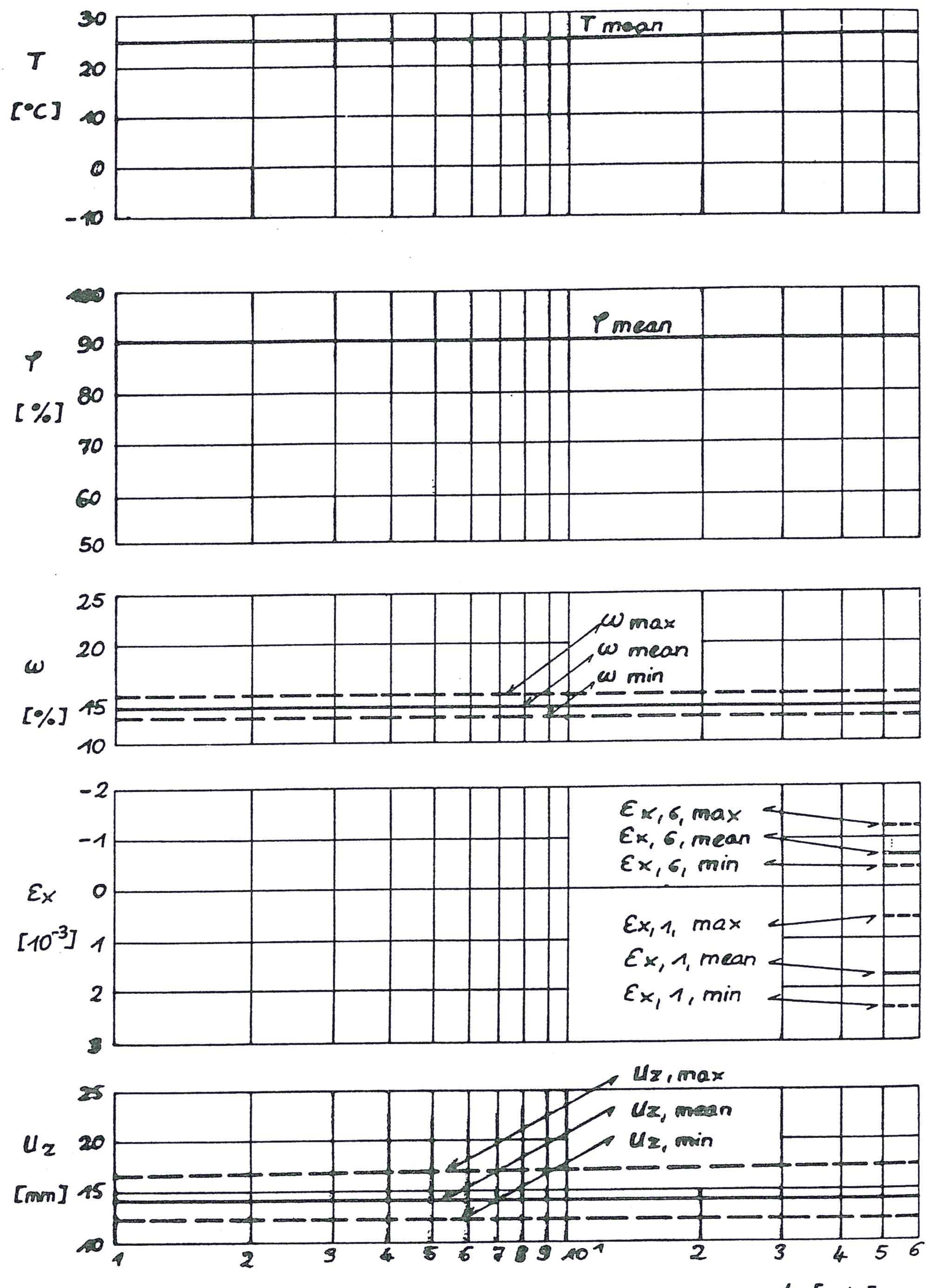


Figure 8: Measurements within the load range $F_{2,d}$; t = 1 to 60 minutes ; 1st year of loading, from June 29 until December 31, 1988

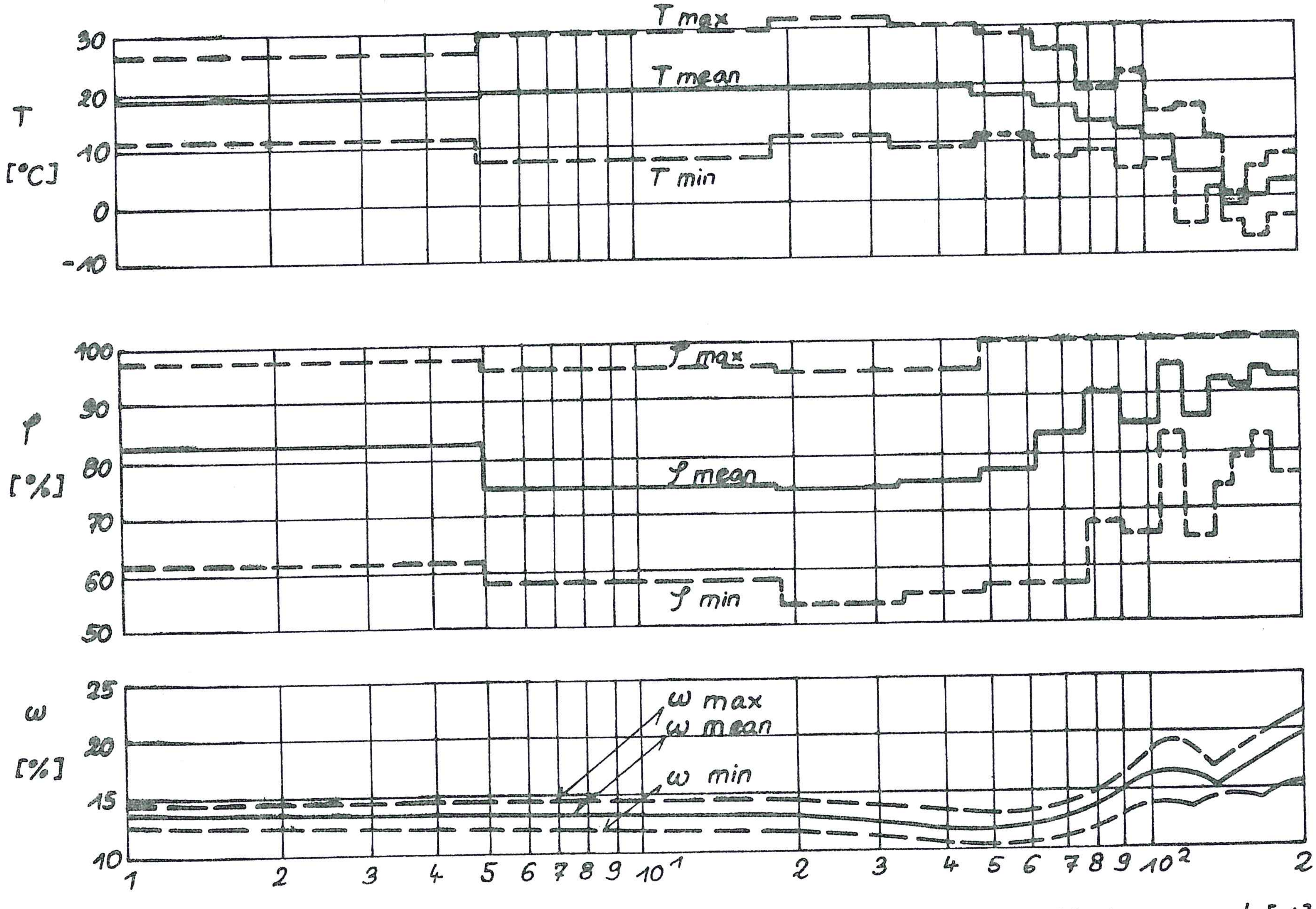


Figure 9: Measurement of T, φ, ω, within the load range $F_{2,d}$; t = 1 to 186 days; 1st year of loading; from June 29 until December 31, 1988

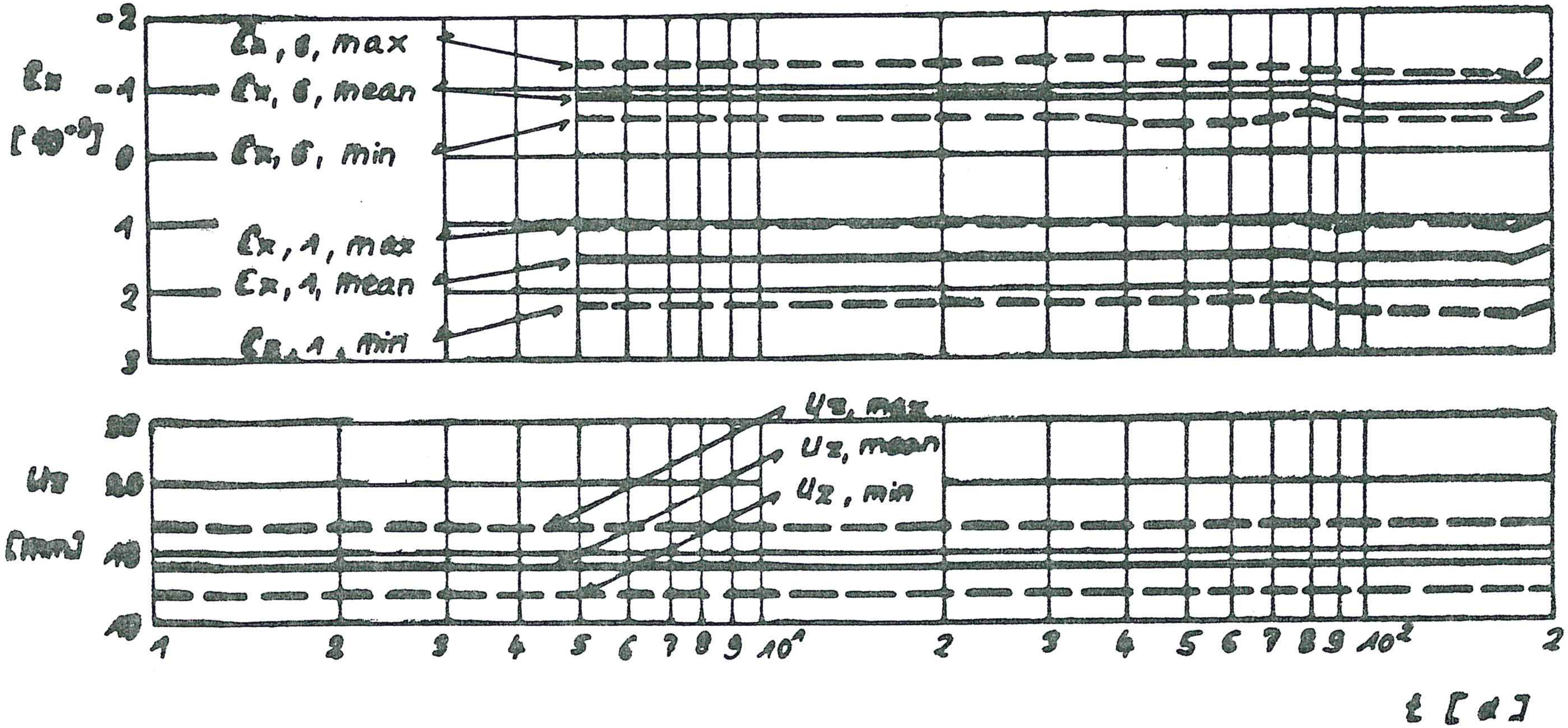


Figure 10: Measurement of ε_x, U_z within the load range $F_{2,d}$; $t = 1$ to 186 days;
1st year of loading; from June 29 until December 31, 1988

load range	time range	$U_{z, mean}$ *) [mm]	r [-]
$F_{1,d}$	0,1 - 60 min	$12{,}51 + 0{,}135 \ln t$	0,92
	0,1 - 108 000 min (75 d)	$12{,}13 + 0{,}488 \ln t$	0,94
$F_{2,d}$	0 - 60 min	$14{,}4 \exp(-1{,}37 \cdot 10^4 t)$	0,9
	0,1 - 267 840 min (186 d)	$14{,}38 - 0{,}0475 \ln t$	0,95

* t in minutes is to be entered

Figure 11: Regression equations of the mean deflections $U_{z, mean}$ according to /11/

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VOLUME II

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SEPTEMBER 1989