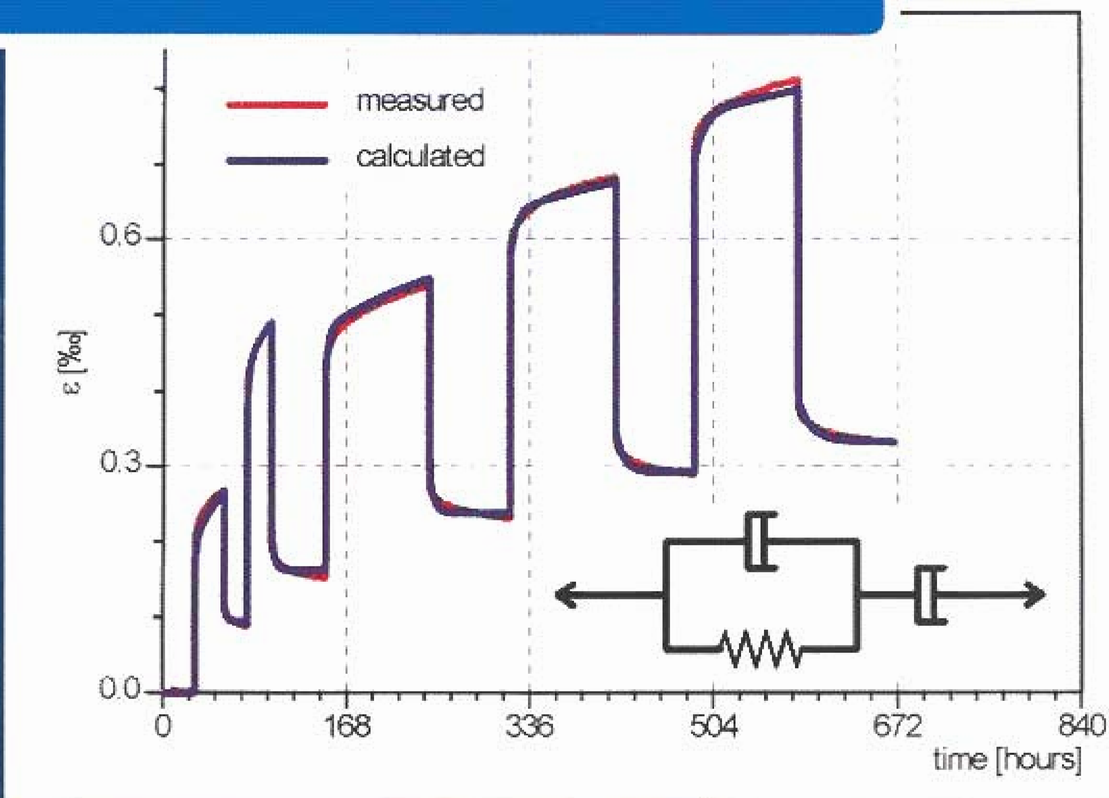
HETEK

Control of Early Age Cracking in concrete Phase 1: Early Age Properties of Selected Concrete



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Abstract

This report forms a part of the Danish Road Directorate's research programme - called High Performance Concrete - The Contractor's Technology (abbreviated to HETEK).

This report determines the early age properties of a selected concrete. The test programme used corresponds to the one used in practice for the time being (March 1996). The properties regarded are:

- Heat development
- E-modulus and compressive strength development
- Splitting tensile strength development
- Thermal expansion coefficient
- Shrinkage in early age
- Creep in early age

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0. Preface

This project on control of early age cracking is part of the Danish Road Directorate's research programme, High Performance Concrete - The Contractor's Technology, [1] abbreviated to HETEK.

In this programme high performance concrete is defined as concrete with a service life in excess of 100 years in an aggressive environment.

The research programme includes investigations concerning the contractor's design of high performance concrete and execution of the concrete work with reference to the required service life of 100 years.

The total HETEK research programme is divided into segments parts with the following topics:

- chloride penetration
- frost resistance
- control of early-age cracking
- compaction
- curing (evaporation protection)
- trial casting
- repair of defects.

The Danish Road Directorate invited tenders for this research programme which is mainly financed by the Danish Ministry for Commerce and Industry - The Commission of Research and Development Contracts.

The present report referes to the part of the HETEK project which deals with control of early age cracking.

For durability reasons reinforced structural members should be well protected against penetration of water, chloride etc. This means that cracks should be avoided or at least the crack-width limited. Formation of cracks can take place already during the hardening process. An evaluation of the risk of crack formation involves a stress analysis. In stress analysis of hardening concrete structures, the load consists of the differences in thermal strains that arise from the heat of hydration. The mechanical properties (including autogenous shrinkage) of the concrete also change during the hardening process. If a stress analysis shows high stresses compared to the tensile strength there is a high risk of crack formation.

In Danish: Højkvalitetsbeton - Entreprenørens Teknologi

The purpose of this project is to investigate these effects and to prepare a guideline regarding Control of Early Age Cracking.

The project was carried out by a consortium consisting of:

Danish Concrete Institute represented by:

Højgaard & Schultz A/S
Monberg & Thorsen A/S
RAMBØLL
COWI

and

Danish Technological Institute, represented by the Concrete Centre

and

Technical University of Denmark, represented represented by the Department of Structural Engineering and Materials.

Two external consultants, professor Per Freiesleben Hansen and manager Jens Frandsen, are connected with the consortium.

1. Objective

This report determines the early age properties of a selected concrete as described below. The test programme used corresponds to the one used in practice for the time being (March 1996).

The properties regarded are:

- Heat development
- E-modulus and compressive strength development
- Splitting tensile strength development
- Thermal expansion coefficient
- Shrinkage in early age
- Creep in early age

The HETEK project deals with High Performance Concrete defined as concrete with a service life in excess of 100 years in an aggressive environment e.g. marine, with salt and frost.

The Danish Road Directorate normally prescribes a maximum w/c-ratio of 0.45 for concrete in exposure class A (aggressive) and 0.40 in exposure class C (chlorid). The minimum content of cement is 275 kg/m^3 respectively 300 kg/m^3.

The exposure class C is to be used only for structural elements with severe chloride exposure. This is relevant for concrete in a marine environment with a service life of 100 years.

However, this type of concrete corresponds more to the concrete used at the most exposed parts of the Storebælt Link and the off-shore part of the Øresund Link than to the type of concrete used for bridges in general.

Therefore it has been decided to use a concrete between exposure class A and C, with a maximum w/c-ratio of 0.40 and a minimum content of cement of 285 kg/m^3. As addition fly ash and silica fume will be used. This type of concrete corresponds closely to the concrete used at the onshore parts of the Øresund Link, where maximum w/c is 0.42.

2. Test Methods

The following test methods have been used:

DS423.12 (March 1984)	Consistency of fresh concrete. Slump test.
DS423.15 (March 1984)	Determination of the content of airvoid in fresh concrete.
DS423.16 (March 1984)	Fresh concrete. Density.
DS423.23 (March 1984)	Hardened concrete. Compressive Strength.
DS423.25 (March 1984)	Hardened concrete. Modulus of Elasticity.
DS423.34 (January 1985)	Tensile strength deduced from splitting test on cylindical specimens
NT Build 388. (1992)	Heat Development.

TI-B 101 (Sept. 1994) Test Method. Concrete. Thermal Expansion Coefficient.
TI-B 102 (Nov. 1995) Test Method. Concrete. Strains from creep and shrinkage in early ages.

The test methods TI-B 101 and TI-B 102 are enclosed in appendix 13 and 14.

3. Concrete

The concrete used was concrete no. 6001 from 4K-BETON with reduced slump and adjusted content of cement. (Delivery note no. 966100364). The concrete composition is shown in table 1. The mix report is shown in appendix 1. The equivalent w/c-ratio is 0.40, calculated as water/(cement + 2·silica fume + 0.5·fly ash). The concrete corresponds to concrete no. 6021 from 4K-Beton (Concrete form is shown in appendix 1).

The concrete was mixed at 4K-BETON, København and transported to DTI, Taastrup where the specimens were casted. The transportation time was app. 50 min.

Table 1: Mix design

Mix design			
	Type/origin/class	kg/m^3	
Cement	Low-alkali Sulfatresistant CEM I 42,5(HS/EA/≤2)	285	1)
Flyash	Danaske	60	1)
Silica fume	Elkem	12	2)
Water	Water	127	3)
Fine aggregate	RN, Avedøre sand 0/4, SA	758	4)
Coarse aggregate	Rønne granite 8/16, A	535	4)
Coarse aggregate	Rønne granite 16/25, A	565	4)
Air entrainment	Conplast 316 AEA	0,357	5)
Plasticiser	Conplast 212	1,428	6)
Superplasticiser	Peramin F	2,856	7)

1) Dry
2) Silica fume, slurry. The quantity corresponds to dry silica fume. The amount of water is included in the 127 kg/m^3 of water.
3) Added water + free water content of aggregates + water content of silica fume, slurry. The quantity of water does not include the water content of plasticizer and air - entrainment.
4) Water-saturated surface - dry.
5) The quantity includes water content (95 % of the stated value).
6) The quantity includes water content (64 % of the stated value).
7) The quantity includes water content (66 % of the stated value).

4. Test Specimens

For determination of E-modulus and strength developments 49 cylinders D150 x h300 mm were casted.

For determination of thermal expansion coefficient according to TI-B101 3 prisms - 100x100x400 mm were casted. In one of the prisms a thermocouple was placed.

For determination of shrinkage and creep 6 cylinders D130 x h700 mm were casted. Specimen 1-3 were loaded and specimen 4-6 remained unloaded. The concrete temperature was measured in specimen 2 and 5. Furthermore the air temperature was measured.

5. Results

5.1 Properties of fresh concrete

Time of mixing was 1996-01-16 at 8:51. The concrete arrived at DTI 1996-01-16 at 9:40. Slump, air content, density and temperature were measured at 4-K BETON and just after arrival at DTI. The results are shown in table 2.

Table 2: Properties of fresh concrete measured before transportation and just after arrival at DTI.

Measured at	Slump [mm]	Air content [%]	Density [kg/m³]	Temp. [°C]
4K-BETON	95	6.7	2332	10.0
DTI	70	8.0	2328	9.0

5.2 Heat development

The heat development was determined on 5 samples. The results are shown in appendix 2. The main results are shown in table 3.

Table 3: Heat development (ref. appendix 2).

$$Q(M) = Q_\infty \cdot \exp\left(-\left(\frac{\tau_e}{M}\right)^\alpha\right)$$

	Q_∞ kJ/kg cement [1)]	Q_∞ kg/kg cement + min.add. [2)]	τ_e [hour]	α [-]	τ_0 [hour]
Mean	348.6	279.9	14.2	0.96	5.0
St. dev.	6.3	5.0	0.29	0.01	0.12

1) Corresponding content of cement = 281.6 kg/m³
2) Corresponding content of cement + min. add. = 350.8 kg/m³

The mixdesign stated in the test report of appendix 2 differs a little from the one stated in table 1. The values in appendix 2 are based on the actual values stated in the delivery note (appendix 1) compensated for the air content measured at DTI. The densities used are the densities normally used at DTI.

5.3 Thermal expansion coefficient

The thermal expansion coefficient was determined according to TI-B 101 at 1, 3 and 7 days. The results are shown in appendix 3. The main results are shown in table 4.

Table 4: Thermal expansion coefficient according to TI-B 101 (ref. appendix 3).

Time [days]	1	3	7	mean
Th. exp.coef. [$°C^{-1}$]	$0.87 \cdot 10^{-5}$	$0.88 \cdot 10^{-5}$	$0.84 \cdot 10^{-5}$	$0.87 \cdot 10^{-5}$

5.4 E-modulus- and strength developments

E-modulus, compressive strength and splitting tensile strength was determined at ½, 1, 2, 3, 7, 14 and 28 days. The results of the E-modulus and compressive strength tests are shown in appendix 4. The results of the splitting tensile strength tests are shown in appendix 5. The parameters for description of the developments of the properties are shown in table 5. The parameters have been determined by regression.

Table 5: Parameters for description of developments (ref. appendix 4 and 5).

$$Property\ (M) = V_\infty \cdot \exp\left(-\left(\frac{\tau_e}{M}\right)^\alpha\right)$$

Property	V_∞	τ_e	α
E-modulus, DS 423 [MPa]	34327	12.89	1.15
Comp. strength [MPa]	60.1	65.34	0.52
Split.tens. str. [MPa]	3.7	29.22	0.77

5.5 Shrinkage and Creep

The test specimens were casted 1996-01-16 at app. 10:30. The age and maturtity at time of casting and at start of measurings are shown in table 6. The setting time defined as τ_0 determined from the heat development was 5.0 hours.

Table 6: Age and maturity of specimens for creep and shrinkage test.

	Date / Time	Age [h]	Maturity [h]
Mixing	1996-01-16 / 8:51	0	0
Casting of specimens	1996-01-16 / 10:30	1.7	0.8
Start of measurings	1996-01-16 / 16:20	7.5	6.0

The results are shown in appendix 6-12. Time zero is at end of mixing.

The temperature in the concrete is measured in two of the specimens and shown in appendix 6.1 together with the calculated maturity as a function of time.

The measured air temperature is shown in appendix 6.2. It is seen to be app. 21.2 °C except during the period of the heat development of the concrete. In this period the maximum air temperature is seen to be app 22.1 °C, which is 0.1 °C above the temperature limit stated in TI-B 102. The maximum concrete temperture in the same period is app. 26.8 °C.

5.5.1 Shrinkage

The shrinkage as a function of maturity is shown in appendix 7.1. The determined shrinkage as a function of time for the three specimens is shown in appendix 7.2 together with the mean shrinkage.

The strains due to shrinkage is determined as the concrete strains in the specimens kept unloaded compensated for the strains due to deformations from temperature. In this compensation the mean of the temperature measured in two specimens is used together with a thermal expansion coefficient of $0.87 \cdot 10^{-5}\,°C^{-1}$ (table 4). The thermal expansion coefficient is assumed to be constant during the test period.

The curves shows that the specimens apparently expands during the first hours after the start of measurings. As mentioned above the temperature compensation is performed with a constant thermal expansion coefficient based on the measurings at 1, 3 and 7 days. In the very early age (before 1 day) the expansion coefficient is probably higher which could explain the "expansion". However the shrinkage in this early age only leads to very small stresses as the E-modulus is still low.

The measured concrete strain in each of the three specimens is shown in appendix 7.3-7.5 together with the temperature compensated strain.

In stress calculations of hardening concrete structures the shrinkage can be described by an idealised curve given by the values of maturity and strain shown in table 6. This idealised curve is shown in appendix 7.1 together with the measured shrinkage.

Table 6: Strains to describe shrinkage in stress calculations.

Maturity [hours]	Strain [m/m]	Maturity [hours]	Strain [m/m]
0	0	168	-0.0000270
6	0	252	-0.0000400
7	+0.0000090	336	-0.0000510
8	+0.0000090	420	-0.0000580
16	-0.0000110	504	-0.0000650
24	-0.0000170	588	-0.0000690
32	-0.0000190	672	-0.0000730
72	-0.0000190	756	-0.0000755
96	-0.0000190	840	-0.0000780
120	-0.0000210	866	-0.0000785
144	-0.0000240		

5.5.2 Creep

The concrete strain in the loaded specimens as a function of time is shown in appendix 8.1-8.3 together with the part of the strain which is due to external load. The strain from external load is determined as the measured concrete strain compensated for deformations due to shrinkage and temperature. The compensation is based on the measurings on the 3 specimens kept unloaded.

The load histories are shown in appendix 9.1-9.3. The load level is chosen as app. 40% of the expected compressive strength. The maximum load which can be applied corresponds to app. 16 MPa. At load times where the strength was not determined, the strength was estimated using the knowledge from the strength development.

The creep strains as a function of time for specimen 1-3 are shown in appendix 10.1-10.3. The creep strains have been determined as the strains in the loaded specimens compensated for temperature deformations, shrinkage and initial elastic deformations.

In the compensation of the initial elastic strains, the idealised load histories shown in appendix 9.1-9.3 and table 7 are used. The E-modulus used is the E-modulus determined on the measurings during loading and unloading of the creep specimens (ref. table 8).

Table 7: Idealized load histories used in calculations of creep parameters.

Specimen 1		Specimen 2		Specimen 3	
Time [h]	load [Mpa]	Time [h]	load [MPa]	Time [h]	load [MPa]
0	0.01	0	0.01	0	0.00
13.42	0.76	13.44	0.66	-	-
28.84	4.49	28.73	0.08	28.78	4.46
-	-	55.19	7.66	55.15	0.14
-	-	76.07	0.10	76.10	8.81
98.53	9.03	98.50	10.01	98.47	0.14
-	-	148.20	0.08	148.23	8.95
173.62	12.34	-	-	-	-
-	-	243.98	7.88	243.98	0.17
317.69	12.68	317.70	0.08	317.73	12.40
359.03	15.56	-	-	-	-
-	-	414.14	15.12	414.10	0.12
486.15	16.06	486.15	0.08	486.19	15.72
580.64	15.71	580.67	16.15	580.65	0.05
671.28	0.02	671.25	0.003	-	-

Table 8: E-modulus determined during loading and unloading of creep specimens. Used in calculation of creep parameters.

Specimen 1			Specimen 2			Specimen 3		
Time [h]	Maturity [h]	E [MPa]	Time [h]	Maturity [h]	E [MPa]	Time [h]	Maturity [h]	E [MPa]
13.42	13.5	16580	13.44	13.6	17100	-	-	-
28.84	31.9	25300	28.73	31.8	29180	28.78	31.8	25330
-	-	-	55.19	60.6	29180	55.15	60.6	30220
-	-	-	76.07	83.1	31650	76.10	83.1	30640
98.53	107.0	32210	98.50	107.0	32570	98.47	107.0	32070
-	-	-	148.20	159.7	34120	148.23	159.8	33590
173.62	186.7	35770	-	-	-	-	-	-
-	-	-	243.98	260.9	35060	243.98	260.9	33520
317.69	339.1	38770	317.70	339.1	37400	317.73	339.1	36260
359.03	383.0	38840	-	-	-	-	-	-
-	-	-	414.14	441.2	38030	414.10	441.2	37360
486.15	517.2	39250	486.15	517.2	38390	486.19	517.3	38030
580.64	617.2	37460	580.67	617.3	39240	580.65	617.2	38370
671.28	713.1	38660	671.25	713.0	39580	-	-	-

The creep parameters for use in stress calculations of hardening concrete structures are determined according to TI-B 102, Annex B with some modification as described in the following.

The creep model used can be described as a serial connection between a dashpot and a parallel connection of a dashpot and a spring. In this model the external dashpot represents the part of the creep, which causes irreversible deformations while the parallel connection represents the reversible deformations.

The development of the properties of the components in the parallel correction are described by a function of the type

$$a \cdot \exp(b \cdot \text{maturity}).$$

The development of the property of the external dashpot is described by a function of the type

$a+b\cdot\exp(-(c/maturity)^d)$.

In TI-B 102, Annex B the first type of function is suggested for all of the components.

The parameters are determined by use of least squares method on all specimens at the same time. Doing this, a usable solution could not be found using the function suggested in TI-B 102, Annex B, which is why the function describing the external dashpot was changed as stated above. The approach was made on the measurings during the first 28 days. The results are shown in table 9. The development of the properties are shown in appendix 11.

The parameters in table 9 describes the development of the properties as a function of maturity. The maturity is calculated as Maturity = 1.06332 · Time.

The calculated strains of the specimens due to external load based on the parameters of table 9 are shown in appendix 12.1 - 12.3. In the calculation of the strains the E-modulus determined during the creep test (ref. table 8) is used together with the idealised load histories (ref. table 7).

Property	**Function**	**a**	**b**	**c**	**d**
η_1 [MPa hours]	$a+b\cdot\exp[-(\frac{c}{M})^d]$	$0.177\cdot10^7$	$0.1975\cdot10^9$	1438	0.562
η_2 [MPa hours]	$a\cdot\exp(b\cdot M)$	$0.2382\cdot10^6$	$0.4163\cdot10^{-2}$	-	-
E_2 [MPa]	$a\cdot\exp(b\cdot M)$	$0.1302\cdot10^6$	$0.1222\cdot10^{-2}$	-	-

Table 9 Parameters of creep model described in TI-B 102, Annex B.
η_1 is the viscosity of the external dashpot
η_2 is the viscosity of the dashpot in the parallel connection
E_2 is the spring constant

APPENDIX 1

Concrete Composition

4K-BETON A/S - ISLANDS BRYGGE 22 - 2300 KØBENHAVN S

TLF: 31 57 44 44 - FAX: 31 57 63 00 - GIRO: 540-0392 - A/S REG 41487

Leveret fra: KØBENHAVN TLF: 31543010

DATO :160196 ... 08:48

Konto :520352

DANSK TEKNOLOGISK IN
GREGERSENSVEJ
2630 TÅSTRUP

Plads :611501
ADR.
PORT 36
0 TÅSTRUP
Tlf :

Rekvirent :ATT. HELLE SPANGE

Følgeseddel nr. 6100364	PR01

Vareart	:6001
A/S ØRESUNDSFORBINDELSEN	
MILJØKLASSE SA	
Styrke MN/m2	:40
V/C max.	:0.420
Miljø	:S. AGGRESSIV
Sætmål mm	:140
Luftindhold i kitmasse	:MIN 15%
Beton art	:S
Pulver type	:AAP LAVALKALI FLYVEASKE og SILICA
Sten type	:KL. A
Max. stenstørrelse	:32
Sand type	:KL. A
Tilsætning	:PLAST og SUPERPL. LUFT

Kundebeton :

DETTE LÆS	: 3.00
Bestilt m3	: 3.00
Leveret m3	: 3.00
Vogn nr.	: 828
Ankomst.	: 940
Afgang	:
Ventetid	: 950
Overtid	: /

Tillæg for :LÆS UNDER 4 m3
MILJØAFGIFT

HSP

Støbested: ____________ Bemærk.: ____________ Kvitt.: ____________

Vedr. salgs- og leveringsbetingelser samt brugsanvisning, se bagsiden.

4K-013.03

CERTIFICERING
4K-BETON A/S - ISLANDS BRYGGE 22 - 2300 KØBENHAVN S
TLF: 31 57 44 44 - FAX: 31 57 63 00 - GIRO: 5 40 03 92 - A/S REG 41487

Formular 451.02

Betonen er leveret af : 4K-BETON KØBENHAVN
Udskrevet d. 160196

Kunde

Kontonr	520352-611501	Leveringsadresse	
Rekvirent	ATT. HELLE SPANGE	Blande dato-tid	160196-0851
Navn 1		Pladsnavn 1	ADR.
Navn 2	DANSK TEKNOLOGISK IN	Pladsnavn 2	PORT 36
Adresse	GREGERSENSVEJ	Postnr	0
Postnr	2630	By	TASTRUP
By	TASTRUP	Telefon nr	
		Kundebeton	
		Proces nr : 1	

BETONATTEST SIDE 1: Prøvenr.160071 Følgeseddelnr. 966100364

4K-012.01

Vare nr.	: 6001	Bestilt mængde	: 3.00 m3
Styrke	: 40 MN/m2	Leveret mængde	: 3.00 m3
Miljøklasse	: SB	Dette læs	: 3.00 m3
Max stenstørrelse	: 32 mm	Vogn nr.	: 828
Pulverkombination	: PC(A/HS/EA/G), FA og SI		
Betonart	: SPECIAL	Ankomst	: 0000 TTMM
V/C max.	: 0.42	Afgang	: 0000 TTMM.
Sætmål	: 140 mm	Additiver	: PLAST og SUPERPLAST
Luft	: 18 %		
Stenklasse	: KL. A		
Sandklasse	: KL. A		
Betontemperatur	: 0 C		

S T Y R K E - K O N T R O L

Tryk dato	Lab. ID	Alder døgn	Prøve type	Cyl. nr.	Rumvægt kg/m3	Styrke MN/m2	Middel MN/m2	Bemærkninger
130296	AT	28	C	0025	0	0		
130296	AT	28	C	0026	0	0	0	

F R I S K B E T O N K O N T R O L

	Tilstræbt	Målt	Beregnet	Øvrige oplysninger
Bl volume m3	3.00	3.03	3.06	SÆTMAL KUNSTIGT
Rumvægt kg/m3	2332	2332	2306	SAT NED
Sætmål mm	140	95		
Luft %	5.9	6.7		
Luft% kitmasse	18	21		
V/C tal	0.40	j	0.40	
Betontemp		10		
Lufttemperatur		1		
Læsvægt kg	7054	0	7032	

DTI·DBC CERTIFICERING

4K-BETON A/S - ISLANDS BRYGGE 22 - 2300 KØBENHAVN S

TLF: 31 57 44 44 - FAX: 31 57 63 00 - GIRO: 5 40 03 92 - A/S REG 41487

4K

Betonen er leveret af : 4K-BETON KØBENHAVN
Udskrevet d. 160196

Kunde

Kontonr 520352-611501
Rekvirent ATT. HELLE SPANGE
Navn 1
Navn 2 DANSK TEKNOLOGISK IN
Adresse GREGERSENSVEJ
Postnr 2630
By TASTRUP

Leveringsadresse

Blande dato-tid 160196-0851
Pladsnavn 1 ADR.
Pladsnavn 2 PORT 36
Postnr 0
By TASTRUP
Telefon nr
Kundebeton
Proces nr : 1

BETONATTEST SIDE 2: Prøvenr. 160071 Følgeseddelnr. 966100364

B E T O N S A M M E N S Æ T N I N G

Mat. Navn	Mat. Kode	Recept kg	Tilstr kg	Afvej. kg	Afvig. %	Abs. %	Tfugt %	Frit Vand	V.O.T. kg	V.O. kg/m
"AAP Lavalkali"	630701	275.0	873.0	875.0	0.229	0	0	0	875.00	286.0
Flyveaske < 4%	670739	60.00	181.0	179.0	-1.10	0	0	0	179.00	58.51
Silica (slurry)	690751	12.00	72.40	72.00	-0.55	0	50.00	36.00	36.000	11.76
Vand	990000	127.0	239.0	239.0	0	0	100.0	239.0	413.73	135.2
Spædevand	990002	0	0	3.800		0	100.0	3.800	0	[illegible]
00/04,SA,RN,Aved	131049	767.3	2317	2322	0.216	0.20	5.000	106.1	2215.9	724.3
16/25,A,SC,Rønne	167183	565.0	1712	1713	0.058	0.50	1.010	8.649	1704.4	557.1
08/16,A,SC,Rønne	155181	535.0	1623	1636	0.801	0.50	1.130	10.19	1625.8	531.4
CONPLAST 212	720811	1.388	4.362	4.360	-0.05	0	64.00	2.790	1.5696	0.513
PERAMIN F	730811	2.776	8.724	8.730	0.069	0	66.00	5.762	2.9682	0.970
CONPLAST 316 AEA	710811	0.347	1.472	1.466	-0.41	0	95.00	1.393	0.0733	0.024
Total		2346	7032	7054					7054	230

4K-012.01

TLF: 31 57 44 44 - FAX: 31 57 63 00 - GIRO: 5 40 03 92 - A/S REG 41487

BETONBLANKET

Basisbetonbeskrivelse (BBB)

	Recept opdateret d. 2 2 96 af AT(45)		Klassifikation		Check	Ref.
1	Sag	3	Recept	6021		
	DTI	4	Miljøklasse	SB		
	BETON TIL HETEK,DELOPGAVE 6	5	Styrkeklasse	40 MPa		
2	Anvendelse	6	Kontrolklasse			
		7	Største sten	32 mm		
		8	Standardbeton	NEJ		
			Sætmålsinterval	61-160		

9 Betonidentifikation

	Recept	Type/opr./kl.	Dens.	Kg/m3	l/m3	Check	Ref.
	Sætmål	100					
10	Cement	"AAP Lavalkali"	3.20	285.0	89.1		
11	Flyveaske	Flyveaske < 4%	2.27	60.0	26.4		
12	Mikrosilica	Silica (slurry)	2.23	12.0	5.4		
13	Vand	Vand	1.00	127.0	127.0		
14	Luftindbl.	CONPLAST 316 AEA	1.01	0.357	0.353		
15	Plast	CONPLAST 212	1.17	1.428	1.221		
16	Plast	PERAMIN F	1.21	2.856	2.360		
17	Andet tss.						
18	Sand	00/04,SA,RN,Aved	2.63	758	288.5		
19	Sand						
20	Sten						
21	Sten	08/16,A,SC,Rønne	2.72	535	196.7		
22	Sten	16/25,A,SC,Rønne	2.72	565	207.7		
	Luftindhold	5.5 %			55.3		
			Tot.Σ	2346.6	1000.0		

	Kontrolpunkter	Enhed	Beregning	Mængde	Check	Ref.
23	Mikrosilica	%	....	3.36		
24	Flyveaske+Mikrosilica	%	....	20.17		
25	Ækv.cementindhold	kg/m3	....	339		
26	Effektivt vandindhold	kg/m3	....	130		
27	Ækv.v/c-forhold	--	....	0.384		
28	Mørtelindhold	l/m3	....	583		
29	Fillerindhold i mørtel	kg/m3	....	820		
30	Kitmasseindhold	l/m3	....	307		
31	Luftindhold i kitmasse	%	....	18.01		
32	Max.alkaliindhold	kg/m3	....	1.705		
33	Max.chloridindhold	%	....	0.10		
34	Blandetid	s	....	60		

Producent: 4K Beton A/S Islands Brygge 22 2300 København S. Tlf: 31543010

Blanket udskrevet d. 2. 2.96 kl.12:59. fabrik nr: 61

Entreprenør ______________________ Dato ______ Set af tilsyn ______

4K-BETON A/S - ISLANDS BRYGGE 22 - 2300 KØBENHAVN S
TLF: 31 57 44 44 - FAX: 31 57 63 00 - GIRO: 5 40 03 92 - A/S REG 41487

Trykstyrkens variationskoefficient	DS 411 8.1.1	Dokumenteret 40 prøver.	Dokumenteret 100 prøver.

Recept: 6021

		Alkaliberegning (ækv Na2O)			Chloridberegning Cl÷		
	Kg/m3	%	Kg/m3	Ref.	%	Kg/m3	Ref.
Cement	285.0	0.40	1.140	V.DEK	0.02	0.057	V.DEK
Flyveaske	60.0			V.DEK	0.10	0.060	V.DEK
Mikrosilica	12.0			V.DEK	0.10	0.012	V.DEK
Vand	127.0	0.06	0.076	BBB	0.04	0.051	BBB
Luftindhold	0.357	1.00	0.004	V.DEK	0.02	0.000	V.DEK
Plast	1.428	0.40	0.006	V.DEK	0.05	0.001	V.DEK
Plast	2.856	5.00	0.143	V.DEK	0.05	0.001	V.DEK
Andet tss.							
Sand	758	0.04	0.303	RN	0.02	0.152	RN
Sand							
Sten							
Sten	535	.003	0.016	V.DEK	.001	0.005	V.DEK
Sten	565	.003	0.017	V.DEK	.001	0.006	V.DEK
Total Σ	2347		1.705			0.345	

% af C+Fa+Ms: 0.10

SAMMENSÆTNING AF TILSLAG

Fordeling af tilslag.

		kg/m3	%	Ref.
Sand	00/04,SA,RN,Aved	758	41	
Sand			0	
Sten			0	
Sten	08/16,A,SC,Rønne	535	29	
Sten	16/25,A,SC,Rønne	565	30	
Total		1858	100	

KONTROL AF TILSLAG.

Sand	1	2
Humus	L	
Reak	0.87	
Ekspan.		
Densitet	2.63	
Absorp	0.33	
CL÷ind.	0.02	

GENNEMFALD %

Sigte mm	Sand 1	Sand 2	Sten 1	Sten 2	Sten 3	Tot	Ref
64	100			100	100	100	
32	100			100	93	98	
16	100			93	13	72	
8	100			5	1	43	
4	95			1	0	39	
2	84			0	0	34	
1	68			0	0	28	
0.5	52			0	0	21	
0.25	16			0	0	7	
0.125	1			0	0	0	
0.075	0			0	0	0	

Sten	1	2	3
Vægt %			
~~(2500~~		0.20	0.10
(2400		0.00	
(2200			
Absorp i alt:		0.5	0.5
Kr.10% andel)2400:			
CL÷ind		.001	.001
Dens		2.72	2.72

4K012.01

APPENDIX 2

Heat Development

HETEK
Subtask 3 + 4
Stage 1
DTI Byggeri

Test report

Objective	Determination of heat development of concrete.
Sample	Concrete delivered by 4K Beton A/S on 1996.01.16. Delivery note No. 96-6100364. Concrete identification: 6001. 5 samples, each 5 l, were cast by DTI Byggeri.
Test Method	NT Build 388, 1992. Heat Development.
Test Results	The heat development is calculated as kJ/kg of cement, pages 2, 4, 6, 8 and 10. The heat development is calculated as kJ/kg of cement + mineral additives, pages 3, 5, 7, 9 and 11. Additional information about the concrete and results are given on pages 12 and 13.

Birte Fangel
B.Sc.
Direct telephone: +45 43504122

Jens Ole Frederiksen
Head of section

DTI Building Technology
Danish Technological Institute

☒ Gregersensvej
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DK-2630 Taastrup
Denmark
Tel. +45 43 50 43 50
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○ Teglbækvej 20
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DK-8361 Hasselager
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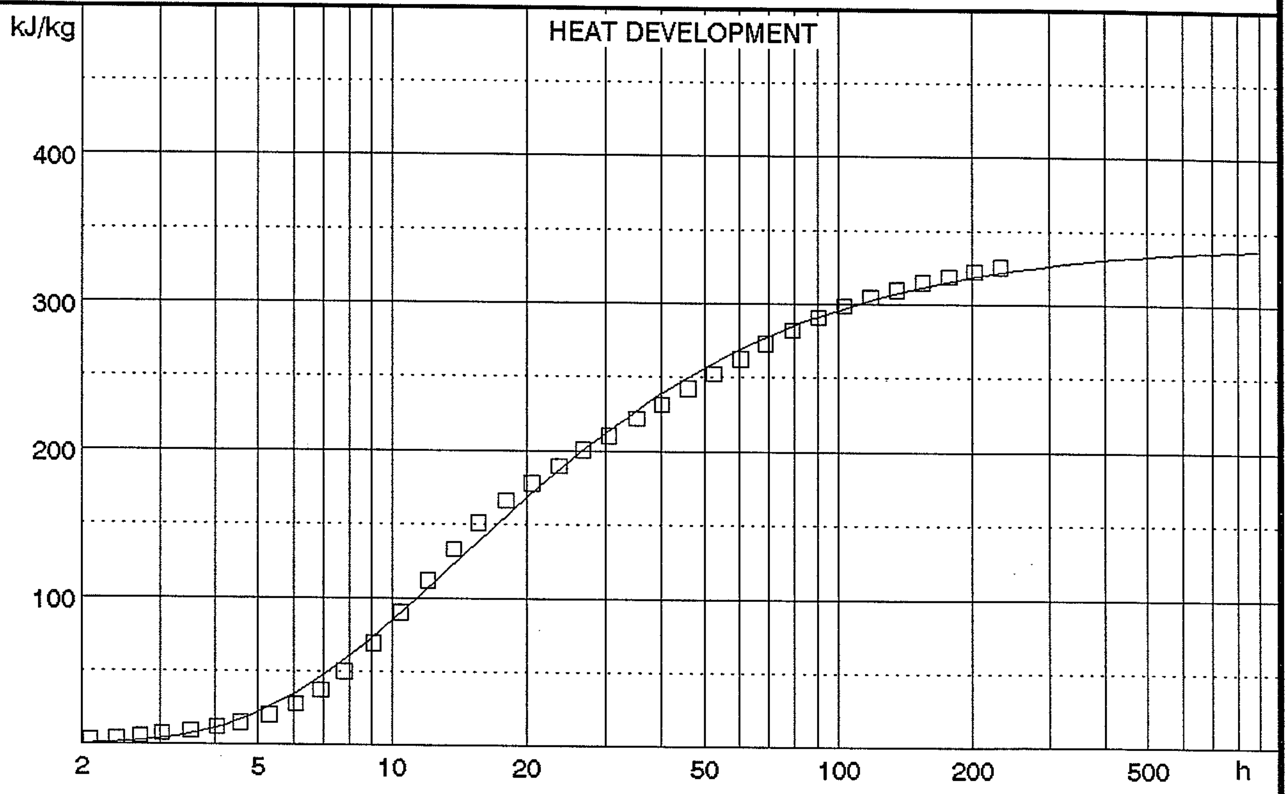
Fax +45 86 28 34 54

○ Teknologiparken
DK-8000 Århus C
Denmark
Tel. +45 89 43 89 43
Fax +45 89 43 81 43

DTI Byggeri Gregersensvej, Box 141, 2630 Taastrup	HEAT DEVELOPMENT Documentation sheet

Client: HETEK
Name:

Number: 53453 Initials: bf
Date: 01.02.96 Job file: DEMO



DATAFILE: HE160116.LOG
CONCRETE: 4K BETON 60116 Cement only Specific heat: 1.04 kJ/kg/dC

LINEAR MODEL
Qo=122.9 kJ/kg To=5.05 h

EXPONENTIAL MODEL
Qinf=343.6 kJ/kg Te=14.12 h Alpha=0.97

MIX MATERIALS	type	density kg/m3	weight kg/m3	volume m3/m3	comment
Water	VAND	1000.0	129.9	0.130	
Cement	PC(A/HS/EA/G)	3150.0	281.6	0.089	
Mineral additive	FLYVEASKE	2200.0	57.6	0.026	
	SILICA SLURRY	2300.0	11.6	0.005	
Aggregate	RN-AVEDø0-4A	2620.0	713.1	0.272	
	16/25A SC RØNN	2730.0	548.5	0.201	
	08/16A SC RØNN	2720.0	523.2	0.192	
Chemical Admixture	CONPLAST 212	1170.0	1.4	0.001	
	PERAMIN F	1210.0	2.8	0.002	
	CONPL.316 AEA	1003.0	0.5	0.000	
Air				0.080	

CONCRETE PROPERTIES

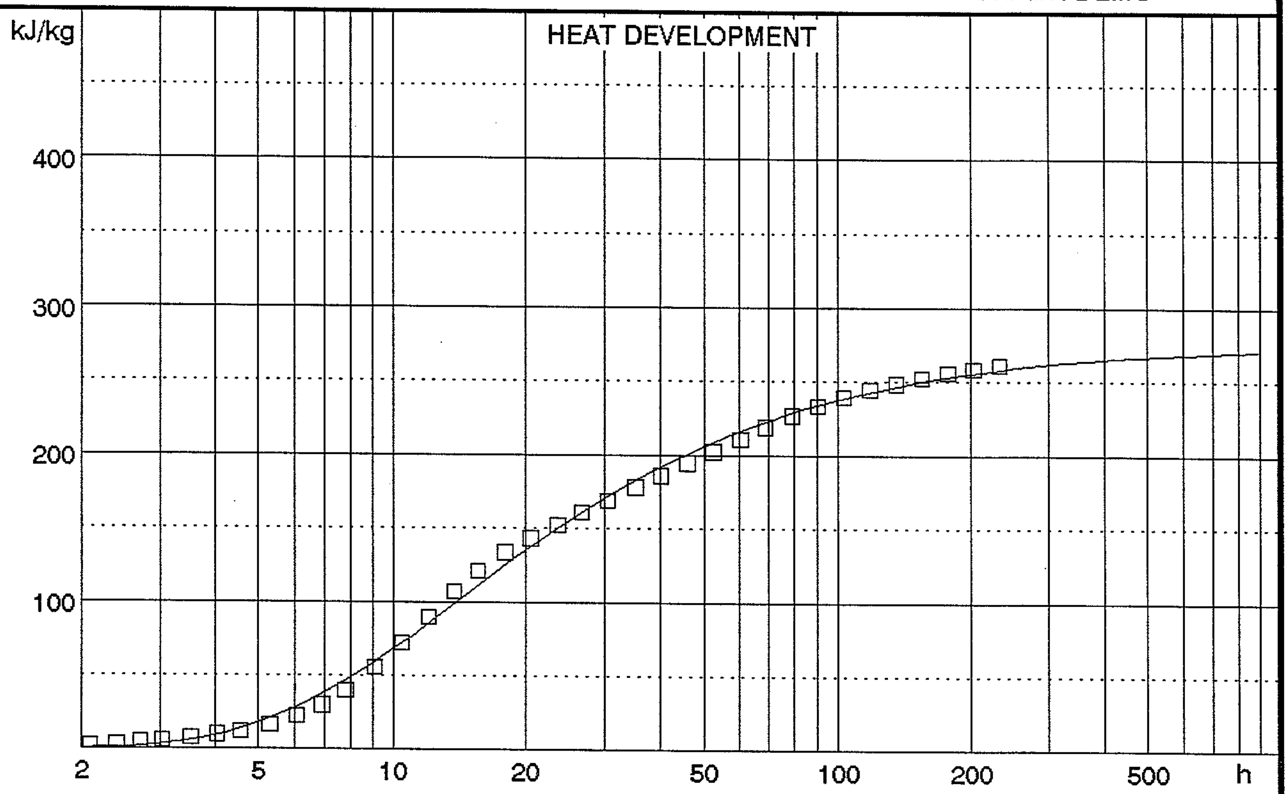
density measured kg/m3	density calculated kg/m3	w/c-ratio kg/kg	air content %	haybox no.	c. factor
2328.0	2270.2	0.40	8.0	1	1.257

COMMENTS:

DTI Byggeri Gregersensvej, Box 141, 2630 Taastrup	HEAT DEVELOPMENT Documentation sheet

Client: HETEK
Name:

Number: 53453 Initials: bf
Date: 01.02.96 Job file: DEMO



DATAFILE: HE160116.LOG
CONCRETE: 4K BETON 60116 Cement + min. additives Specific heat: 1.04 kJ/kg/dC

LINEAR MODEL
Qo=98.6 kJ/kg To=5.05 h

EXPONENTIAL MODEL
Qinf=275.9 kJ/kg Te=14.12 h Alpha=0.97

MIX MATERIALS	type	density kg/m3	weight kg/m3	volume m3/m3	comment
Water	VAND	1000.0	129.9	0.130	
Cement	PC(A/HS/EA/G)	3150.0	281.6	0.089	
Mineral additive	FLYVEASKE	2200.0	57.6	0.026	
	SILICA SLURRY	2300.0	11.6	0.005	
Aggregate	RN-AVEDø0-4A	2620.0	713.1	0.272	
	16/25A SC RØNN	2730.0	548.5	0.201	
	08/16A SC RØNN	2720.0	523.2	0.192	
Chemical Admixture	CONPLAST 212	1170.0	1.4	0.001	
	PERAMIN F	1210.0	2.8	0.002	
	CONPL.316 AEA	1003.0	0.5	0.000	
Air				0.080	

CONCRETE PROPERTIES

density measured kg/m3	density calculated kg/m3	w/c-ratio kg/kg	air content %	haybox no.	c. factor
2328.0	2270.2	0.40	8.0	1	1.257

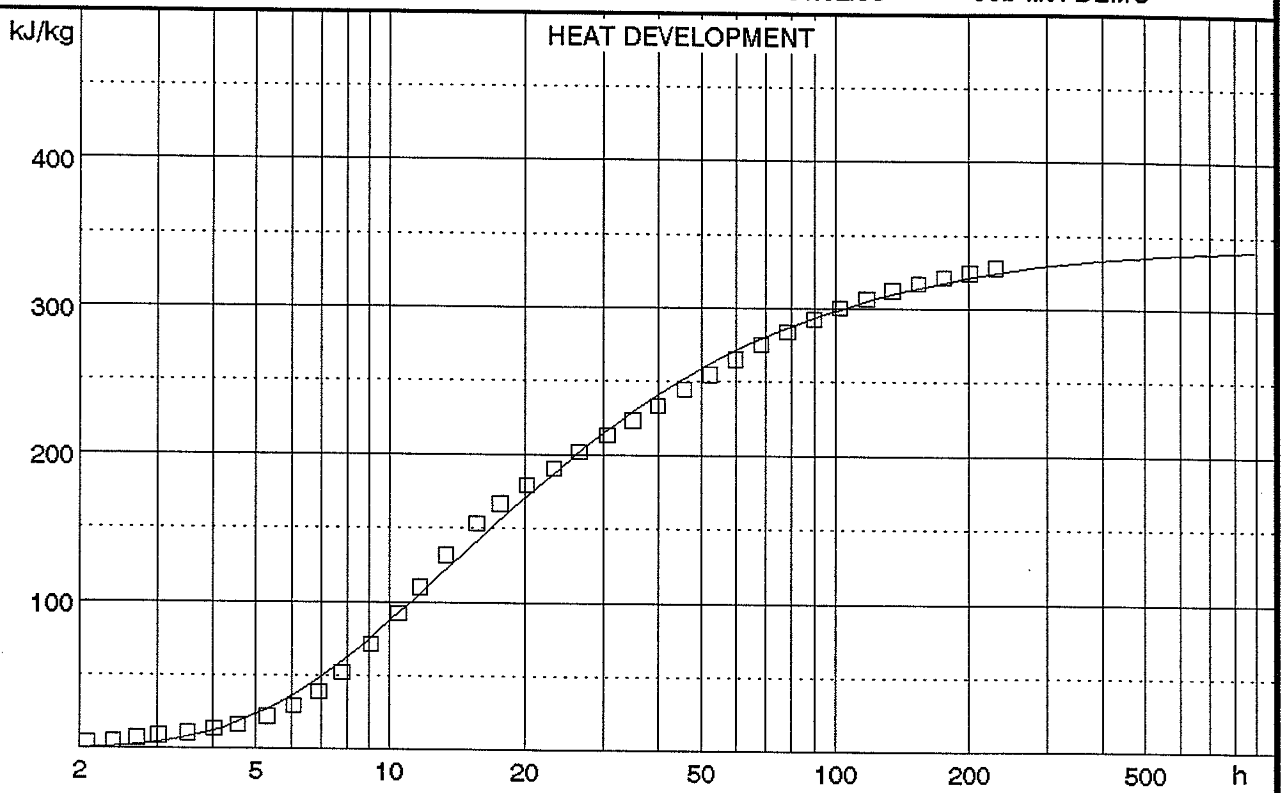
COMMENTS:

DTI Byggeri
Gregersensvej, Box 141, 2630 Taastrup

HEAT DEVELOPMENT
Documentation sheet

Client: HETEK
Name:

Number: 53453 Initials: bf
Date: 01.02.96 Job file: DEMO



DATAFILE: HE160116.LOG
CONCRETE: 4K BETON 60116 Cement only Specific heat: 1.04 kJ/kg/dC

LINEAR MODEL
Qo=123.0 kJ/kg To=4.96 h

EXPONENTIAL MODEL
Qinf=346.8 kJ/kg Te=13.98 h Alpha=0.96

MIX MATERIALS	type	density kg/m3	weight kg/m3	volume m3/m3	comment
Water	VAND	1000.0	129.9	0.130	
Cement	PC(A/HS/EA/G)	3150.0	281.6	0.089	
Mineral additive	FLYVEASKE	2200.0	57.6	0.026	
	SILICA SLURRY	2300.0	11.6	0.005	
Aggregate	RN-AVEDø0-4A	2620.0	713.1	0.272	
	16/25A SC RØNN	2730.0	548.5	0.201	
	08/16A SC RØNN	2720.0	523.2	0.192	
Chemical Admixture	CONPLAST 212	1170.0	1.4	0.001	
	PERAMIN F	1210.0	2.8	0.002	
	CONPL.316 AEA	1003.0	0.5	0.000	
Air				0.080	

CONCRETE PROPERTIES

density measured kg/m3	density calculated kg/m3	w/c-ratio kg/kg	air content %	haybox no.	c. factor
2328.0	2270.2	0.40	8.0	5	1.161

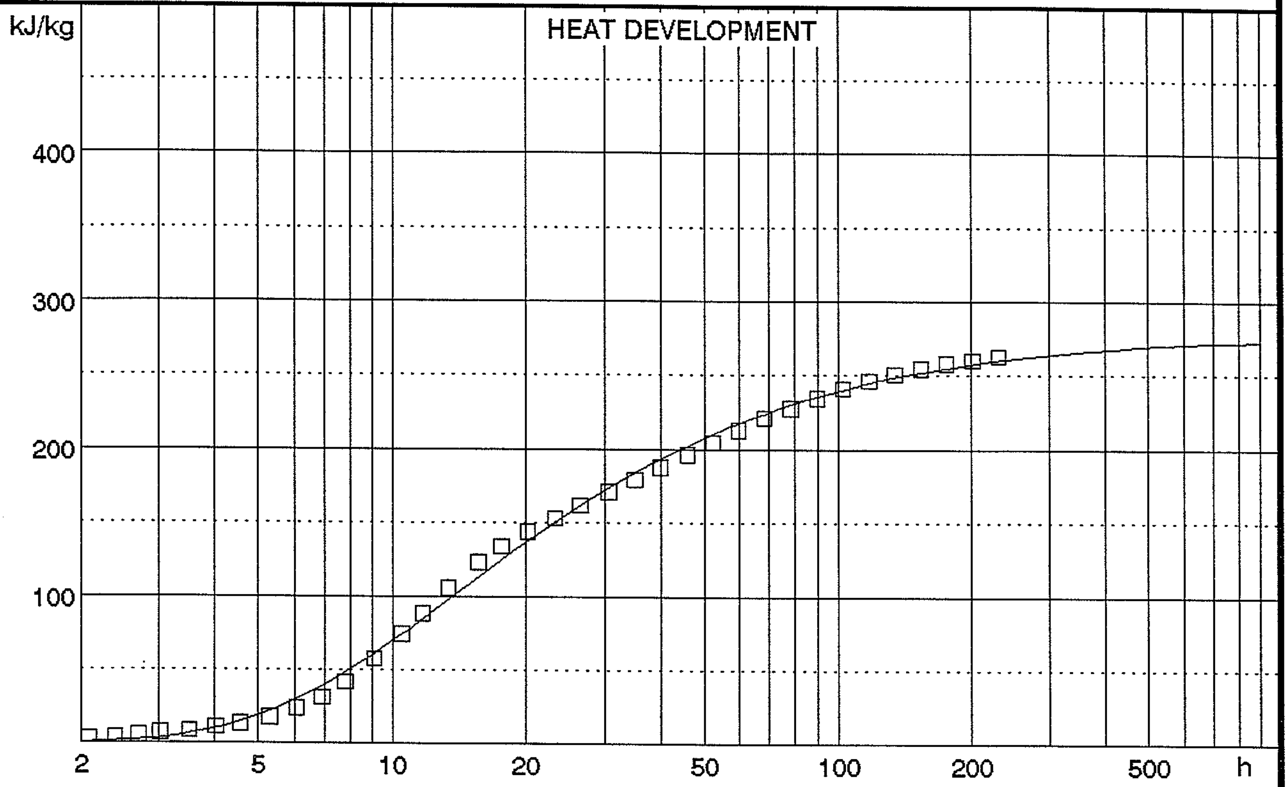
COMMENTS:

DTI Byggeri
Gregersensvej, Box 141, 2630 Taastrup

HEAT DEVELOPMENT
Documentation sheet

Client: HETEK
Name:

Number: 53453 Initials: bf
Date: 01.02.96 Job file: DEMO



DATAFILE: HE160116.LOG
CONCRETE: 4K BETON 60116 Cement + min. additives Specific heat: 1.04 kJ/kg/dC

LINEAR MODEL
Qo=98.8 kJ/kg To=4.96 h

EXPONENTIAL MODEL
Qinf=278.4 kJ/kg Te=13.98 h Alpha=0.96

MIX MATERIALS	type	density kg/m3	weight kg/m3	volume m3/m3	comment
Water	VAND	1000.0	129.9	0.130	
Cement	PC(A/HS/EA/G)	3150.0	281.6	0.089	
Mineral additive	FLYVEASKE	2200.0	57.6	0.026	
	SILICA SLURRY	2300.0	11.6	0.005	
Aggregate	RN-AVEDø0-4A	2620.0	713.1	0.272	
	16/25A SC RØNN	2730.0	548.5	0.201	
	08/16A SC RØNN	2720.0	523.2	0.192	
Chemical Admixture	CONPLAST 212	1170.0	1.4	0.001	
	PERAMIN F	1210.0	2.8	0.002	
	CONPL.316 AEA	1003.0	0.5	0.000	
Air				0.080	

CONCRETE PROPERTIES

density measured kg/m3	density calculated kg/m3	w/c-ratio kg/kg	air content %	haybox no.	c. factor
2328.0	2270.2	0.40	8.0	5	1.161

COMMENTS:

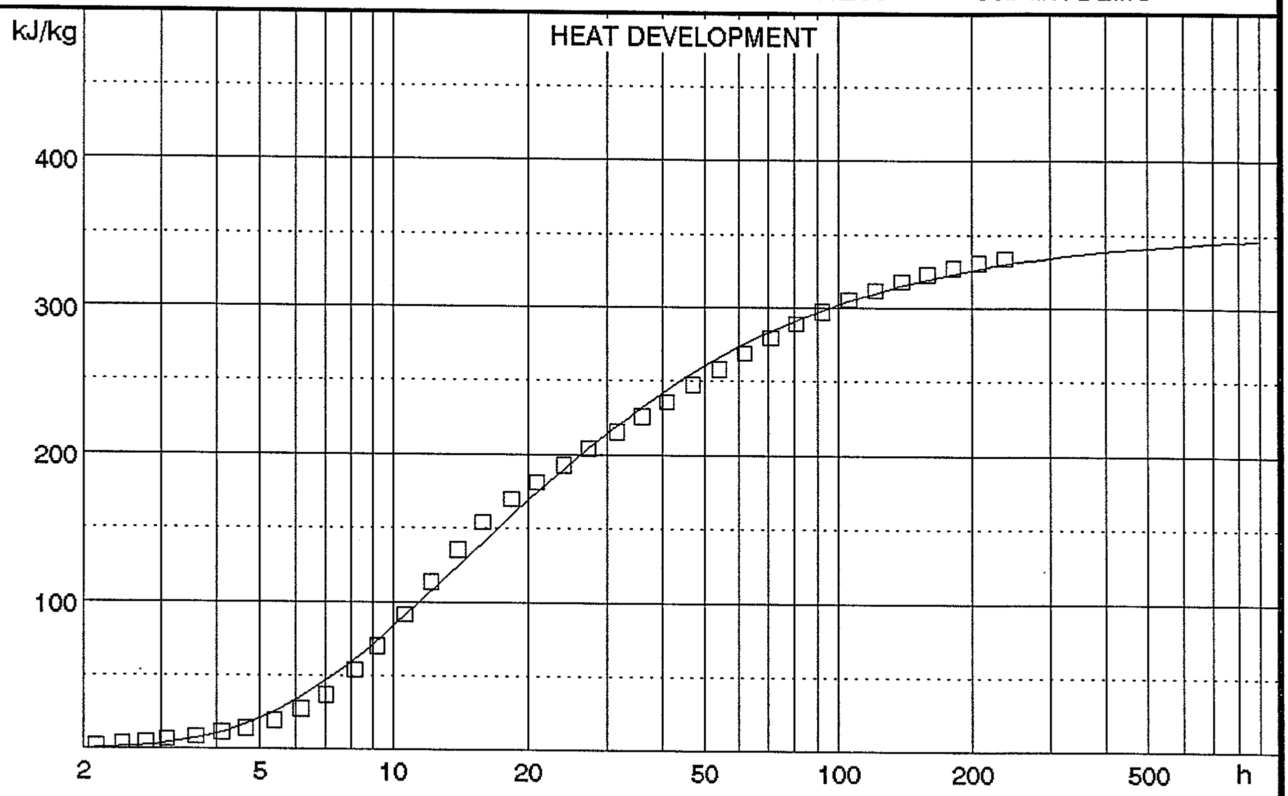
DTI Byggeri
Gregersensvej, Box 141, 2630 Taastrup

HEAT DEVELOPMENT

Documentation sheet

Client: HETEK
Name:

Number: 53453 Initials: bf
Date: 01.02.96 Job file: DEMO



DATAFILE: HE160116.LOG
CONCRETE: 4K BETON 60116 Cement only Specific heat: 1.04 kJ/kg/dC

LINEAR MODEL
Qo=125.8 kJ/kg To=5.19 h

EXPONENTIAL MODEL
Qinf=352.5 kJ/kg Te=14.55 h Alpha=0.97

MIX MATERIALS	type	density kg/m3	weight kg/m3	volume m3/m3	comment
Water	VAND	1000.0	129.9	0.130	
Cement	PC(A/HS/EA/G)	3150.0	281.6	0.089	
Mineral additive	FLYVEASKE	2200.0	57.6	0.026	
	SILICA SLURRY	2300.0	11.6	0.005	
Aggregate	RN-AVEDø0-4A	2620.0	713.1	0.272	
	16/25A SC RØNN	2730.0	548.5	0.201	
	08/16A SC RØNN	2720.0	523.2	0.192	
Chemical Admixture	CONPLAST 212	1170.0	1.4	0.001	
	PERAMIN F	1210.0	2.8	0.002	
	CONPL.316 AEA	1003.0	0.5	0.000	
Air				0.080	

CONCRETE PROPERTIES

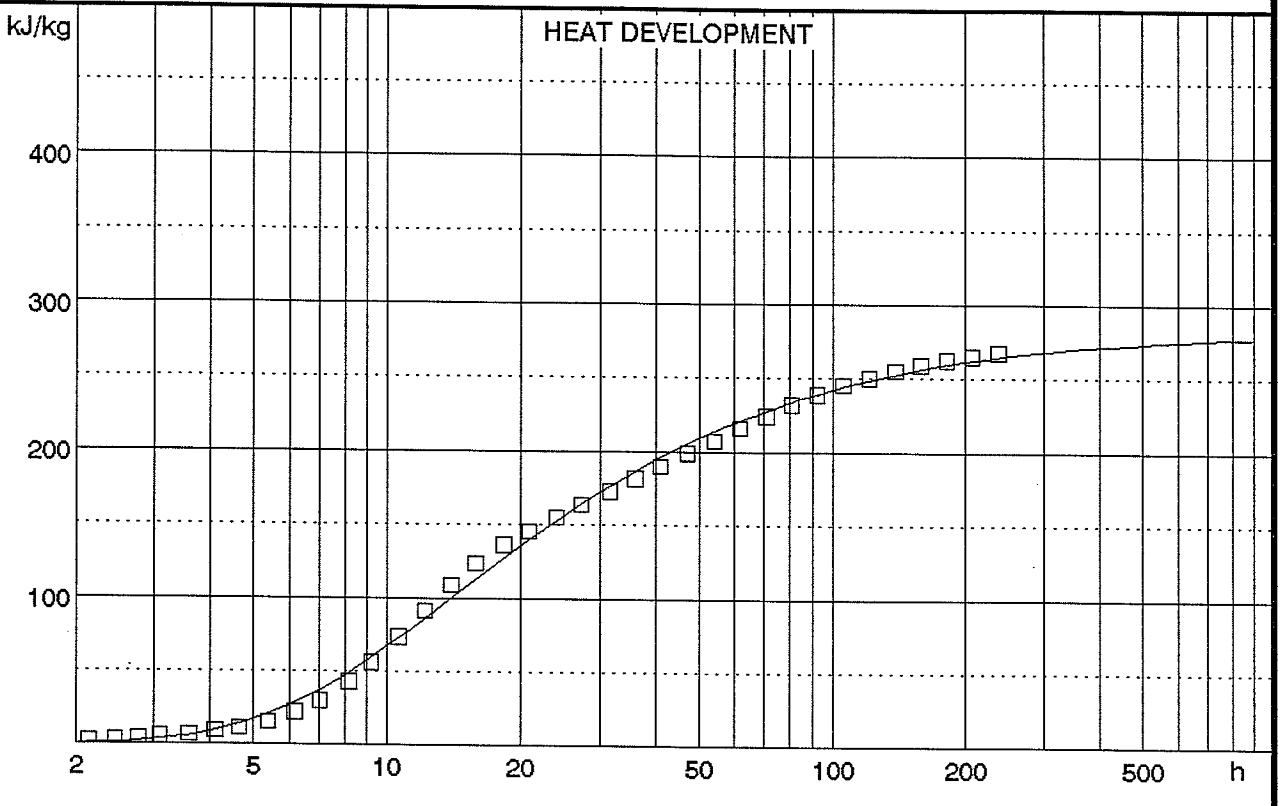
density measured kg/m3	density calculated kg/m3	w/c-ratio kg/kg	air content %	haybox no.	c. factor
2328.0	2270.2	0.40	8.0	6	0.966

COMMENTS:

DTI Byggeri Gregersensvej, Box 141, 2630 Taastrup	HEAT DEVELOPMENT Documentation sheet

Client: HETEK
Name:

Number: 53453 Initials: bf
Date: 01.02.96 Job file: DEMO



DATAFILE: HE160116.LOG
CONCRETE: 4K BETON 60116 Cement + min. additives Specific heat: 1.04 kJ/kg/dC

LINEAR MODEL
Qo=101.0 kJ/kg To=5.19 h

EXPONENTIAL MODEL
Qinf=282.9 kJ/kg Te=14.55 h Alpha=0.97

MIX MATERIALS	type	density kg/m3	weight kg/m3	volume m3/m3	comment
Water	VAND	1000.0	129.9	0.130	
Cement	PC(A/HS/EA/G)	3150.0	281.6	0.089	
Mineral additive	FLYVEASKE	2200.0	57.6	0.026	
	SILICA SLURRY	2300.0	11.6	0.005	
Aggregate	RN-AVEDø0-4A	2620.0	713.1	0.272	
	16/25A SC RØNN	2730.0	548.5	0.201	
	08/16A SC RØNN	2720.0	523.2	0.192	
Chemical Admixture	CONPLAST 212	1170.0	1.4	0.001	
	PERAMIN F	1210.0	2.8	0.002	
	CONPL.316 AEA	1003.0	0.5	0.000	
Air				0.080	

CONCRETE PROPERTIES

density measured kg/m3	density calculated kg/m3	w/c-ratio kg/kg	air content %	haybox no.	c. factor
2328.0	2270.2	0.40	8.0	6	0.966

COMMENTS:

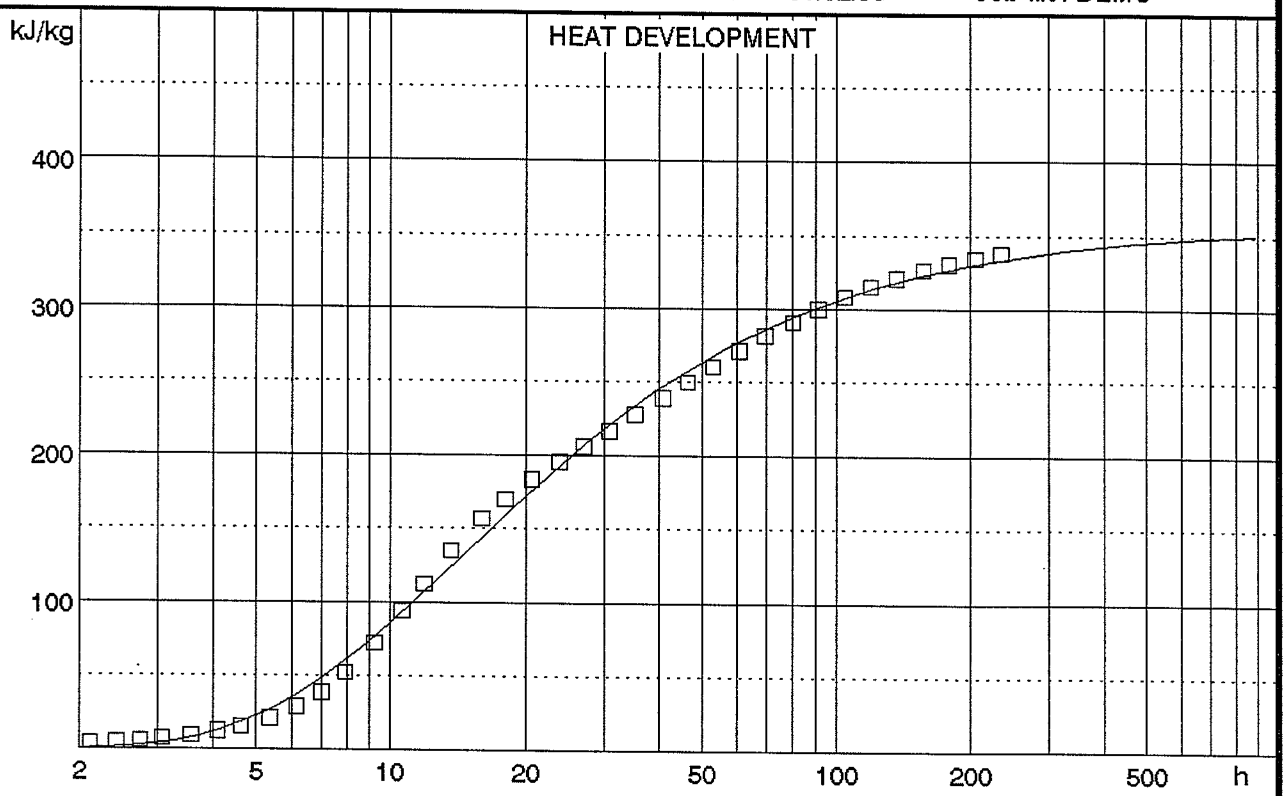
DTI Byggeri
Gregersensvej, Box 141, 2630 Taastrup

HEAT DEVELOPMENT

Documentation sheet

Client: HETEK
Name:

Number: 53453 Initials: bf
Date: 01.02.96 Job file: DEMO



DATAFILE: HE160116.LOG
CONCRETE: 4K BETON 60116 Cement only Specific heat: 1.04 kJ/kg/dC

LINEAR MODEL
Qo=126.2 kJ/kg To=5.10 h

EXPONENTIAL MODEL
Qinf=357.5 kJ/kg Te=14.45 h Alpha=0.96

MIX MATERIALS	type	density kg/m3	weight kg/m3	volume m3/m3	comment
Water	VAND	1000.0	129.9	0.130	
Cement	PC(A/HS/EA/G)	3150.0	281.6	0.089	
Mineral additive	FLYVEASKE	2200.0	57.6	0.026	
	SILICA SLURRY	2300.0	11.6	0.005	
Aggregate	RN-AVEDø0-4A	2620.0	713.1	0.272	
	16/25A SC RØNN	2730.0	548.5	0.201	
	08/16A SC RØNN	2720.0	523.2	0.192	
Chemical Admixture	CONPLAST 212	1170.0	1.4	0.001	
	PERAMIN F	1210.0	2.8	0.002	
	CONPL.316 AEA	1003.0	0.5	0.000	
Air				0.080	

CONCRETE PROPERTIES

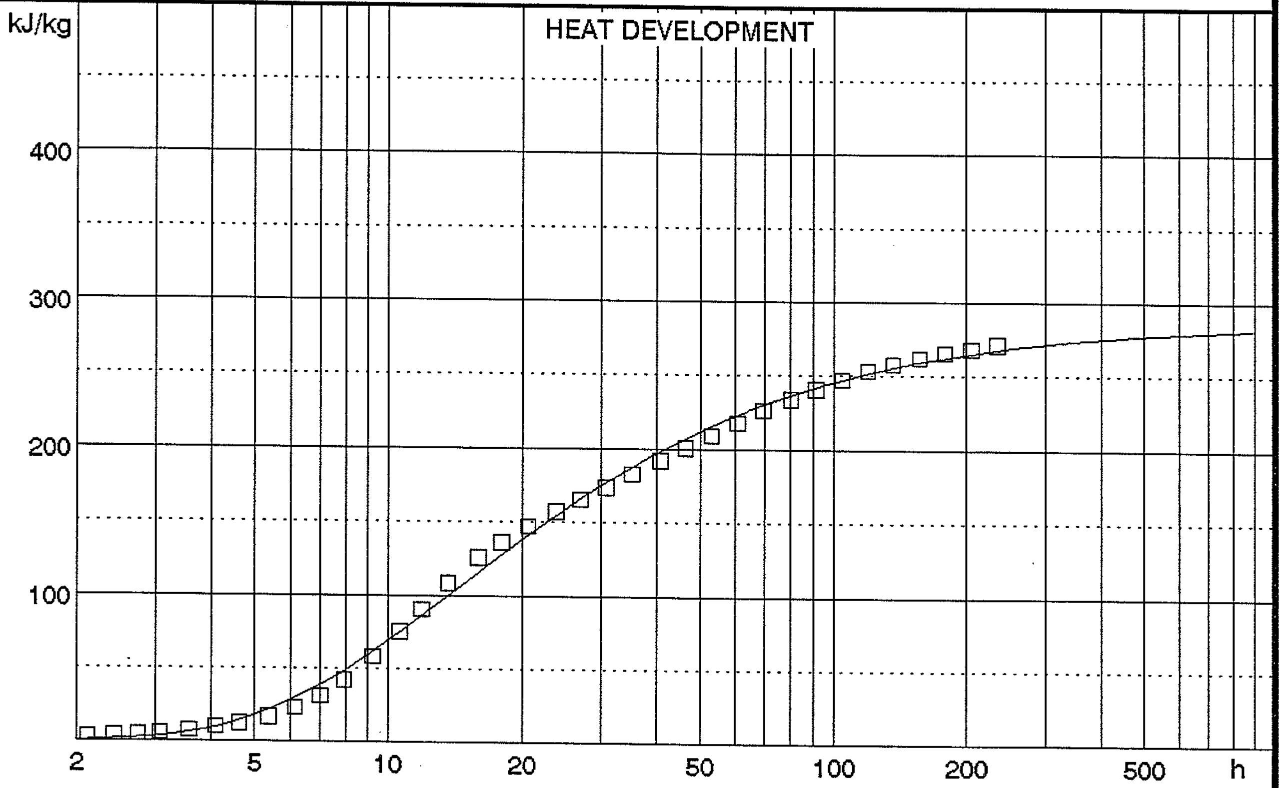
density measured kg/m3	density calculated kg/m3	w/c-ratio kg/kg	air content %	haybox no.	c. factor
2328.0	2270.2	0.40	8.0	7	1.155

COMMENTS:

DTI Byggeri Gregersensvej, Box 141, 2630 Taastrup	**HEAT DEVELOPMENT** Documentation sheet

Client: HETEK
Name:

Number: 53453 Initials: bf
Date: 01.02.96 Job file: DEMO



DATAFILE: HE160116.LOG
CONCRETE: 4K BETON 60116 Cement + min. additives Specific heat: 1.04 kJ/kg/dC

LINEAR MODEL
Qo=101.3 kJ/kg To=5.10 h

EXPONENTIAL MODEL
Qinf=287.0 kJ/kg Te=14.45 h Alpha=0.96

MIX MATERIALS	type	density kg/m3	weight kg/m3	volume m3/m3	comment
Water	VAND	1000.0	129.9	0.130	
Cement	PC(A/HS/EA/G)	3150.0	281.6	0.089	
Mineral additive	FLYVEASKE	2200.0	57.6	0.026	
	SILICA SLURRY	2300.0	11.6	0.005	
Aggregate	RN-AVEDø0-4A	2620.0	713.1	0.272	
	16/25A SC RØNN	2730.0	548.5	0.201	
	08/16A SC RØNN	2720.0	523.2	0.192	
Chemical Admixture	CONPLAST 212	1170.0	1.4	0.001	
	PERAMIN F	1210.0	2.8	0.002	
	CONPL.316 AEA	1003.0	0.5	0.000	
Air				0.080	

CONCRETE PROPERTIES

density measured kg/m3	density calculated kg/m3	w/c-ratio kg/kg	air content %	haybox no.	c. factor
2328.0	2270.2	0.40	8.0	7	1.155

COMMENTS:

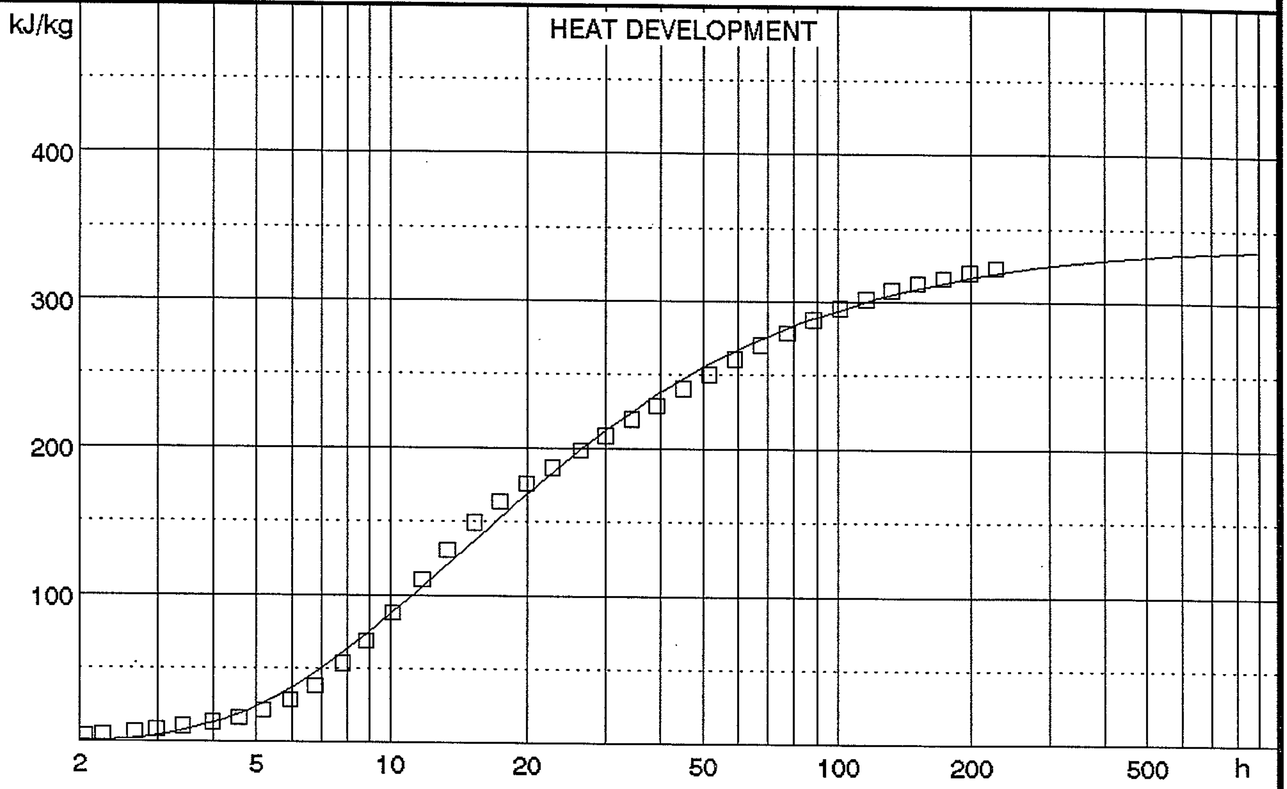
DTI Byggeri
Gregersensvej, Box 141, 2630 Taastrup

HEAT DEVELOPMENT

Documentation sheet

Client: HETEK
Name:

Number: 53453 Initials: bf
Date: 01.02.96 Job file: DEMO



DATAFILE: HE260116.LOG
CONCRETE: 4K BETON 60116 Cement only Specific heat: 1.04 kJ/kg/dC

LINEAR MODEL
Qo=120.3 kJ/kg To=4.88 h

EXPONENTIAL MODEL
Qinf=342.7 kJ/kg Te=13.90 h Alpha=0.95

MIX MATERIALS	type	density kg/m3	weight kg/m3	volume m3/m3	comment
Water	VAND	1000.0	129.9	0.130	
Cement	PC(A/HS/EA/G)	3150.0	281.6	0.089	
Mineral additive	FLYVEASKE	2200.0	57.6	0.026	
	SILICA SLURRY	2300.0	11.6	0.005	
Aggregate	RN-AVEDø0-4A	2620.0	713.1	0.272	
	16/25A SC RØNN	2730.0	548.5	0.201	
	08/16A SC RØNN	2720.0	523.2	0.192	
Chemical Admixture	CONPLAST 212	1170.0	1.4	0.001	
	PERAMIN F	1210.0	2.8	0.002	
	CONPL.316 AEA	1003.0	0.5	0.000	
Air				0.080	

CONCRETE PROPERTIES

density measured kg/m3	density calculated kg/m3	w/c-ratio kg/kg	air content %	haybox no.	c. factor
2328.0	2270.2	0.40	8.0	18	1.085

COMMENTS:

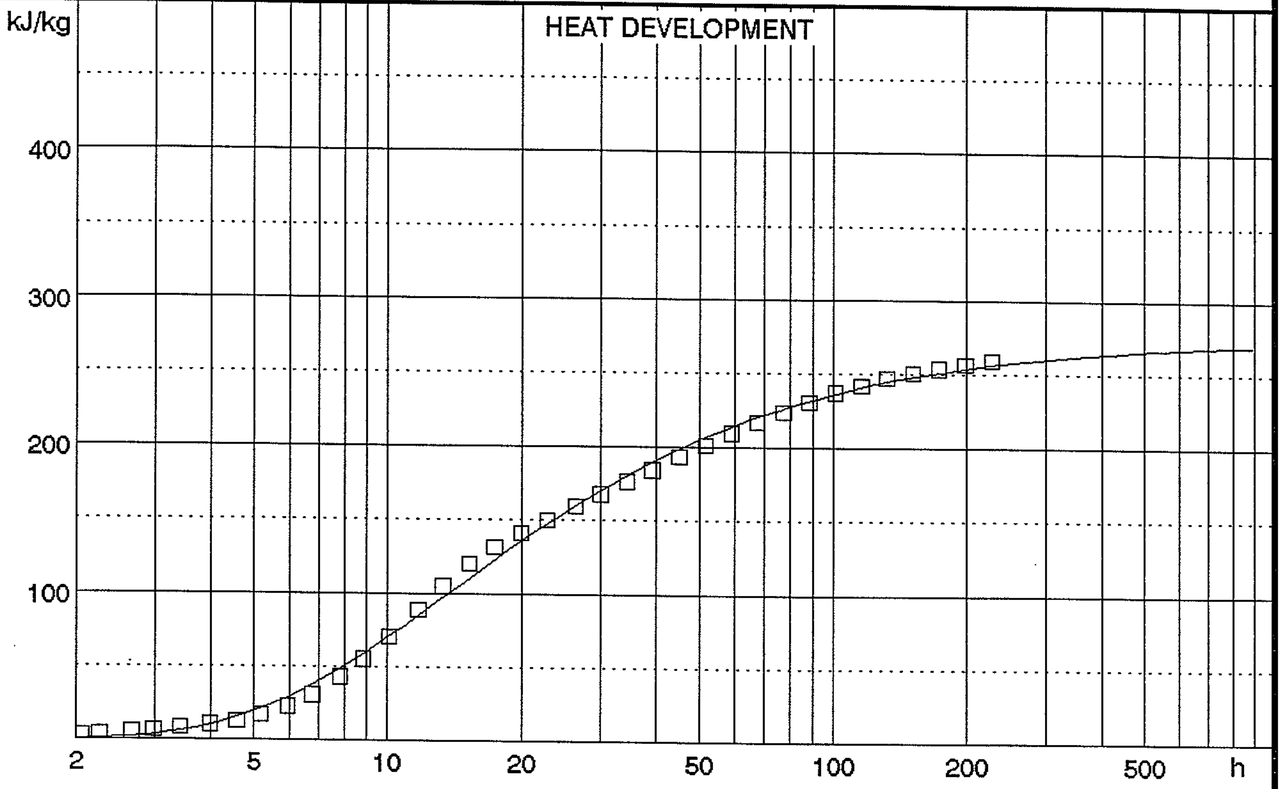
DTI Byggeri
Gregersensvej, Box 141, 2630 Taastrup

HEAT DEVELOPMENT

Documentation sheet

Client: HETEK
Name:

Number: 53453 Initials: bf
Date: 01.02.96 Job file: DEMO



DATAFILE: HE260116.LOG
CONCRETE: 4K BETON 60116 Cement + min. additives Specific heat: 1.04 kJ/kg/dC

LINEAR MODEL
Qo=96.6 kJ/kg To=4.88 h

EXPONENTIAL MODEL
Qinf=275.1 kJ/kg Te=13.90 h Alpha=0.95

MIX MATERIALS	type	density kg/m3	weight kg/m3	volume m3/m3	comment
Water	VAND	1000.0	129.9	0.130	
Cement	PC(A/HS/EA/G)	3150.0	281.6	0.089	
Mineral additive	FLYVEASKE	2200.0	57.6	0.026	
	SILICA SLURRY	2300.0	11.6	0.005	
Aggregate	RN-AVEDø0-4A	2620.0	713.1	0.272	
	16/25A SC RØNN	2730.0	548.5	0.201	
	08/16A SC RØNN	2720.0	523.2	0.192	
Chemical Admixture	CONPLAST 212	1170.0	1.4	0.001	
	PERAMIN F	1210.0	2.8	0.002	
	CONPL.316 AEA	1003.0	0.5	0.000	
Air				0.080	

CONCRETE PROPERTIES

density measured kg/m3	density calculated kg/m3	w/c-ratio kg/kg	air content %	haybox no.	c. factor
2328.0	2270.2	0.40	8.0	18	1.085

COMMENTS:

The concrete mix report states that the composition of the concrete is as follows:

Concrete composition

Cement	875.0	kg	
Fly ash	179.0	kg	
Silica fume, slurry	36.0	kg	***
Sand, RN-Avedøre	2215.9	kg	**
16/25A SC RØNN	1704.4	kg	**
08/16A SC RØNN	1625.8	kg	**
Conplast 212	4.36	kg	
Peramin F	8.73	kg	
Complast 316 AEA	1.47	kg	
Water	403.8	kg	*

* The quantity of water does not include the water content of plasticizer and air entrainment.

** The values are stated as values for materials in water saturated surface dry condition

*** Quantity and density is valid for dry silica fume, the amount of water is included in the 403.8 kg of water.

We have been informed that the concrete was mixed on 1996.01.16, at 8.51 a.m.

DTI Byggeri has determined:

Air content: 8.0 %
Density: 2328 kg/m^3
Slump: 70 mm

Haybox No.	1	5	6	7	19
Weight of concrete[kg] Weight of bucket [kg]	12,379 0.541	12,622 0.540	12,471 0.538	12,569 0.540	12,493 0.539

The densities given on pages 2 - 13 are the densities normally used at DTI.

The water/cement ratios stated on pages 2 - 13 are the equivalent water/cement ratios calculated as:

water/(cement + 2 x silica fume + 0.5 x fly ash).

Summary of results:

Sample in Haybox No.	1	5	6	7	18	Aver-age	Devi-ation
Quen [kJ/kg cement]	343.6	346.8	352.5	357.5	342.7	348.6	6.3
Quen [kJ/kg cement + min. additives]	275.9	278.4	282.9	287.0	275.1	279.9	5.0
Te [hours]	14.12	13.98	14.55	14.45	13.90	14.20	0.29
Alfa	0.97	0.96	0.97	0.96	0.95	0.96	0.01

APPENDIX 3

Thermal Expansion Coefficient

HETEK
Subtask 3 + 4
Stage 1
DTI Byggeri

Report no. : 53453-2
Date : 1996-02-12
Page : 1 of 2
Appendix :

Test report

Objektive Determination of Thermal Expansion Coefficient.

Client : HETEK
Sampler : The specimens was casted by DTI with concrete delivered by 4k-Beton København
Delivery note: Delivery note no. 966100364

Specimens
Type : casted concrete prisms 100x100x400 mm.
Designation : 6001
Casting : 1996-01-16

Test Methods TI-B 101 (September 1994) : Test Method. Concrete. Thermal Expansion Coefficient.

Test Results The results of the tests are shown at page 2.

The heating from 5°C to 30°C lasted between 2,5 and 3 h. In this relative short period no measurable shrinkage was detected.

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Thermal expansion coeff. according to TI-B 101

Date of Casting: 1996-01-16

Date of testing: 1996-01-17 Maturity: app. 1 day

Specimen Mark	alfa 1/°C
1 2 3	0,87E-5 0,87E-5 0,87E-5
Mean St. dev.	0,87E-5 0,001E-5

Date of testing: 1996-01-19 Maturity: app. 3 day

Specimen Mark	alfa 1/°C
1 2 3	0,83E-5 0,91E-5 0,90E-5
Mean St. dev.	0,88E-5 0,045E-5

Date of testing: 1996-01-23 Maturity: app. 7 day

Specimen Mark	alfa 1/°C
1 2 3	0,84E-5 0,90E-5 0,85E-5
Mean St. dev.	0,86E-5 0,029E-5

Mean of all measurings: 0,87E-5 1/°C

APPENDIX 4

E-modulus and Compressive Strength Developments

HETEK
Subtask 3 + 4
Stage 1
DTI Byggeri

Report no. : 53453-3
Date : 1996-02-13

Appendix : 1

Test report

Objektive

Determination of E-modulus and compressive strength developments.

Client : HETEK
Sampler : The specimens was casted by DTI with concrete delivered by 4k-Beton København.
Delivery note: Delivery note. no. 966100364

Specimens

Type : casted concrete cylinders D150 x h300 mm.
Designation : 6001
Casting : 1996-01-16

The maturity of the specimens was estimated to be 3.8 h at 1996-01-16 - 14:30.

Test Methods

DS 423.23 (March 1984): Testing of Concrete - Hardened Concrete - Compressive Strength

DS 423.25 (March 1984): Testing of Concrete - Hardened Concrete - Modulus of Elasticity

The tests departs from the methods at early ages (1/2, 1, 2 and 3 days), as the loadrate used was 0.2 MPa/s. For testing of E-modulus at 1/2 day all load levels were 45% of comp. strength.

Test Results

The results of the tests are shown at page 2-10. E-modulus and compressive strength developments are shown in appendix 1.

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E-modulus according to DS 423.25 - Main Results

Time	Specimen	Maturity hours	E0 MPa	Ec MPa
0	0-2 0-3 0-4	11,3 11,5 11,6	8400 11400 10600	8900 10800 11300
mean		11,5	10100	10300
1	1-2 1-3 1-4	23,6 23,7 24,0	24000 23000	24500 21500 23000
mean		23,7	23500	23000
2	2-2 2-3 2-4	47,2 47,5 47,7	26000 28600 25500	26300 28900 25700
mean		47,5	26700	27000
3	3-2 3-3 3-4	71,3 71,6 71,9	28500 27700 27600	28700 28100 27700
mean		71,6	27900	28200
7	7-2 7-3 7-4	167,3 167,7 167,9	30900 32100 31700	31500 32500 31700
mean		167,6	31600	31900
14	14-2 14-3 14-4	337,9 338,1 338,5	33400 32500 33100	33800 32400 33000
mean		338,2	33000	33100
28	28-2 28-3 28-4	674,2 674,5 674,7	36400 36100 35600	36400 35700 35500
mean		674,5	36000	35900

Compressive Strength according to DS 423.23 - Main Results

Time	Specimen	Maturity hours	Comp. strength MPa
0	0-1	10,9	2,4
	0-2 0-3 0-4	11,3 11,5 11,6	2,8 3,0 3,3
1	1-1	23,3	12,3
	1-2 1-3 1-4	23,6 23,7 24,0	13,2 13,0 13,0
2	2-1	47,1	19,7
	2-2 2-3 2-4	47,2 47,5 47,7	19,9 20,0 19,6
3	3-1	71,0	21,9
	3-2 3-3 3-4	71,3 71,6 71,9	23,1 23,0 22,3
7	7-1	167,0	30,8
	7-2 7-3 7-4	167,3 167,7 167,9	31,5 33,7 30,6
14	14-1	337,7	39,5
	14-2 14-3 14-4	337,9 338,1 338,5	40,8 37,4 36,7
28	28-1	673,9	44,5
	28-2 28-3 28-4	674,2 674,5 674,7	44,2 45,7 47,3

E-modulus according to DS 423.25

Date of casting: 1996-01-16
Date of testing: 1996-01-16

Spec. Mark	Maturity hours	Dia-meter mm	Height mm	Densi-ty kg/m³	E0 MPa	Ec MPa	Comp. strength MPa
0-2	11,3	149,9	300,4	2290	8400	8900	2,8
0-3	11,5	149,4	300,2	2317	11400	10800	3,0
0-4	11,6	150,3	300,5	2314	10600	11300	3,3
Mean				2307	10100	10300	3,0
Standard deviation				15	1550	1270	0,2

If the specimen was recentered E0 is not determined.

The compressive strength departs more than 20% from the presumed.

Compressive strength determined just before determination of the E-modulus:

Spec. Mark	Maturity hours	Dia-meter mm	Height mm	Density kg/m³	Comp. strength MPa
0-1	10,9	150,5	300,1	2301	2,4

E-modulus according to DS 423.25

Date of casting: 1996-01-16
Date of testing: 1996-01-17

Spec. Mark	Maturity hours	Diameter mm	Height mm	Density kg/m³	E0 MPa	Ec MPa	Comp. strength MPa
1-2	23,6	150,5	300,6	2320	24000	24500	13,2
1-3	23,7	150,6	300,2	2320		21500	13,0
1-4	24,0	150,3	300,0	2310	23000	23000	13,0
Mean				2317	23500	23000	13,1
Standard deviation				6		1500	0,1

If the specimen was recentered E0 is not determined.

Compressive strength determined just before determination of the E-modulus:

Spec. Mark	Maturity hours	Diameter mm	Height mm	Density kg/m³	Comp. strength MPa
1-1	23,3	149,5	300,1	2312	12,3

E-modulus according to DS 423.25

Date of casting: 1996-01-16
Date of testing: 1996-01-18

Spec. Mark	Maturity hours	Dia-meter mm	Height mm	Densi-ty kg/m³	E0 MPa	Ec MPa	Comp. strength MPa
2-2	47,2	150,8	300,2	2322	26000	26300	19,9
2-3	47,5	150,4	300,2	2333	28600	28900	20,0
2-4	47,7	149,4	300,3	2315	25500	25700	19,6
Mean				2323	26700	27000	19,8
Standard deviation				9	1660	1700	0,2

If the specimen was recentered E0 is not determined.

Compressive strength determined just before determination of the E-modulus:

Spec. Mark	Maturity hours	Dia-meter mm	Height mm	Density kg/m³	Comp. strength MPa
2-1	47,1	149,8	300,1	2330	19,7

E-modulus according to DS 423.25

Date of casting: 1996-01-16
Date of testing: 1996-01-19

Spec. Mark	Maturity hours	Dia-meter mm	Height mm	Densi-ty kg/m³	E0 MPa	Ec MPa	Comp. strength MPa
3-2	71,3	150,2	299,9	2319	28500	28700	23,1
3-3	71,6	151,0	300,2	2300	27700	28100	23,0
3-4	71,9	150,3	300,4	2324	27600	27700	22,3
Mean				2314	27900	28200	22,8
Standard deviation				13	490	500	0,5

If the specimen was recentered E0 is not determined.

Compressive strength determined just before determination of the E-modulus:

Spec. Mark	Maturity hours	Dia-meter mm	Height mm	Density kg/m³	Comp. strength MPa
3-1	71,0	150,5	300,4	2317	21,9

E-modulus according to DS 423.25

Date of casting: 1996-01-16
Date of testing: 1996-01-23

Spec. Mark	Maturity hours	Dia-meter mm	Height mm	Densi-ty kg/m³	E0 MPa	Ec MPa	Comp. strength MPa
7-2	167,3	150,5	300,5	2315	30900	31500	31,5
7-3	167,7	149,7	300,5	2335	32100	32500	33,7
7-4	167,9	149,9	301,0	2326	31700	31700	30,6
Mean				2325	31600	31900	31,9
Standard deviation				10	610	530	1,6

If the specimen was recentered E0 is not determined.

Compressive strength determined just before determination of the E-modulus:

Spec. Mark	Maturity hours	Dia-meter mm	Height mm	Density kg/m³	Comp. strength MPa
7-1	167,0	150,7	300,2	2304	30,8

E-modulus according to DS 423.25

Date of casting: 1996-01-16
Date of testing: 1996-01-30

Spec. Mark	Maturity hours	Diameter mm	Height mm	Density kg/m³	E0 MPa	Ec MPa	Comp. strength MPa
14-2	337,9	150,3	300,2	2333	33400	33800	40,8
14-3	338,1	150,0	300,0	2308	32500	32400	37,4
14-4	338,5	151,3	300,1	2323	33100	33000	36,7
Mean				2321	33000	33100	38,3
Standard deviation				13	460	700	2,2

If the specimen was recentered E0 is not determined.

Compressive strength determined just before determination of the E-modulus:

Spec. Mark	Maturity hours	Diameter mm	Height mm	Density kg/m³	Comp. strength MPa
14-1	337,7	150,7	300,3	2323	39,5

E-modulus according to DS 423.25

Date of casting: 1996-01-16
Date of testing: 1996-01-13

Spec. Mark	Maturity hours	Dia-meter mm	Height mm	Densi-ty kg/m³	E0 MPa	Ec MPa	Comp. strength MPa
28-2	674,2	149,6	300,3	2325	36400	36400	44,2
28-3	674,5	150,3	300,8	2326	36100	35700	45,7
28-4	674,7	150,4	300,4	2326	35600	35500	47,3
Mean				2326	36000	35900	45,7
Standard deviation				1	400	470	1,6

If the specimen was recentered E0 is not determined.

Compressive strength determined just before determination of the E-modulus:

Spec. Mark	Maturity hours	Dia-meter mm	Height mm	Density kg/m³	Comp. strength MPa
28-1	673,9	149,4	300,2	2318	44,5

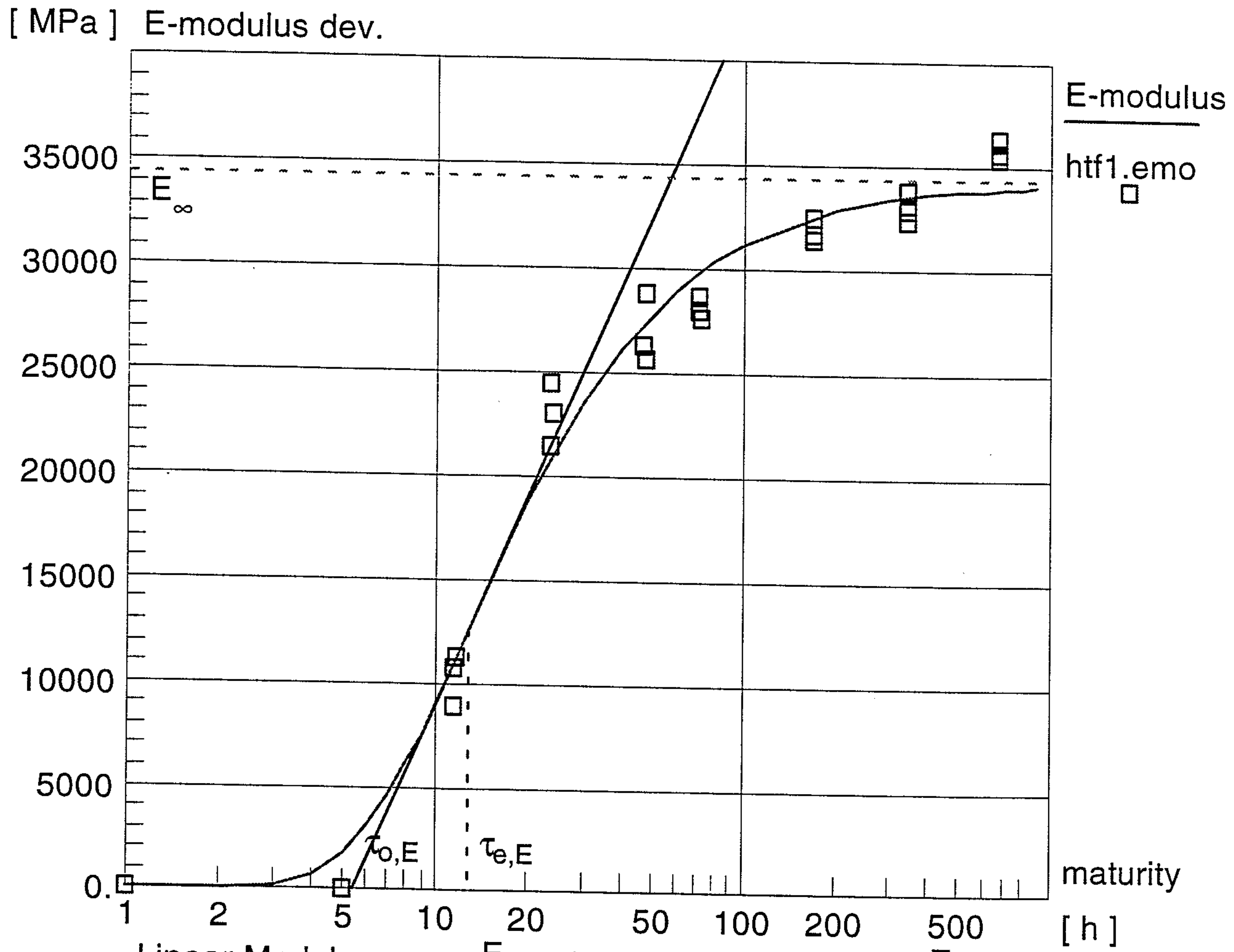
DTI Building Technology Gregersensvej, DK 2630 Taastrup	CALCULATION BASIS Documentation sheet

Client: HETEK 3 + 4 Name: Stage 1	Ref. nr.: 534534 Initials : HSP	Project: Id. nr. : VE-AA0134	Date: 02/14/96 Time: 08:52

Concrete database

Hetek fase1

E-modulus development



Linear Model: E_1 = 14522.51 $\tau_{o,E}$ = 5.4 E_o = 0.
Exponential Model: E_∞ = 34327.2 $\tau_{e,E}$ = 12.89 α_E = 1.15 E_o = 0.

Exponential Model:	Linear Model:
$E = E_o - (E_o - E_\infty) * EXP(-(\tau_{e,E}/M)^{\alpha_E})$	$E = E_o - (E_o - E_1) * LN(M/\tau_{o,E})$
E_∞ : Total	E_1 : Ordinate for $\tau_{e,E}$
$\tau_{e,E}$: Time	$\tau_{o,E}$: Intersection with axis of maturity
α_E : Cuverture	M : Maturity time
M : Maturity time	E_o : Start/Fresh
E_o : Start/Fresh	

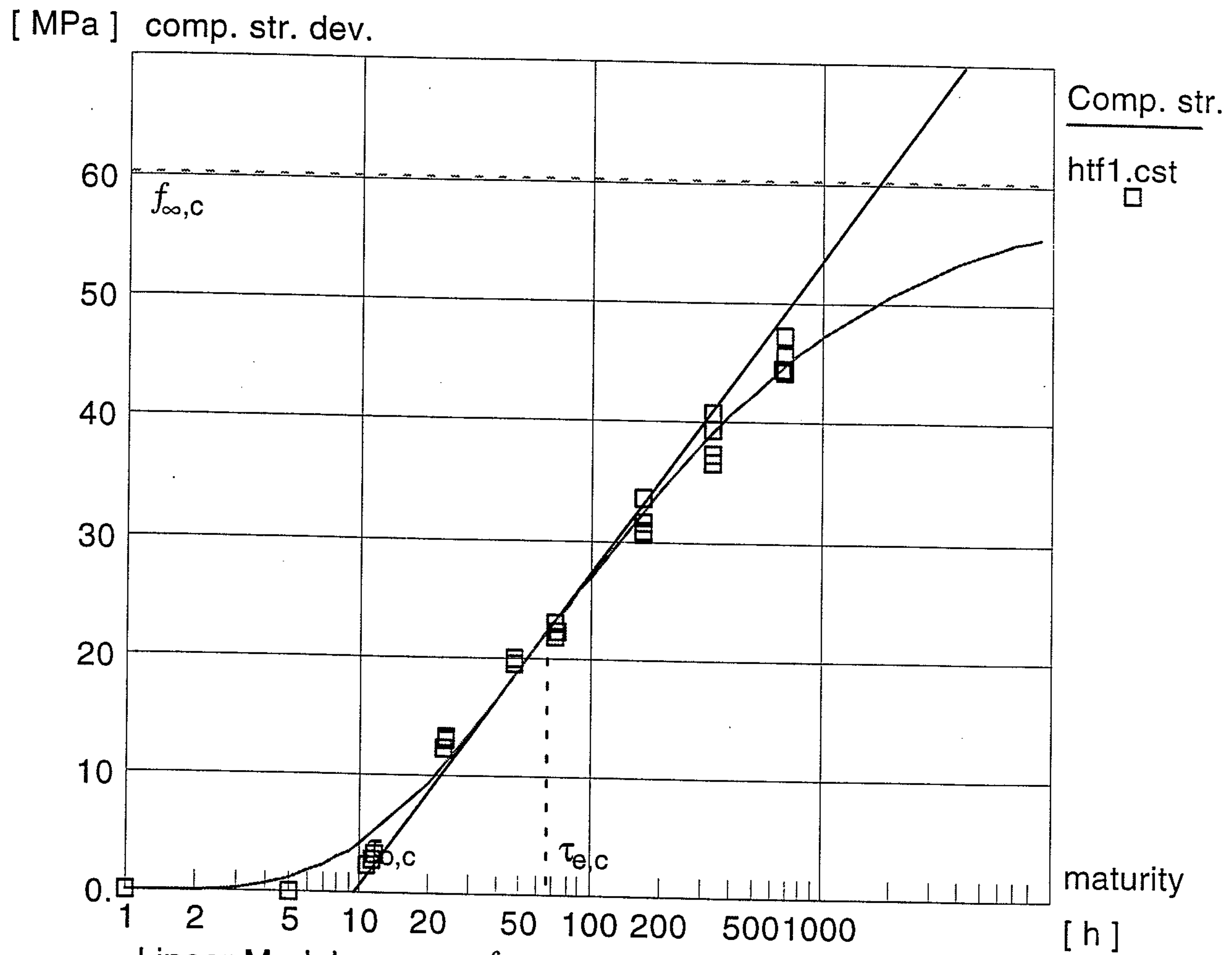
DTI Building Technology Gregersensvej, DK 2630 Taastrup	CALCULATION BASIS Documentation sheet

Client: HETEK 3 + 4 Name: Stage 1	Ref. nr.: 534534 Initials : HSP	Project: Id. nr. : VE-AA0134	Date: 02/14/96 Time: 08:53

Concrete database

Hetek fase1

Compressive strength development



Linear Model: f_1 = 11.5 $\tau_{o,c}$ = 9.55 f_o = 0.
Exponential Model: $f_{\infty,c}$= 60.1 $\tau_{e,c}$ = 65.34 α_c = 0.52 f_o = 0.

Exponential Model:

$f = f_o - (f_o - f_{\infty,c})*EXP(-(\tau_{e,c} / M)^{\alpha_c})$

$f_{\infty,c}$: Total

$\tau_{e,c}$: Time

α_c : Cuverture

M : Maturity time

f_o : Start/Fresh

Linear Model:

$f = f_o - (f_o - f_1)*LN(M/\tau_{o,c})$

f_1 : Ordinate for $\tau_{e,c}$

$\tau_{o,c}$: Intersection with axis of maturity

M : Maturity time

f_o : Start/Fresh

APPENDIX 5

Splitting Tensile Strength Development

HETEK
Subtask 3 + 4
Stage 1
DTI Byggeri

Report no. : 53453-4
Date : 1996-02-13

Appendix : 1

Test report

Objektive

Determination of splitting tensile strength development.

Client : HETEK
Sampler : The specimens was casted by DTI with concrete delivered by 4k-Beton København
Delivery note: Delivery note no. 966100364

Specimens

Type : casted concrete cylinders D150 x h300 mm.
Designation : 6001
Casting : 1996-01-16

The maturity of the specimens was estimated to be 3.8 h at 96-01-16 - 14:30.

Test Method bestemmelser

DS 423.34 (January 1985): Testing of Concrete - Tensile strength deduced from splitting test on cylindrical specimens.

The tests departs from the methods at early ages (1/2, 1, 2 and 3 days), as the load rate used was 0.018 MPa/s.

Test Results

The results of the tests are shown at page 2-9. The splitting tensile strength development is shown in appendix 1.

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Splitting Tensile Strength according to DS 423.34 - Main Results

Time days	Specimen	Maturity (hours)	Split. tens. strength (MPa)
0	0-1 0-2 0-3	11,8 11,9 12,0	0,38 0,44 0,47
mean		11,9	0,43
1	1-1 1-2 1-3	24,5 24,6 24,6	1,30 1,30 1,14
mean		24,6	1,25
2	2-1 2-2 2-3	47,9 48,0 48,1	1,93 1,94 1,75
mean		48,0	1,87
3	3-1 3-2 3-3	72,5 72,4 72,6	2,19 2,59 2,36
mean		72,5	2,38
7	7-1 7-2 7-3	168,1 168,1 168,3	2,59 2,78 2,40
mean		168,2	2,59
14	14-1 14-2 14-3	338,6 338,7 338,8	3,38 3,41 3,16
mean		338,7	3,32
28	28-1 28-2 28-3	674,9 675,0 675,1	3,74 3,39 3,13
mean		675,0	3,42

Splitting Tensile Strength according to DS 423.34

Date of casting: 1996-01-16
Date of testing: 1996-01-16

Spec. Mark	Maturity hours	Dia-meter mm	Heigth mm	Densi-ty kg/m³	Fail. load kN	Split. tens. strength MPa
0-1	11,8	149,5	300,3	2324	27,1	0,38
0-2	11,9	149,6	300,2	2319	30,7	0,44
0-3	12,0	150,1	300,6	2324	33,4	0,47
Mean				2322	30,4	0,43
Standard deviation				3	3,2	0,05

Splitting Tensile Strength according to DS 423.34

Date of casting: 1996-01-16
Date of testing: 1996-01-17

Spec. Mark	Maturity hours	Dia-meter mm	Heigth mm	Densi-ty kg/m³	Fail. load kN	Split. tens. strength MPa
1-1	24,5	150,3	300,2	2304	92,1	1,30
1-2	24,6	149,8	300,3	2315	92,0	1,30
1-3	24,6	149,7	301,2	2326	81,0	1,14
Mean				2315	88,4	1,25
Standard deviation				11	6,4	0,09

The failure mode of spec. 1-3 was not a perfectly splitting fracture.

Splitting Tensile Strength according to DS 423.34

Date of casting: 1996-01-16
Date of testing: 1996-01-18

Spec. Mark	Maturity hours	Diameter mm	Heigth mm	Density kg/m^3	Fail. load kN	Split. tens. strength MPa
2-1	47,9	150,2	299,8	2304	136,3	1,93
2-2	48,0	149,8	300,1	2318	137,3	1,94
2-3	48,1	150,0	300,2	2294	123,6	1,75
Mean				2305	132,4	1,87
Standard deviation				12	7,6	0,11

Splitting Tensile Strength according to DS 423.34

Date of casting: 1996-01-16
Date of testing: 1996-01-19

Spec. Mark	Maturity hours	Dia-meter mm	Heigth mm	Densi-ty kg/m³	Fail. load kN	Split. tens. strength MPa
3-1	72,5	150,4	300,0	2313	155,3	2,19
3-2	72,4	150,1	300,2	2309	183,5	2,59
3-3	72,6	150,3	300,4	2316	167,7	2,36
Mean				2313	168,8	2,38
Standard deviation				4	14,1	0,20

Splitting Tensile Strength according to DS 423.34

Date of casting: 1996-01-16
Date of testing: 1996-01-23

Spec. Mark	Maturity hours	Dia-meter mm	Heigth mm	Densi-ty kg/m³	Fail. load kN	Split. tens. strength MPa
7-1	168,1	150,1	301,0	2314	183,7	2,59
7-2	168,1	151,4	298,9	2306	197,7	2,78
7-3	168,3	150,2	300,4	2320	170,1	2,40
Mean				2313	183,8	2,59
Standard deviation				7	13,8	0,19

Splitting Tensile Strength according to DS 423.34

Date of casting: 1996-01-16
Date of testing: 1996-01-30

Spec. Mark	Maturity hours	Dia-meter mm	Heigth mm	Densi-ty kg/m³	Fail. load kN	Split. tens. strength MPa
14-1 14-2 14-3	338,6 338,7 338,8	149,8 149,7 150,5	300,8 299,8 300,5	2312 2345 2316	239,4 240,3 224,7	3,38 3,41 3,16
Mean Standard deviation				2324 18	234,8 8,8	3,32 0,14

Splitting Tensile Strength according to DS 423.34

Date of casting: 1996-01-16
Date of testing: 1996-02-13

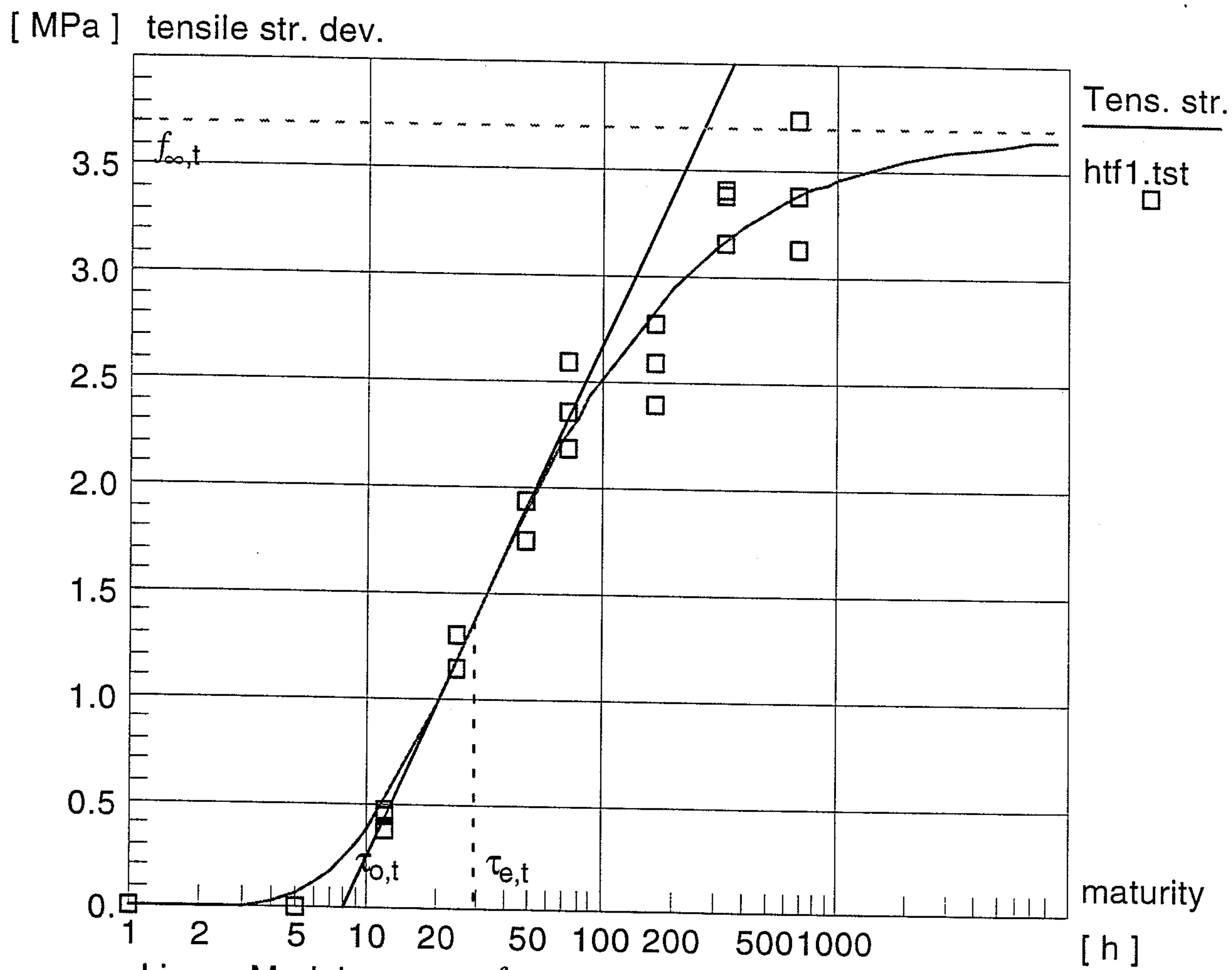
Spec. Mark	Maturity hours	Dia-meter mm	Heigth mm	Densi-ty kg/m³	Fail. load kN	Split. tens. strength MPa
28-1 28-2 28-3	674,9 675,0 675,1	150,0 149,9 150,0	300,7 300,3 300,1	2320 2306 2321	265,2 240,0 221,2	3,74 3,39 3,13
Mean Standard deviation				2316 8	242,1 22,1	3,42 0,31

DTI Building Technology Gregersensvej, DK 2630 Taastrup	CALCULATION BASIS Documentation sheet		
Client: HETEK 3 + 4 Name: Stage 1	Ref. nr.: 534534 Initials : HSP	Project: Id. nr. : VE-AA0134	Date: 02/14/96 Time: 08:53

Concrete database

Hetek fase1

Tensile strength development



Linear Model: f_1 = 1.05 $\tau_{o,t}$ = 7.97 f_o = 0.

Exponential Model: $f_{\infty,t}$ = 3.7 $\tau_{e,t}$ = 29.22 α_t = 0.77 f_o = 0.

Exponential Model:

$$f = f_o - (f_o - f_{\infty,t}) * EXP(-(\tau_{e,t} / M)^{\alpha_t})$$

$f_{\infty,t}$: Total

$\tau_{e,t}$: Time

α_t : Cuverture

M : Maturity time

f_o : Start/Fresh

Linear Model:

$$f = f_o - (f_o - f_1) * LN(M / \tau_{o,t})$$

f_1 : Ordinate for $\tau_{e,t}$

$\tau_{o,t}$: Intersection with axis of maturity

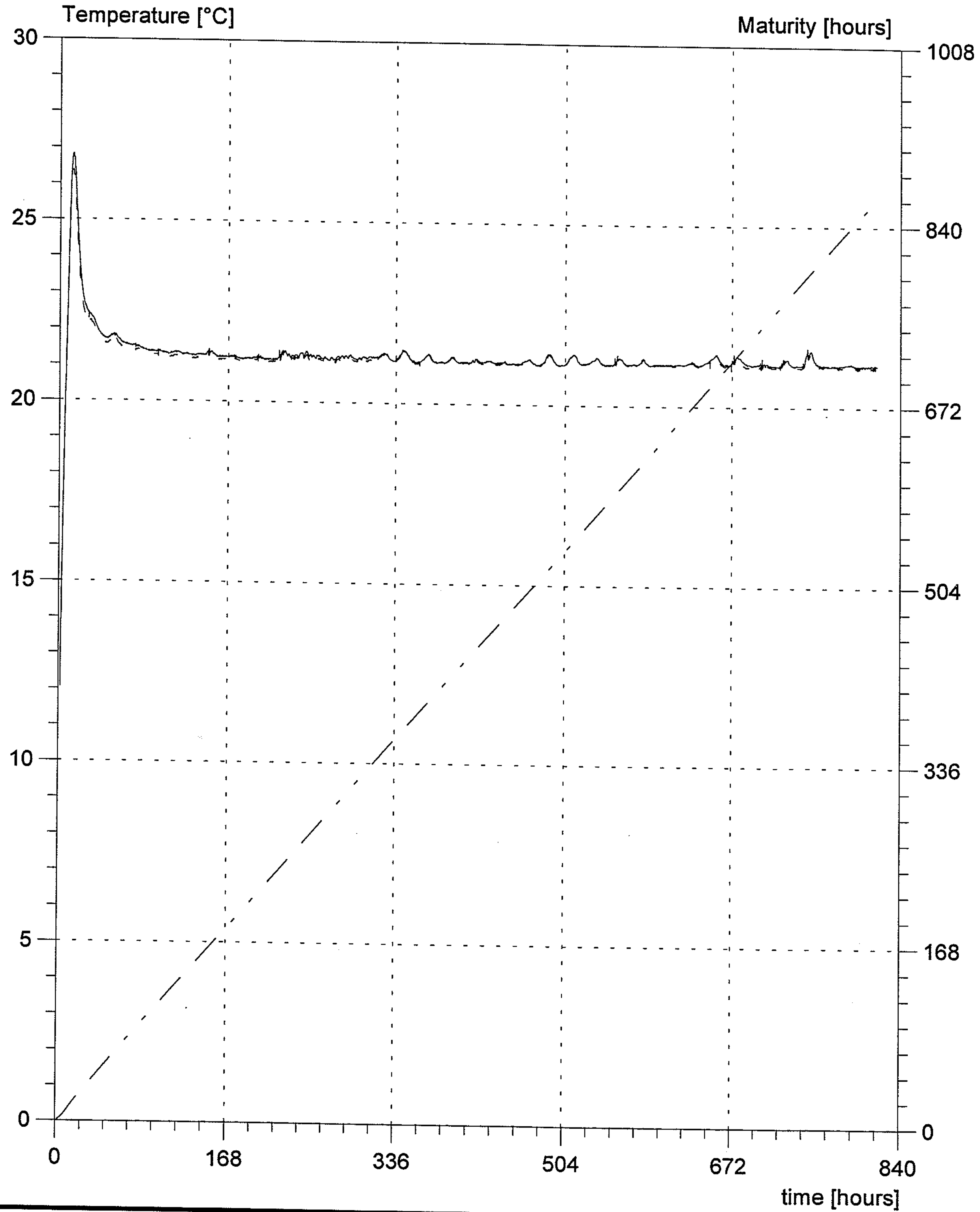
M : Maturity time

f_o : Start/Fresh

APPENDIX 6

Temperatures

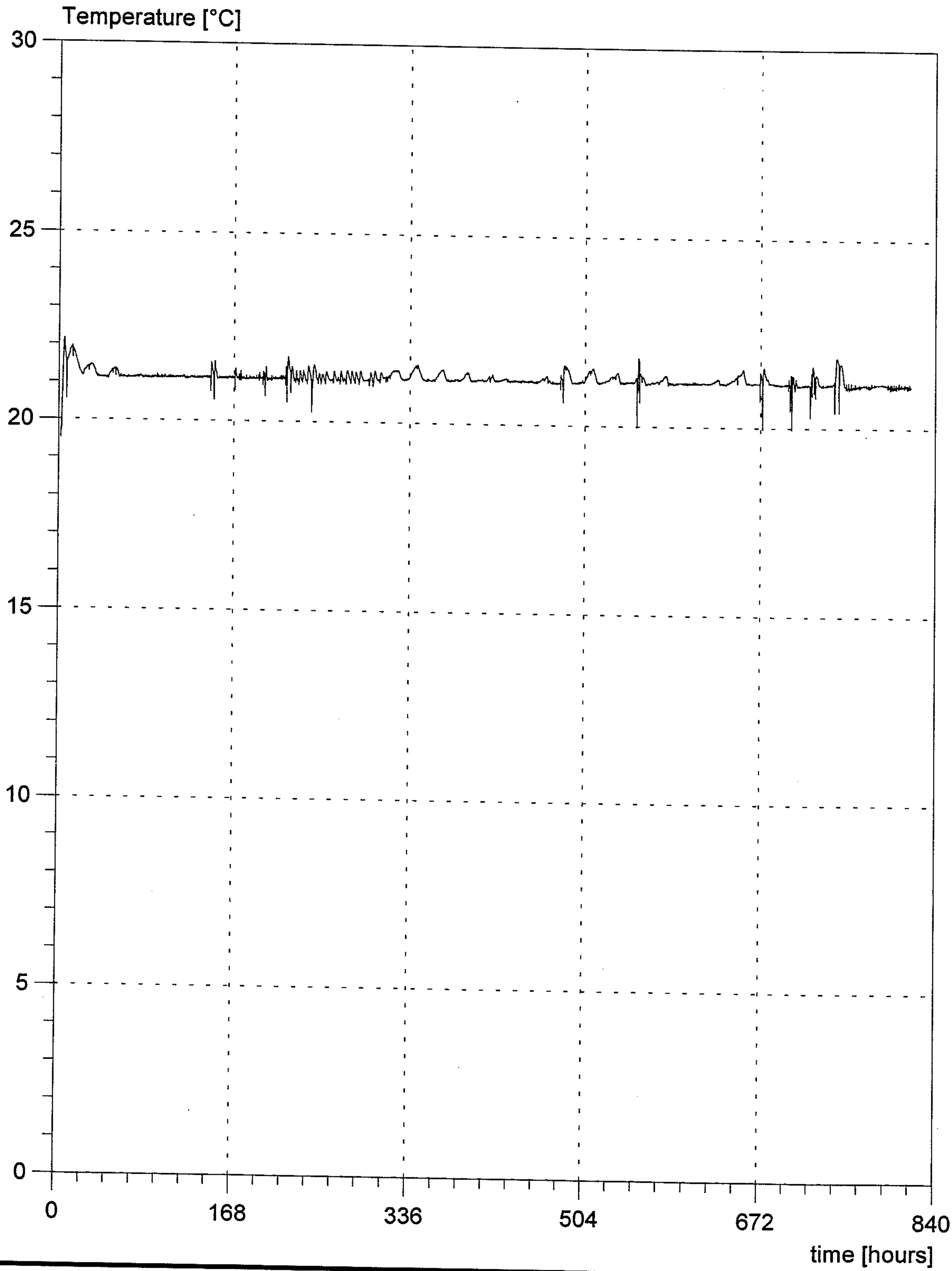
DTI Building Technology Gregersensvej, 2630 Taastrup	Temperature and maturity as func. of time
Client: HETEK 3 + 4 Name: Stage 1	Ref.: 53453 Init.: HSP Date: 03/15/96



t = 0 at time of mixing	– – – concrete temp. - spec. 2 —— concrete temp. - spec. 5 — — maturity

DTI Building Technology Gregersensvej, 2630 Taastrup	Air Temperature as func. of time

Client: HETEK 3 + 4 Name: Stage 1	Ref.: 53453 Date: 03/15/96	Init.: HSP



t = 0 at time of mixing

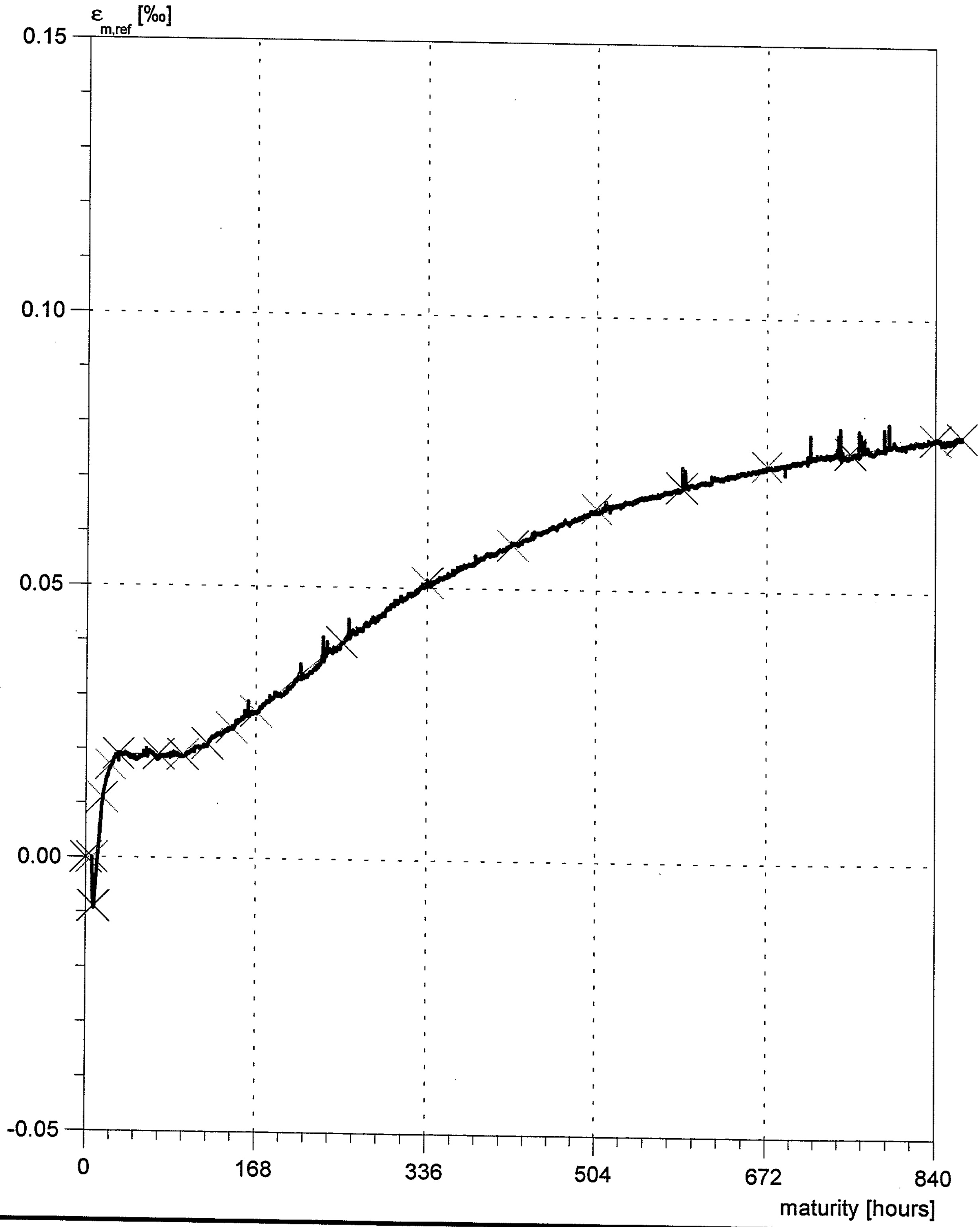
air temp.

APPENDIX 7

Shrinkage

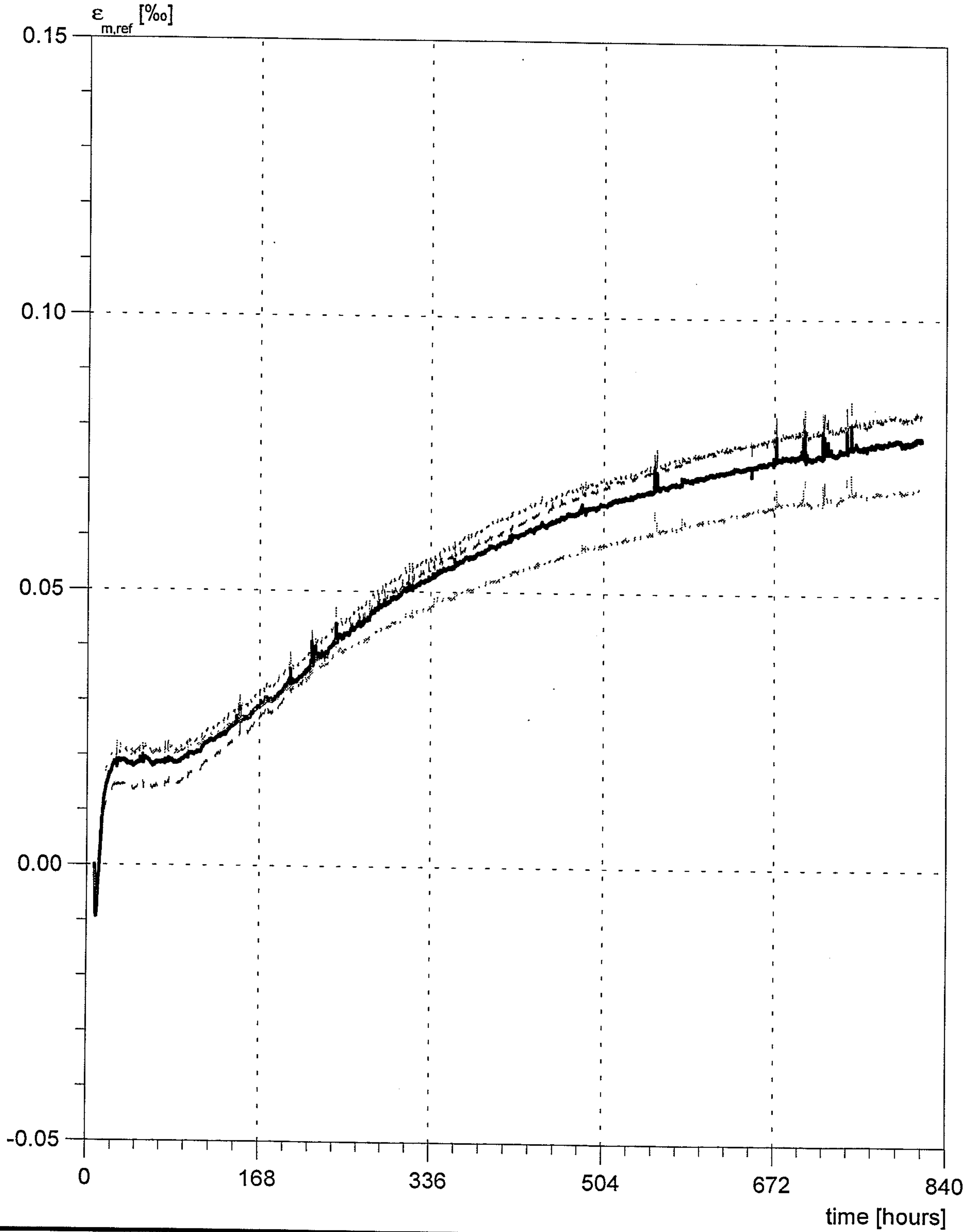
DTI Building Technology Gregersensvej, 2630 Taastrup	Strain due to shrinkage as func. of maturity

Client: HETEK 3 + 4 Name: Stage 1	Ref.: 53453 Date: 03/18/96	Init.: HSP



M = 0 at time of mixing	mean shrinkage idealised shrinkage

DTI Building Technology Gregersensvej, 2630 Taastrup	Strain due to shrinkage spec. 4, 5 og 6
Client: HETEK 3 + 4 Name: Stage 1	Ref.: 53453 Init.: HSP Date: 03/15/96

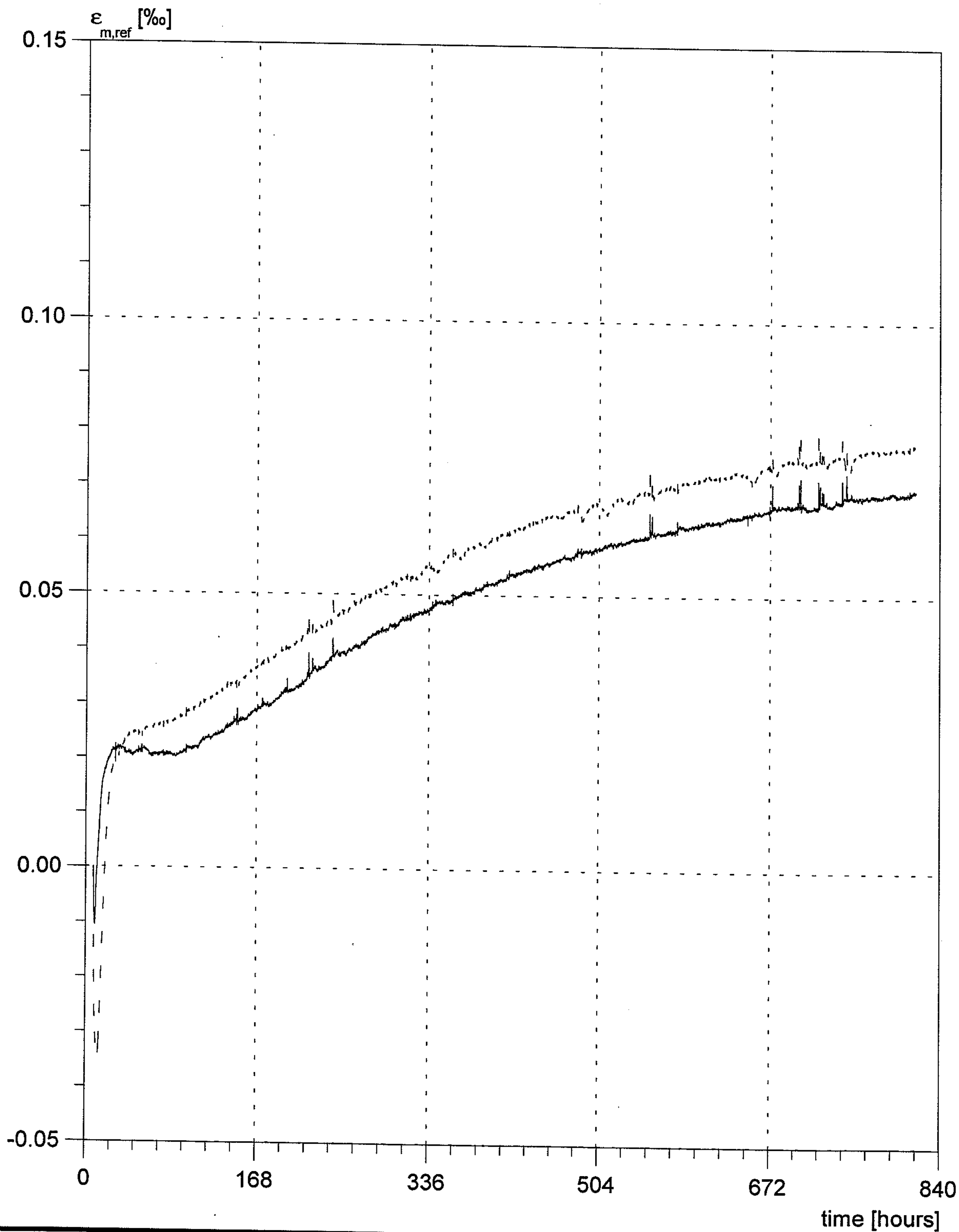


t = 0 at mixing time

spec. 4
spec. 5
spec. 6
mean

DTI Building Technology Gregersensvej, 2630 Taastrup	Strain due to shrinkage spec. 4

Client: HETEK 3 + 4 Name: Stage 1	Ref.: 53453 Date: 03/15/96	Init.: HSP

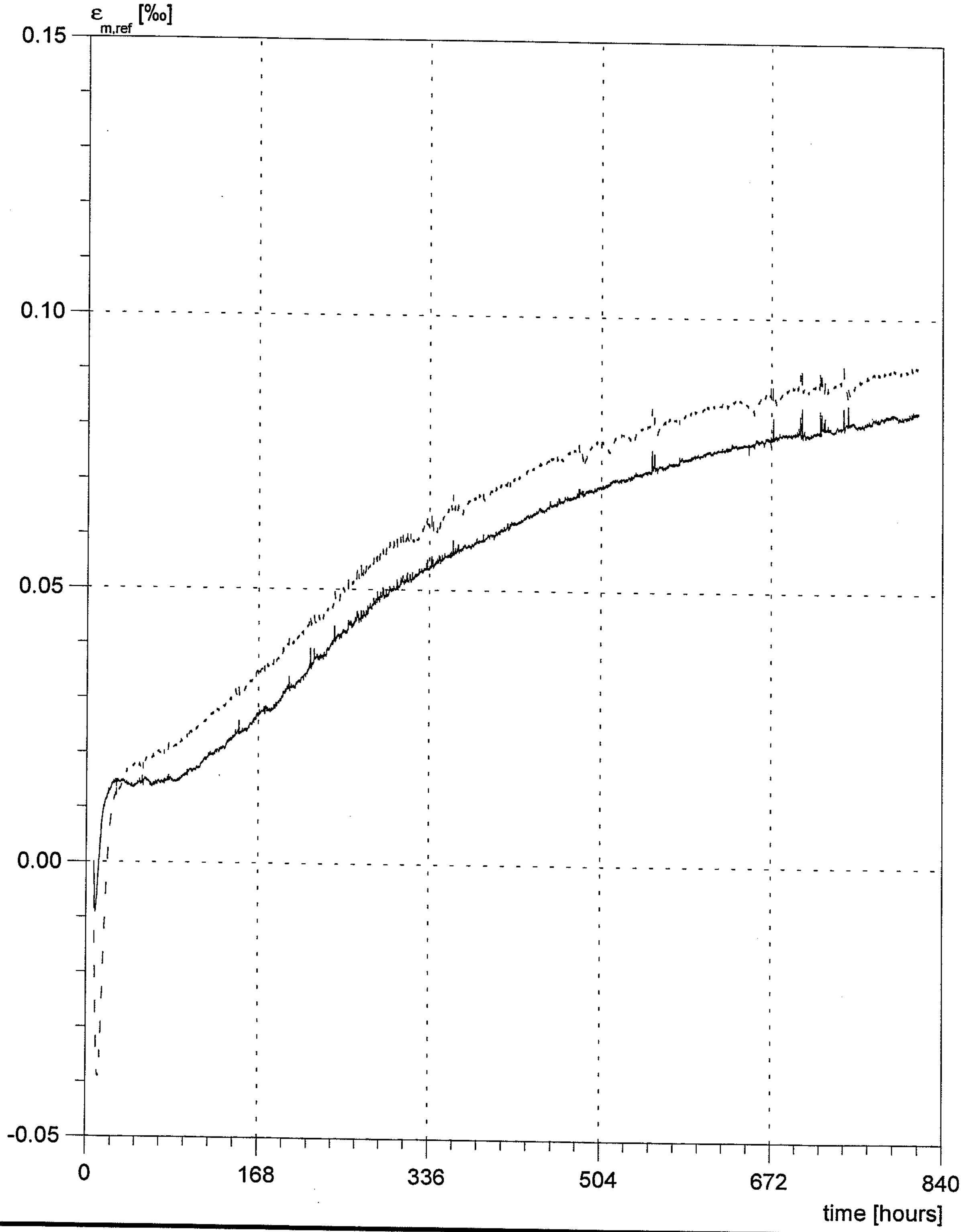


t = 0 at time of mixing

– – – mean strain in concrete

——— mean shrinkage

DTI Building Technology Gregersensvej, 2630 Taastrup	Strain due to shrinkage spec. 5
Client: HETEK 3 + 4 Name: Stage 1	Ref.: 53453 Init.: HSP Date: 03/15/96



t = 0 at time of mixing

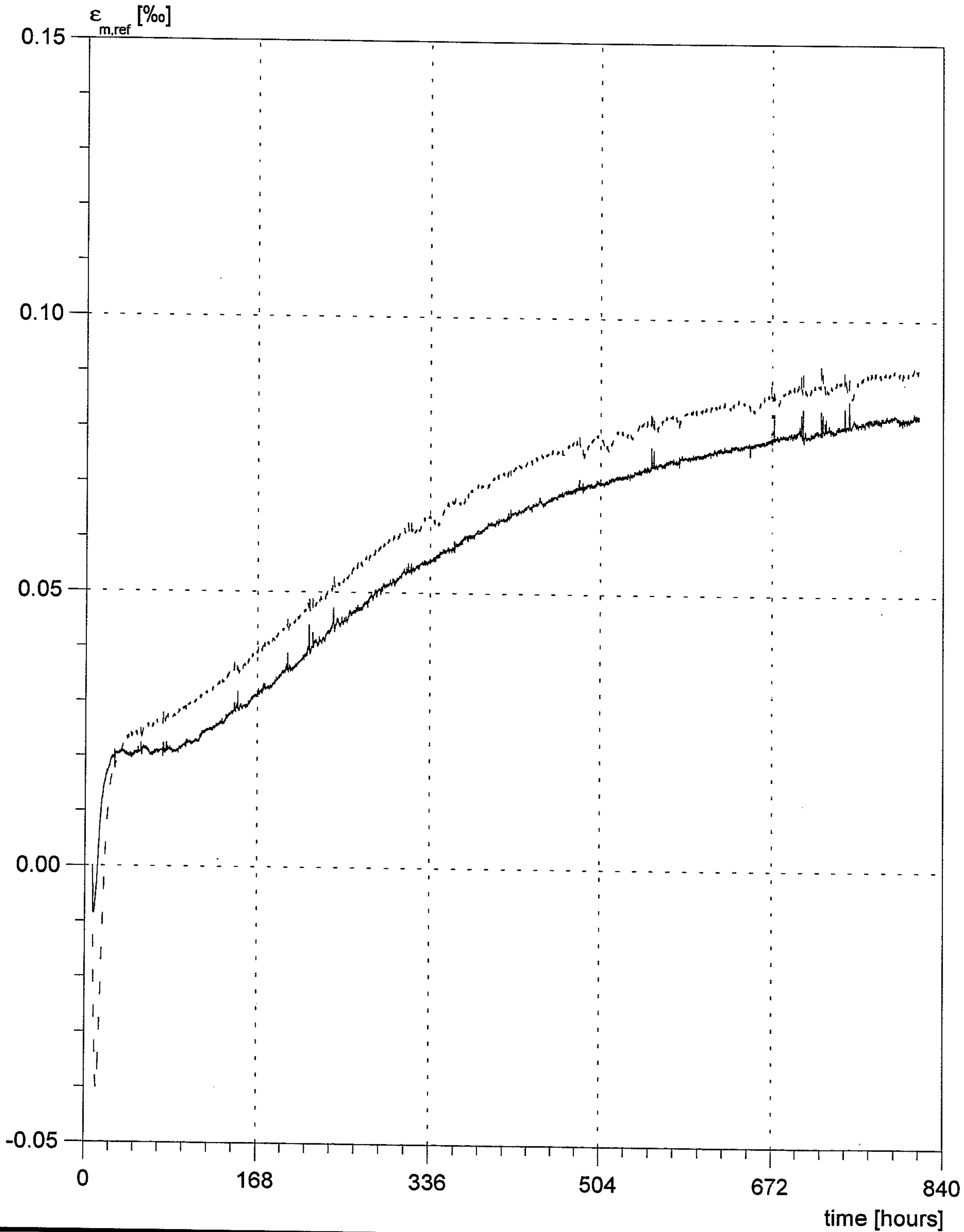
- - - mean strain in concrete

——— mean shrinkage

DTI Building Technology Gregersensvej, 2630 Taastrup	Strain due to shrinkage spec. 6

Client: HETEK 3 + 4
Name: Stage 1

Ref.: 53453
Date: 03/15/96
Init.: HSP



t = 0 at time of mixing

- - - mean strain in concrete
—— mean shrinkage

APPENDIX 8

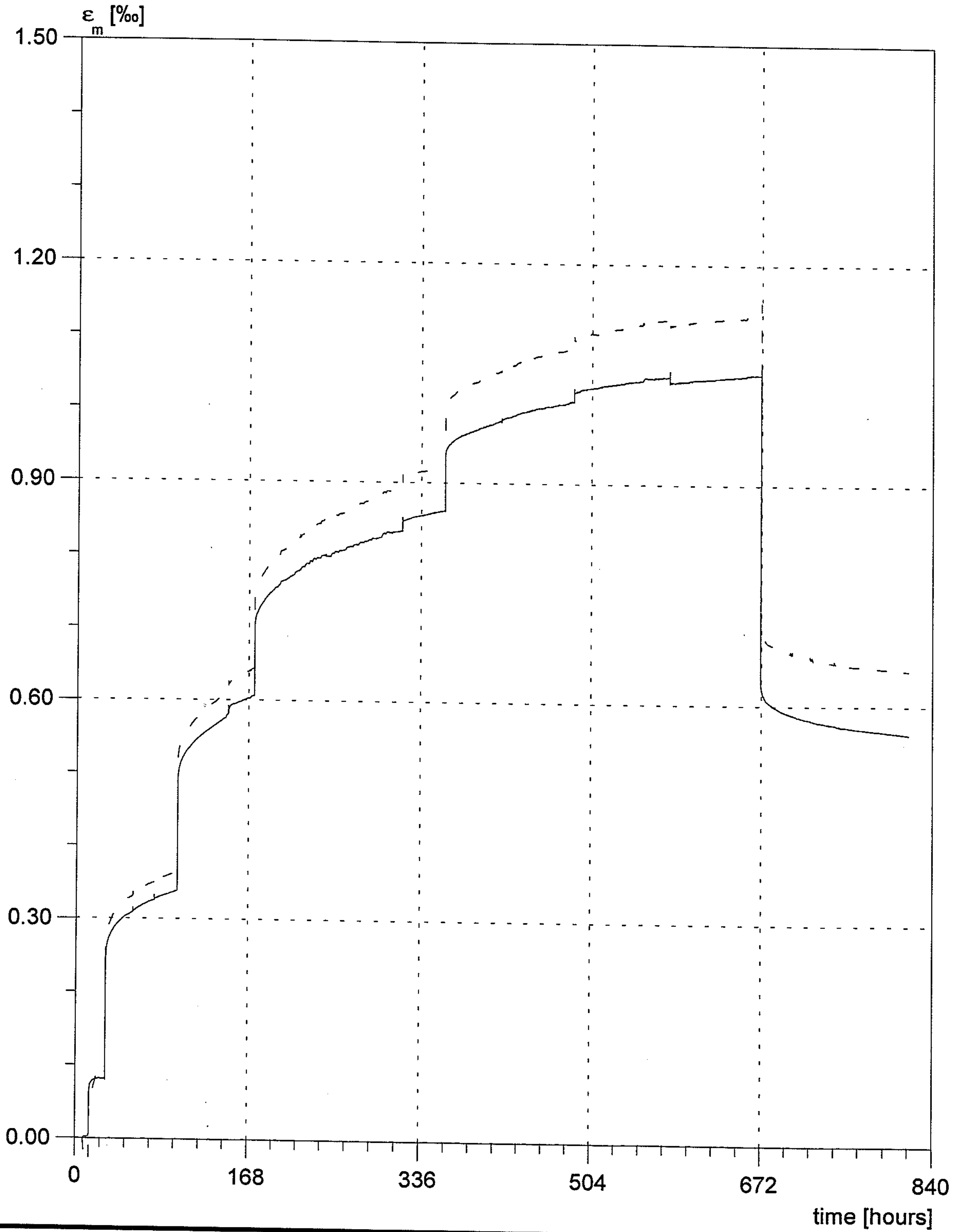
Strains in loaded specimens

DTI Building Technology Gregersensvej, 2630 Taastrup	Strain in concrete and due to external load spec. 1

Client: HETEK 3 + 4
Name: Stage 1

Ref.: 53453
Date: 03/15/96

Init.: HSP



t = 0 at time of mixing

— — — measured strain in concrete

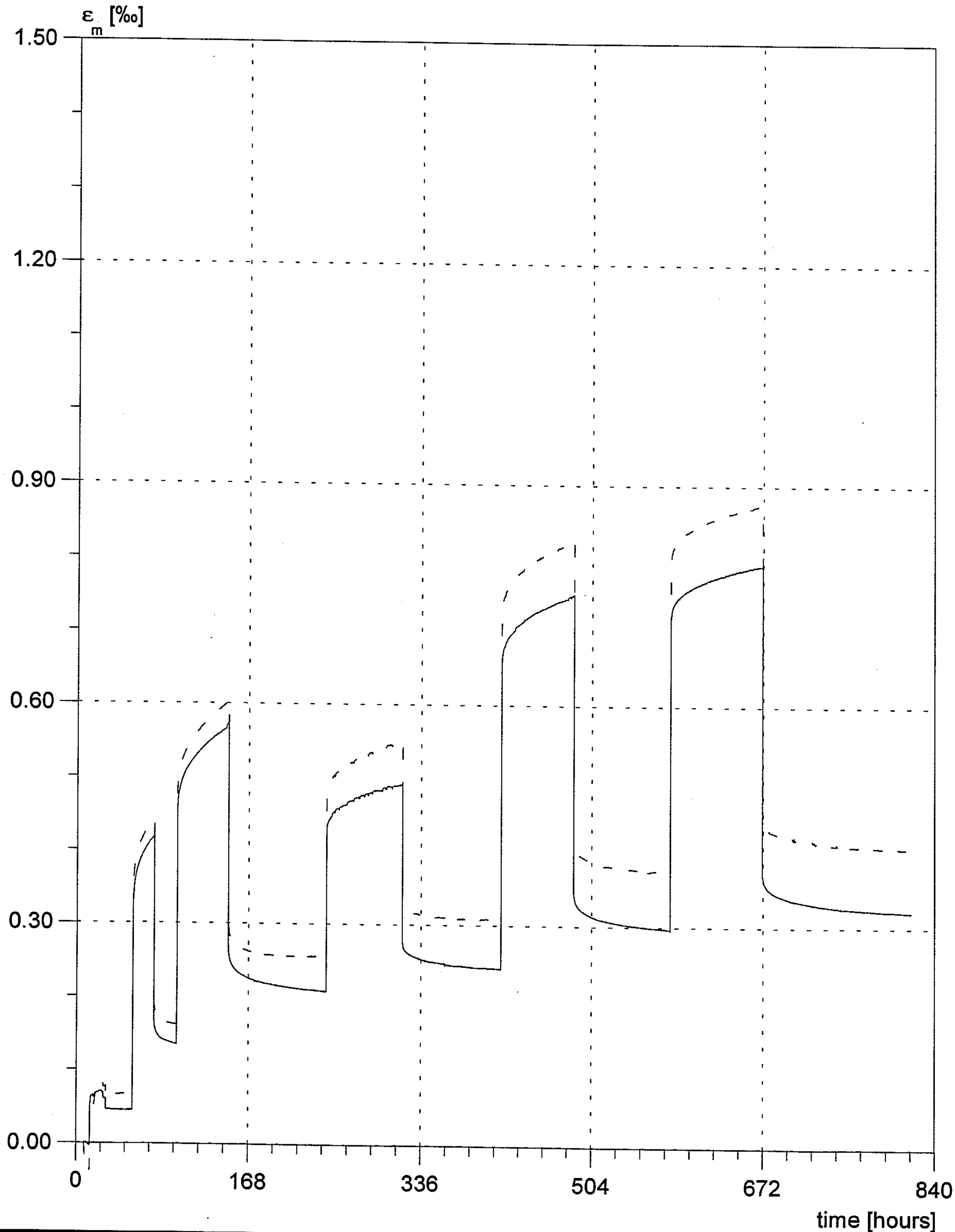
——— strain due to external load

DTI Building Technology Gregersensvej, 2630 Taastrup	**Strain in concrete and due to external load** spec. 2

Client: HETEK 3 + 4
Name: Stage 1

Ref.: 53453
Date: 03/15/96

Init.: HSP

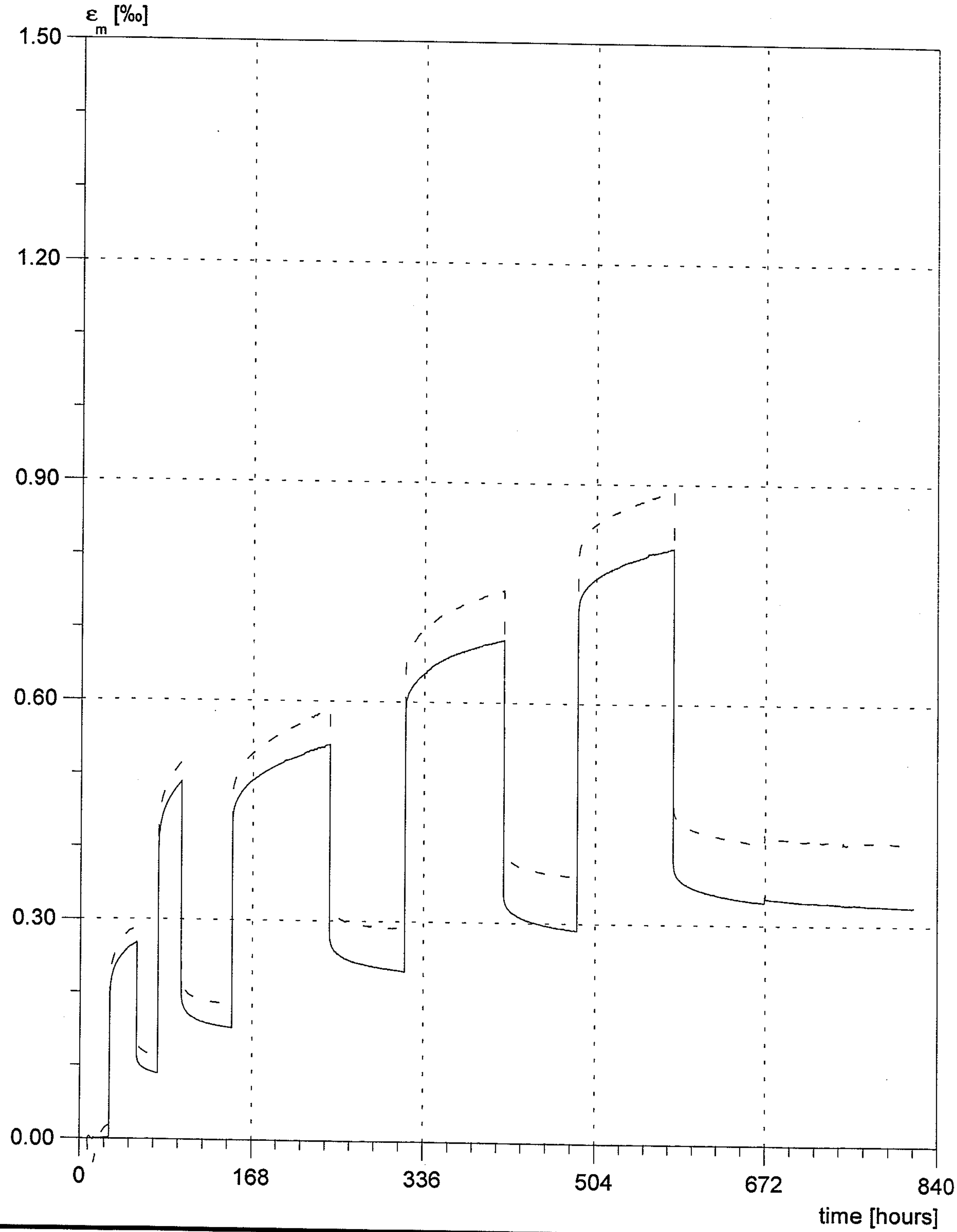


t = 0 at time of mixing

- - - measured strain in concrete

——— strain due to external load

DTI Building Technology Gregersensvej, 2630 Taastrup	Strain in concrete and due to external load spec. 3
Client: HETEK 3 + 4 Name: Stage 1	Ref.: 53453 Init.: HSP Date: 03/15/96



t = 0 at time of mixing

– – – measured strain in concrete

——— strain due to external load

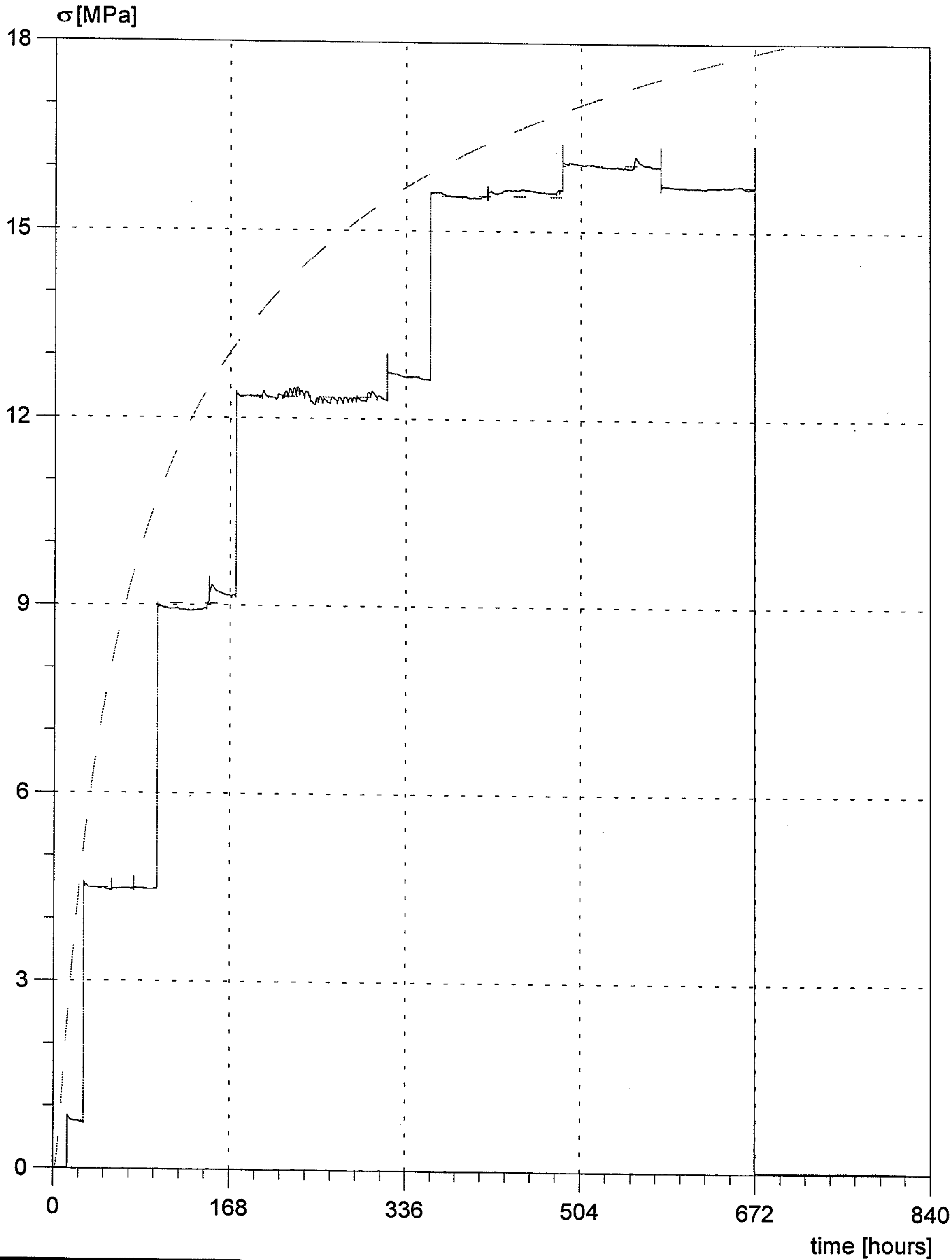
APPENDIX 9

Load Histories

DTI Building Technology Gregersensvej, 2630 Taastrup	Load history spec. 1

Client: HETEK 3 + 4
Name: Stage 1

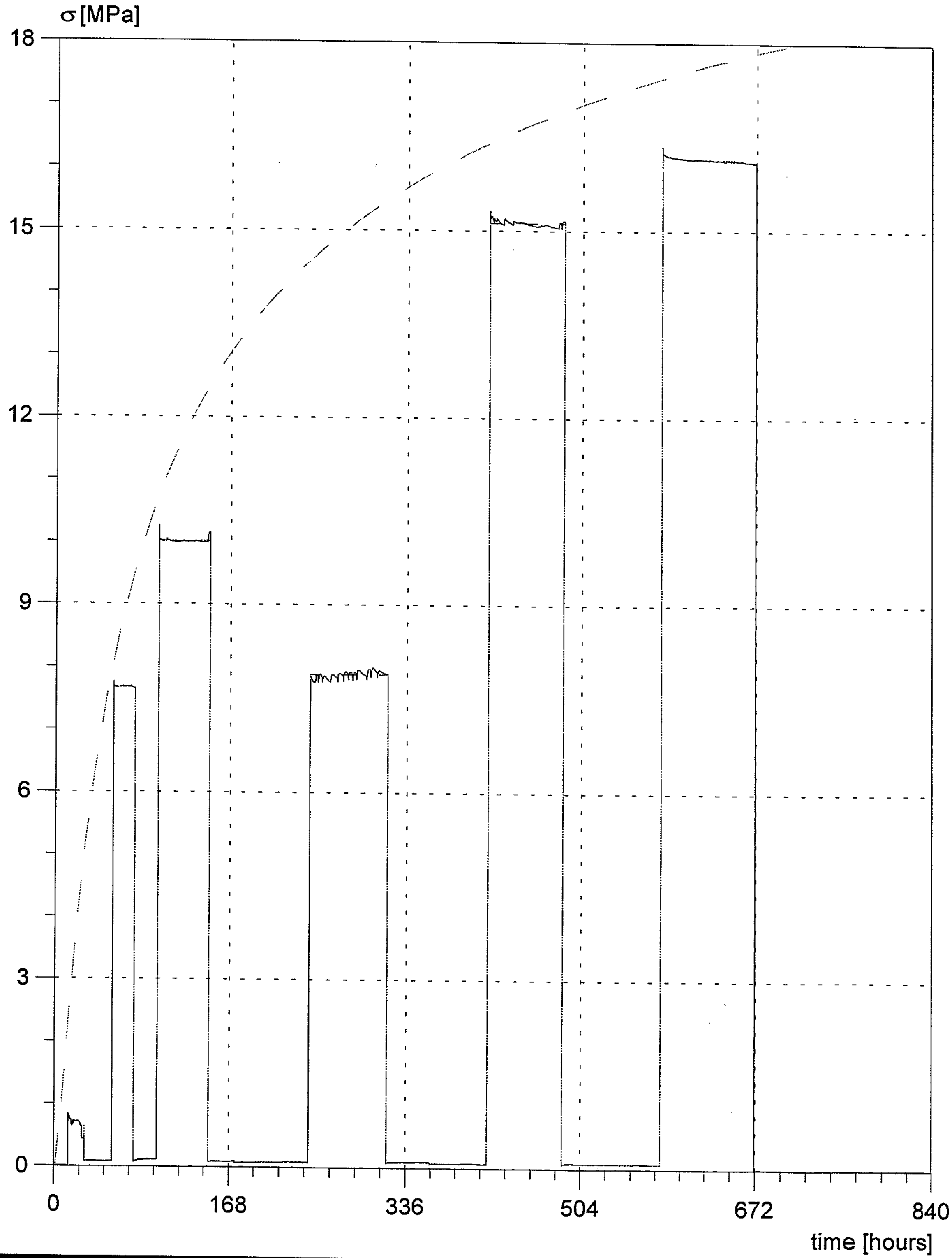
Ref.: 53453
Date: 03/15/96
Init.: HSP



t = 0 at time of mixing

- – – load - idealised
- —— load - measured
- – – 40 % comp. strength

DTI Building Technology Gregersensvej, 2630 Taastrup	Load history spec. 2	
Client: HETEK 3 + 4 Name: Stage 1	Ref.: 53453 Date: 04/11/96	Init.: HSP



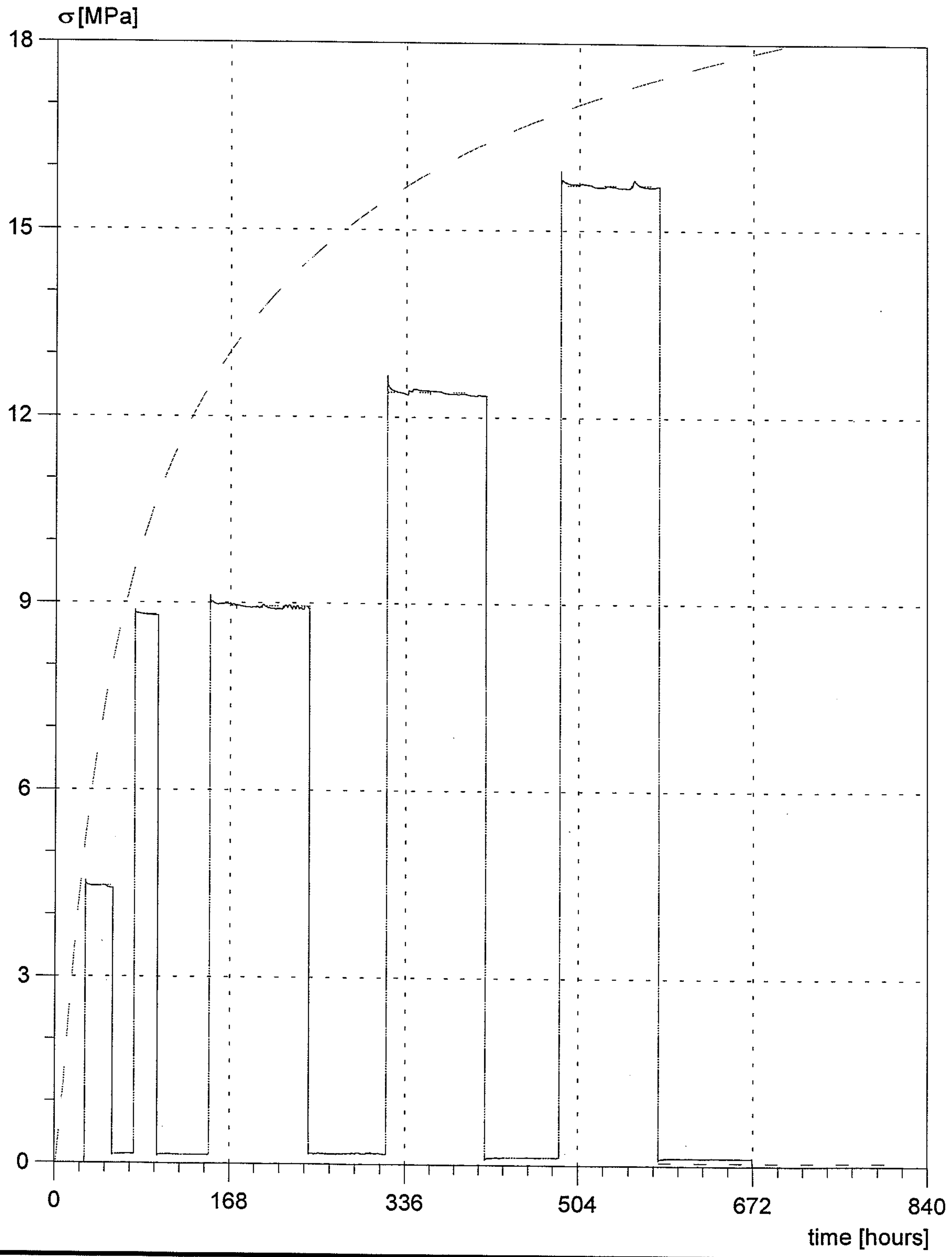
t = 0 at time of mixing

- - - load - idealised

—— load - measured

······ 40 % of comp. strength

DTI Building Technology Gregersensvej, 2630 Taastrup	Load history spec. 3
Client: HETEK 3 + 4 Name: Stage 1	Ref.: 53453 Init.: HSP Date: 04/11/96



t = 0 at time of mixing

load - idealised

load - measured

40 % of comp. strength

APPENDIX 10

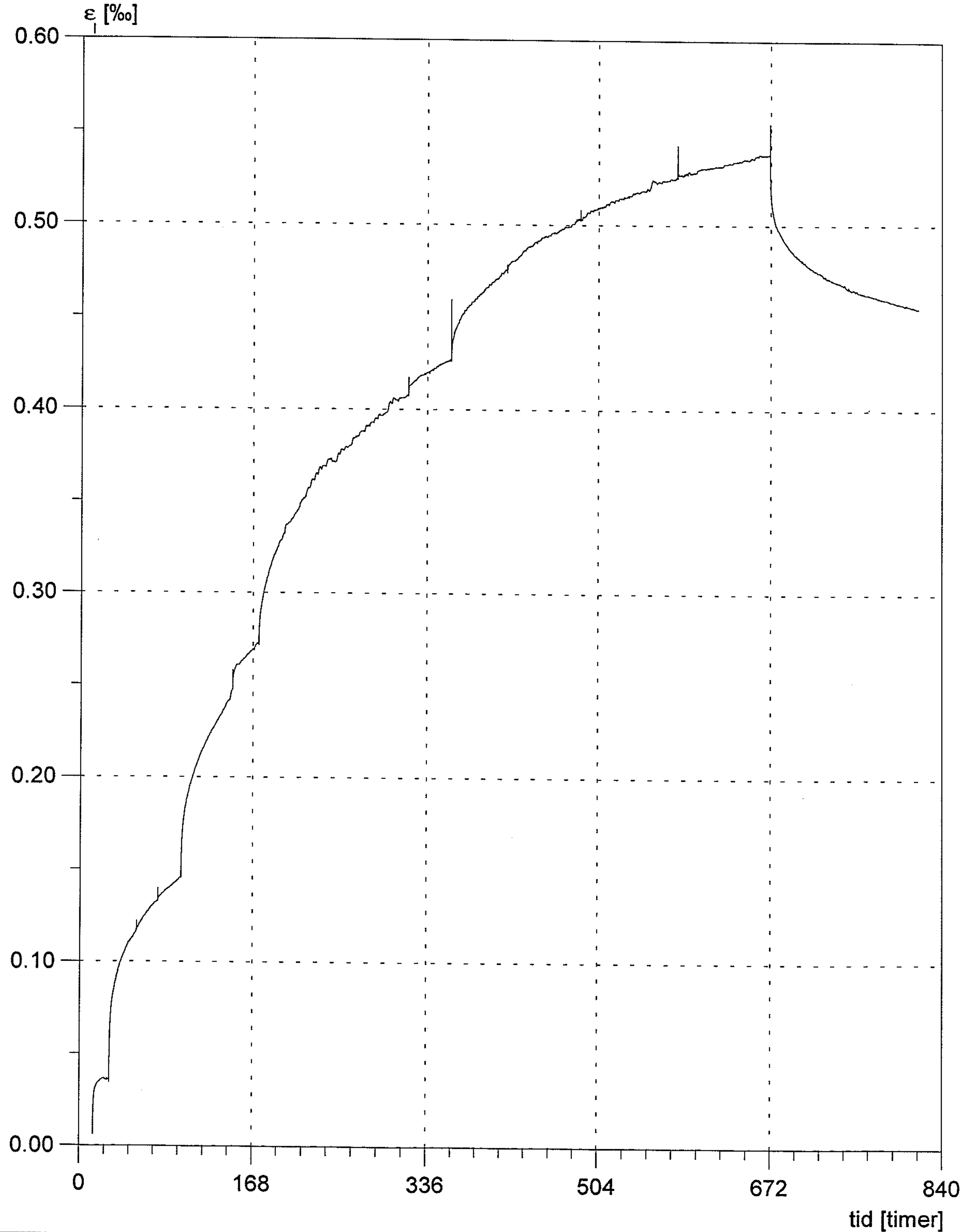
Creep Strains

DTI Building Technology Gregersensvej, 2630 Taastrup	Creep Strain spec. 1

Client: HETEK 3 + 4
Name: Stage 1

Ref.: 53453
Date: 04/12/96

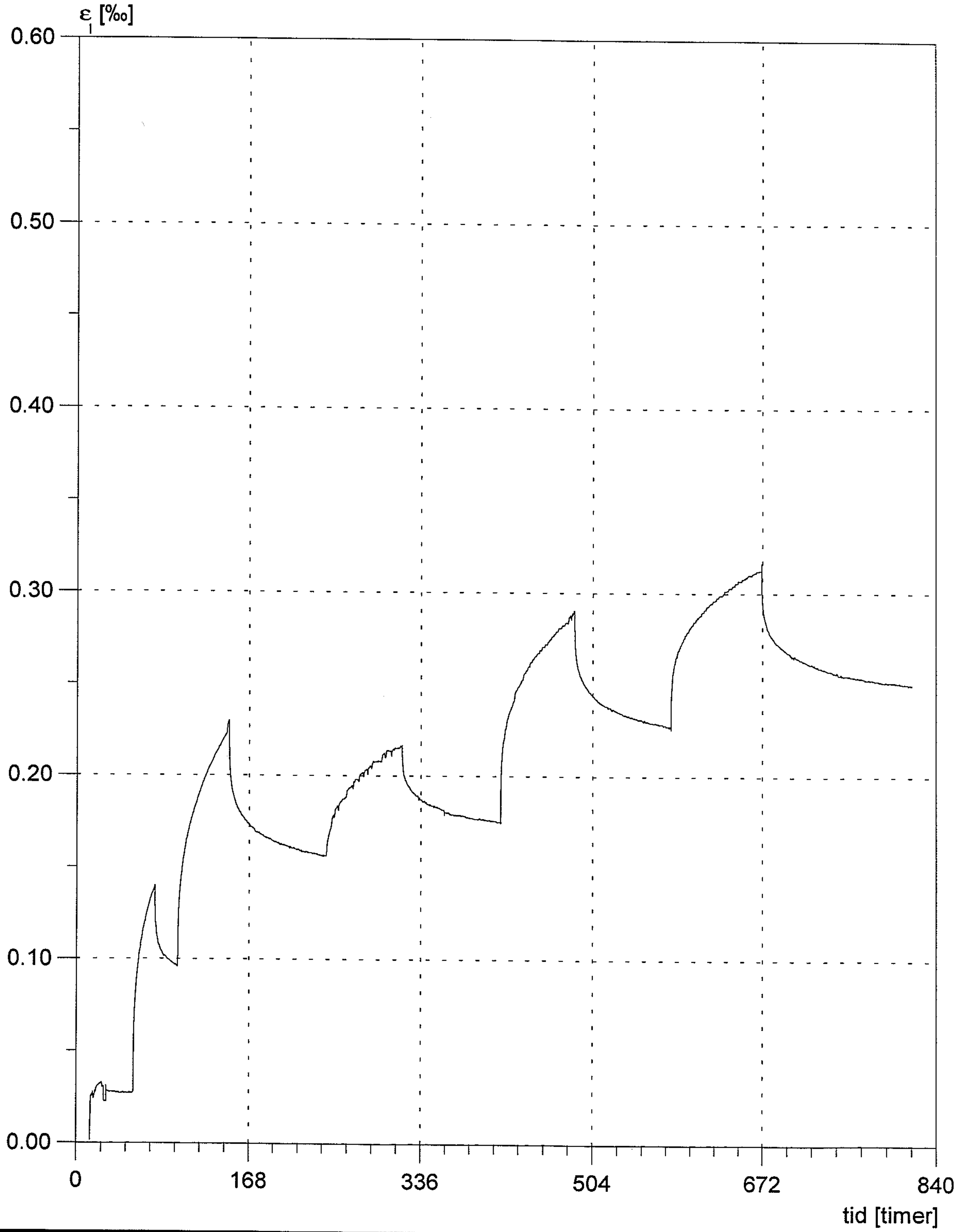
Init.: HSP



t = 0 at time of mixing

creepstrain

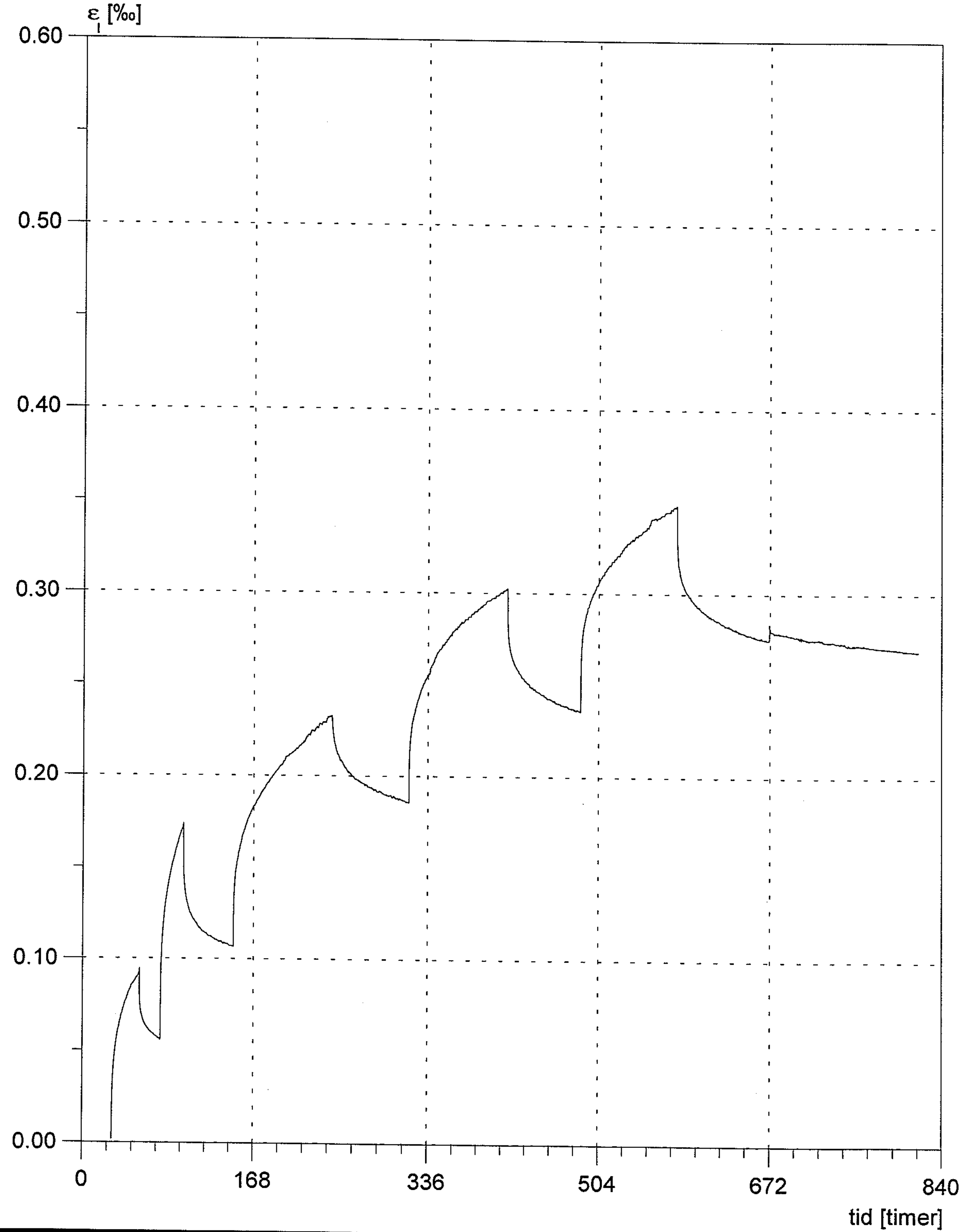
DTI Building Technology Gregersensvej, 2630 Taastrup	Creep Strain spec. 2
Client: HETEK 3 + 4 Name: Stage 1	Ref.: 53453 Init.: HSP Date: 04/12/96



t = 0 at time of mixing

creepstrain

DTI Building Technology Gregersensvej, 2630 Taastrup	Creep Strain spec. 3	
Client: HETEK 3 + 4 Name: Stage 1	Ref.: 53453 Date: 04/12/96	Init.: HSP



t = 0 at time of mixing

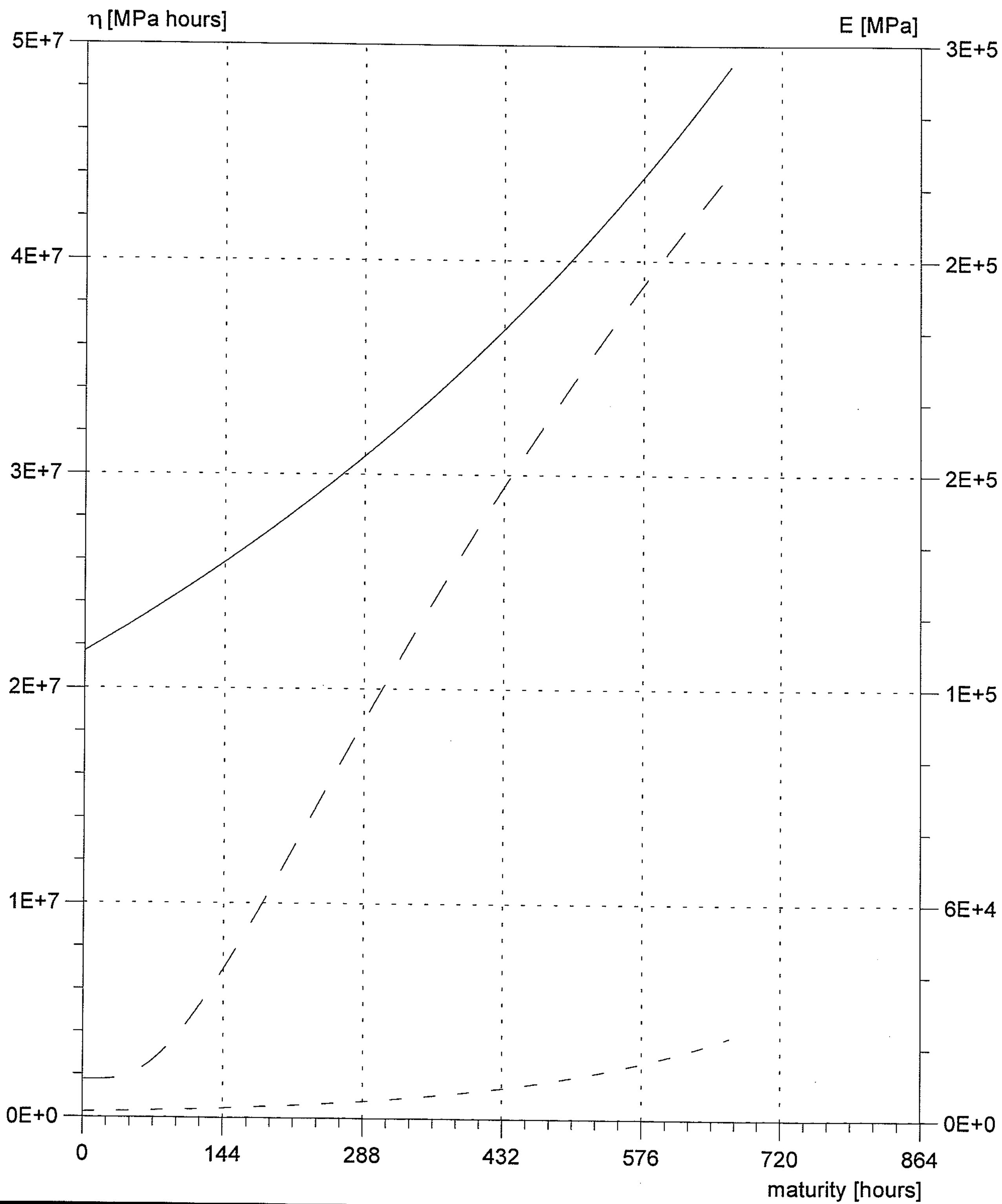
—— creepstrain

APPENDIX 11

Development of Creep Parameters

DTI Building Technology Gregersensvej, 2630 Taastrup	Creep parameters as func. of maturity

Client: HETEK 3 + 4 Name: Stage 1	Ref.: 53453 Date: 06/04/96	Init.: HSP

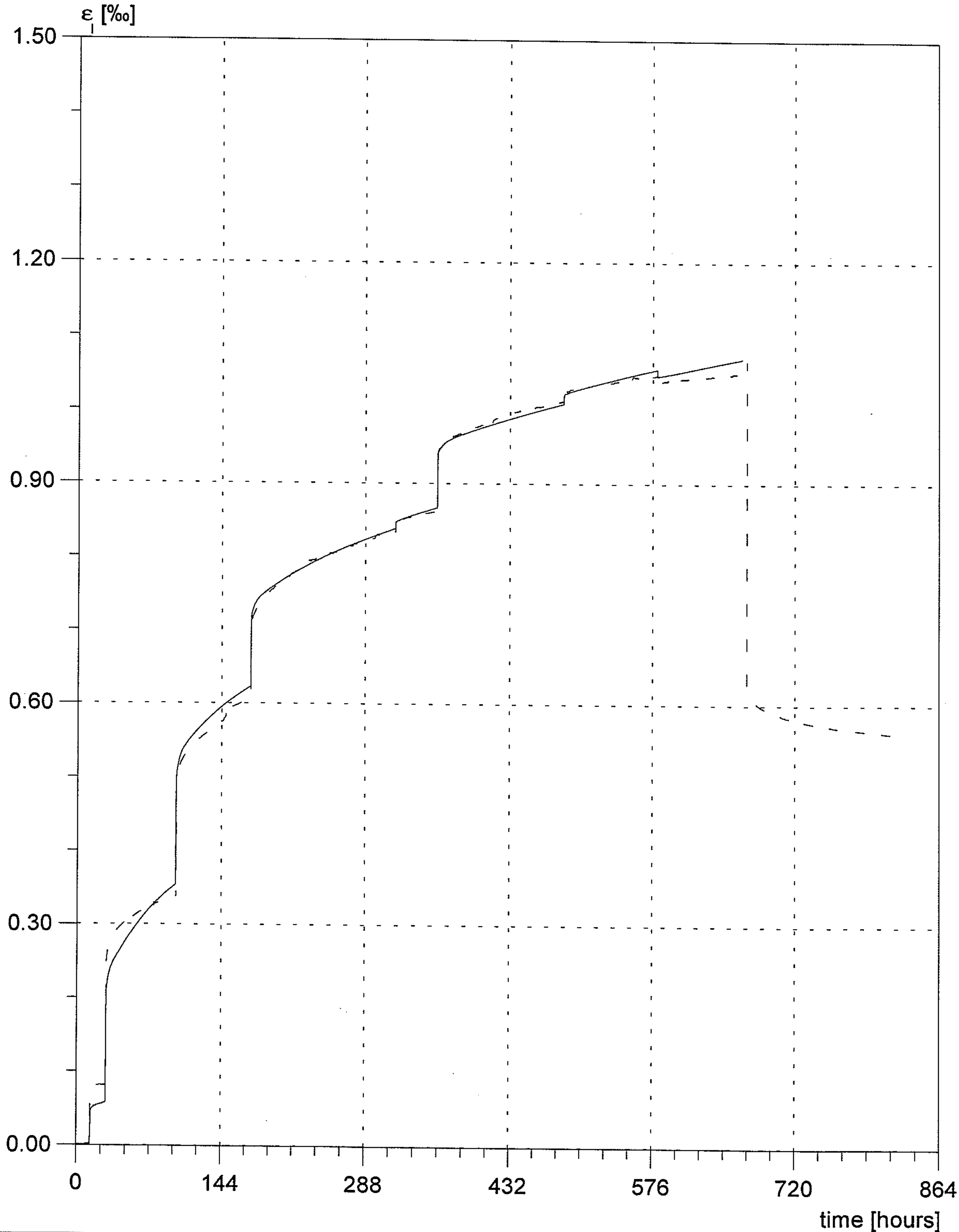


t = 0 at time of mixing

APPENDIX 12

Calculated Strains

DTI Building Technology Gregersensvej, 2630 Taastrup	Calculated strain spec. 1
Client: HETEK 3 + 4 Name: Stage 1	Ref.: 53453 Init.: HSP Date: 06/04/96



t = 0 at time of mixing

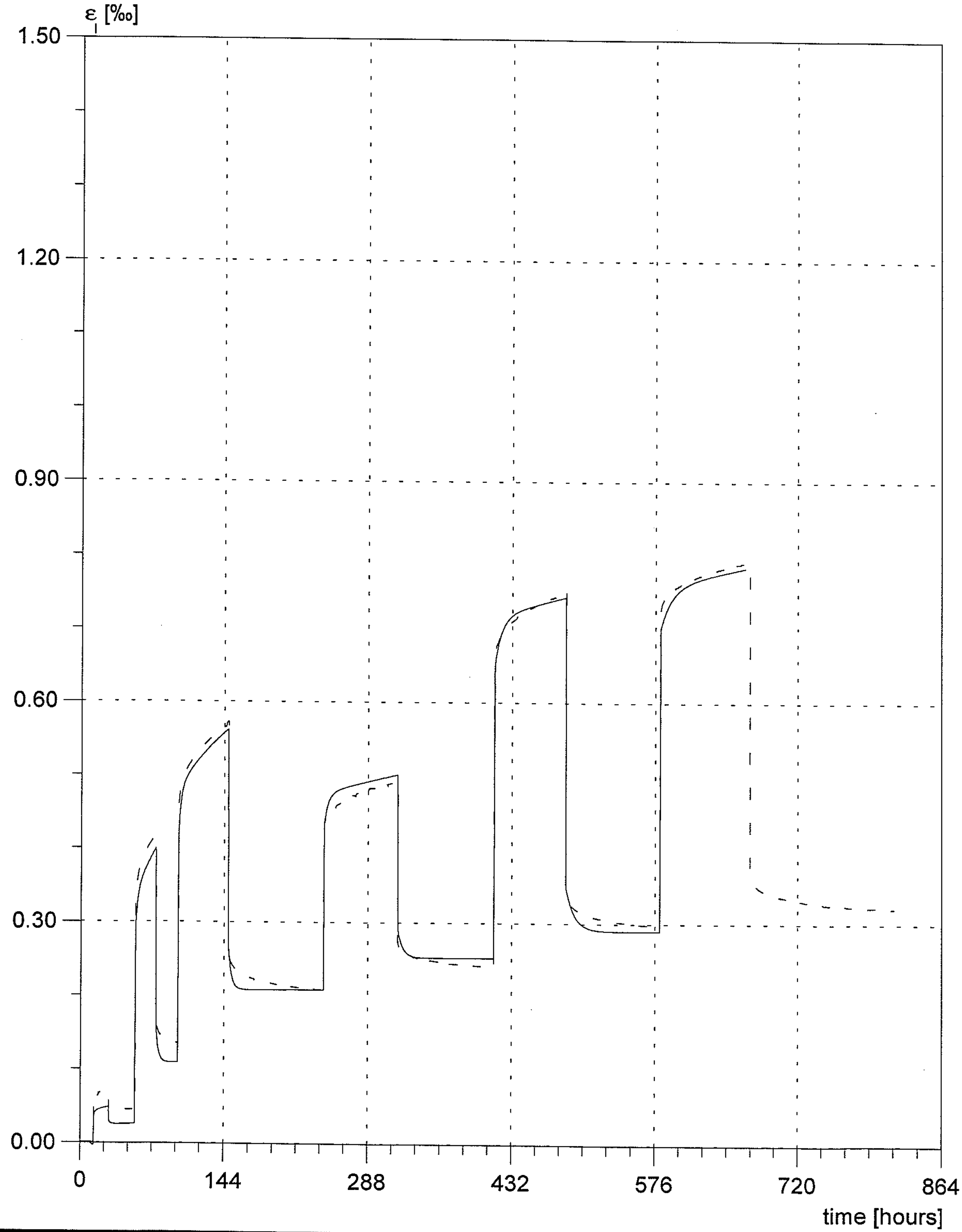
– – – measured

——— calculated

DTI Building Technology Gregersensvej, 2630 Taastrup	Calculated strain spec. 2

Client: HETEK 3 + 4
Name: Stage 1

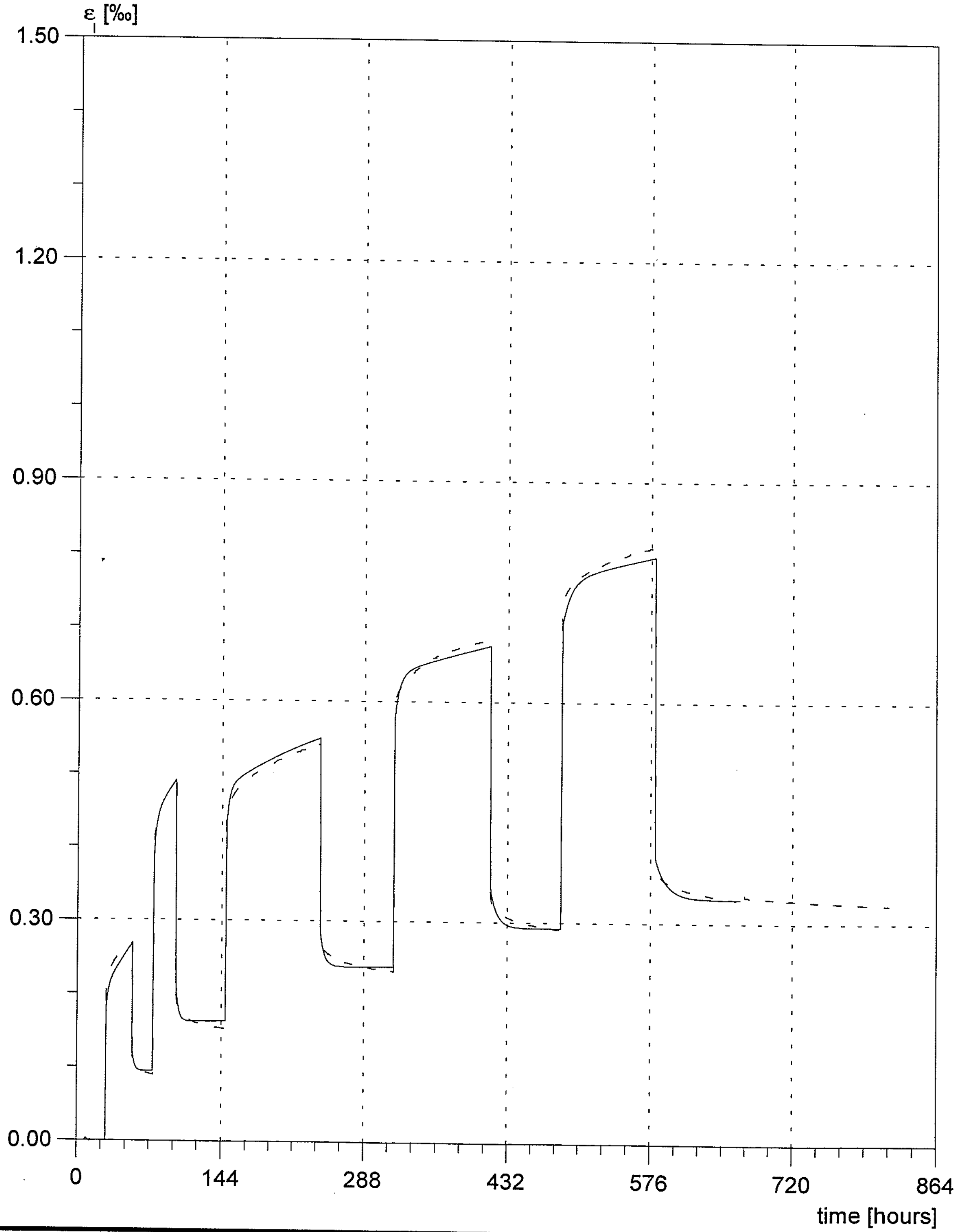
Ref.: 53453
Date: 06/04/96
Init.: HSP



t = 0 at time of mixing

- - - measured
——— calculated

DTI Building Technology Gregersensvej, 2630 Taastrup	Calculated strain spec. 3
Client: HETEK 3 + 4 Name: Stage 1	Ref.: 53453 Init.: HSP Date: 06/04/96



t = 0 at time of mixing

— — — measured

——— calculated

APPENDIX 13

TI-B 101

TI-B 101

Test Method
Concrete
Thermal Expansion
Coefficient

Concrete Centre *DTI Building Technology*

Test Method
Concrete
Thermal Expansion Coefficient

Descriptors:

Concrete, Thermal Expansion Coefficient

Version: 1
Date: March 1996
Pages: 4
Approved: S. Guirud Olsen

Test Method
Concrete
Thermal Expansion Coefficient

0. Foreword

This TI-B method replaces DTI-method "Test method for Thermal Expansion Coefficient of concrete."

1. Background and Scope

This TI-B method describes a method for the determination of the thermal expansion coefficient of concrete in the temperature range of 5°C to 30°C on sealed test specimens. The test specimens are exposed to change in temperatures in the specified temperature range. For each change in temperature the longitudinal deformation (expansion) is measured.

2. References

NT BUILD 367
Concrete, repair materials: Coefficient of Thermal Expansion

3. Definitions

Thermal expansion: change in length due to thermal variations.

Thermal expansion coefficient:

α = $\Delta\varepsilon/\Delta T$
α = thermal expansion coefficient [°C^{-1}]
$\Delta\varepsilon$ = strain [m/m]
ΔT = change in temperature [°C]

4. Test Method

This test method determines the thermal expansion coefficient of concrete. The thermal expansion is measured on concrete specimens at three different temperatures. The measured thermal expansion coefficient is corrected with regard to the temperature sensitivity of the measuring device and with regard to the shrinkage of the concrete.

The change in length, caused by the change in temperature in the range of 5°C to 30°C, is compared to the length l_0 at 20°C at the beginning of the test.

The test specimens are exposed to changes in temperature in the range of 5°C to 30°C. See Figure 1.

The temperatures are obtained by storing the sealed test specimens in a water bath with a constant temperature (± 1°C).

The length between the measuring points on each test specimen is measured when the test specimen is in thermal balance, i.e. the difference between the temperature in the middle of the test specimen and the temperature of the water is less than ± 1°C. The seal on each test specimen is shortly removed during the measurement.

The lengths l_0, l_1 and l_2 between the measuring points are measured at 20°C at the beginning, in the middle and at the end of the test procedure.

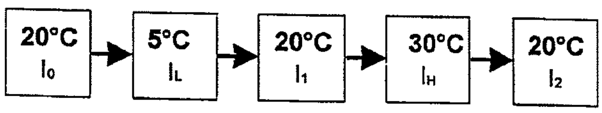


Figure 1 Changes in temperature and length measurements on the test specimens

5. Equipment

A measuring device for measuring the length changes with a strain accuracy of minimum 10•10^{-6} [mm/mm]. See example in annex.

Thermocouples for measuring the temperature in the middle of at least 1/3 of all test specimens and in the water baths with an accuracy of ± 1°C.

Three water baths with a water temperature of 5°C, 20°C and 30°C.

6. Test Specimens

A set of test specimens consists of at least three concrete prisms of 100x100x400 mm. The prisms are sealed in a heavy plastic bag and stored in a water bath at 20°C until testing.

7. Procedure

The concrete prisms are cast as described in DS 423.21 for cubes.

The forms are removed and possible surface defects are reported.

After removing the forms each test specimen is given a number and the measuring points are placed according to the test method, see annex.

The test specimens are sealed in a heavy plastic bag and stored in a water bath at 20°C.

A measurement is carried out as follows:

- Report starting hour
- Measure the temperature in the water bath and the test specimens
- Measure the length between the measuring points. This procedure is repeated for all test specimens
- Measure the temperature in the test specimens
- Report ending hour.

During the test the change in temperature and the measurements are carried out according to the following items:

1 The test specimens are removed from the water bath and the plastic bag and isolated until measuring. A measurement is carried out.

2 The test specimens are sealed in the plastic bag and placed in the water bath at 5°C.

3 When a test specimen is in thermal balance at 5°C (± 1°C) it is removed from the water bath and the plastic bag and isolated until measuring. A measurement is carried out.

4[1)] The test specimens are sealed in the plastic bag and placed in the water bath at 20°C.

5[1)] When a test specimen is in thermal balance at 20°C (± 1°C), it is removed from the water bath and the plastic bag and isolated until measuring. A measurement is carried out.

6 The test specimens are sealed in the plastic bag and placed in the water bath at 30°C.

7 When a test specimen is in thermal balance at 30°C (± 1°C), it is removed from the water bath and the plastic bag and isolated until measuring. A measurement is carried out.

8 The test specimens are sealed in the plastic bag and placed in the water bath at 20°C.

9 When a test specimen is in thermal balance at 20°C (± 1°C), it is removed from the water bath and the plastic bag and isolated until measuring. A measurement is carried out.

After this procedure the test specimens are sealed in the plastic bag and stored at 20°C, if the measurement has to be repeated at another term.

8. Test Result

The measured lengths are corrected with regard to the temperature sensitivity of the measuring device and with regard to the shrinkage of the concrete. The corrections are made on the following conditions:

- A difference in the measured lengths at 20°C are due to shrinkage in the concrete. The shrinkage is assumed to take place linearly in time.

The corrected change in length between the measurements l_H (30°C) and l_L (5°C) is used to calculate the thermal expansion coefficient. The thermal expansion coefficient is calculated according to the following formula:

$$\alpha = \frac{\Delta l}{l_0 \cdot \Delta T}$$

α = thermal expansion coefficient, [1/°C]
Δl = corrected change in length, [m]
l_0 = actual measured length at 20°C at the beginning of the test, [m]
ΔT = temperature difference at the measured lengths, °C.

The test results are reported as average and standard deviation.

---

1) Items 4 and 5 may be omitted in case of late terms.

9. Calibration

The measuring device must be in calibration at the time of testing and must be calibrated according to the instructions for this type of device.

10. Data Accuracy

Repeatability: if normal care and accuracy are shown, it can be expected that the test can be repeated with a 95 % confidence range for an average value of approximately ± 0.03 10^{-5}.

Reproducibility: if normal care and accuracy are shown, it can be expected that the test can be repeated with a 95 % confidence range for an average value of approximately ± 0.05 10^{-5}.

11. Test Report

A test report shall include at least the following information:

a) Name and address of testing laboratory.
b) Date and identification of the report.
c) Name and address of the client.
d) Test method (No. and title).
e) Deviations from the test method, if any.
f) Identification of the concrete:
   Date of receipt of test specimens/selections.
   Description of test specimens/selections.
   Marking of test specimens e.g. mix design, casting specification etc.
g) Date of test period.
h) Records of surface defects.
i) Measuring equipment.
j) Test result.
k) Further information of significance for the evaluation of the result.
l) Evaluation of the result, if included in the assignment.
m) Signature.

Example of a measuring device: DEMEC measuring device type MAYERS, model MD with a measuring length of 200 mm and an accuracy of 0.002 mm.

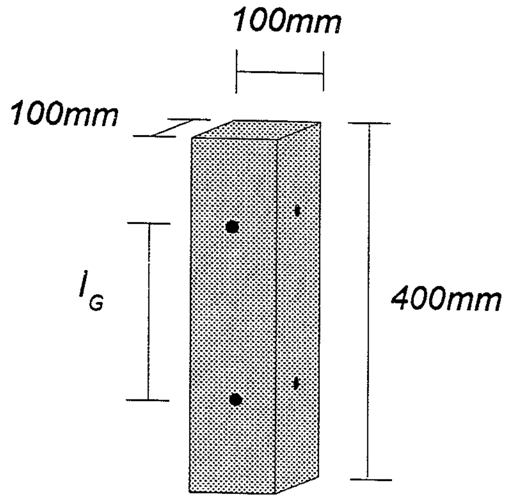


Figure 2 DEMEC: measuring points and dimensions of the test specimens.

Example of a measuring device: SYLVAC measuring device model 100 with a measuring length of 400 mm and an accuracy of 0.001 mm.

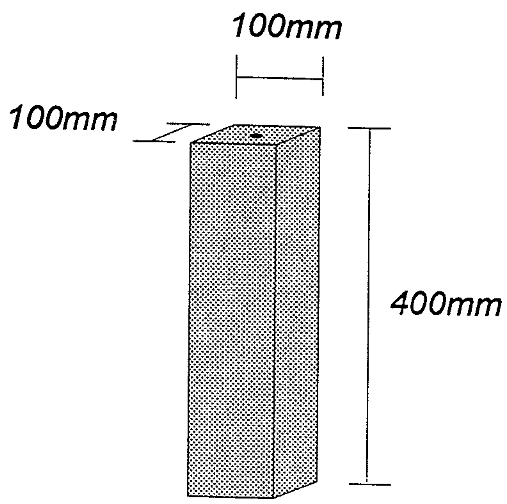


Figure 3 SYLVAC: measuring points and dimensions of the test specimens.

APPENDIX 14

TI-B 102

TI-B 102

Test Method
Concrete
Strains from Creep and Early-Age Shrinkage

Concrete Centre *DTI Building Technology*

Test Method
Concrete
Strains from Creep and Early-Age Shrinkage

Descriptors:

Concrete, Creep and Early-Age Shrinkage

Version: 1
Date: March 1996
Number of pages: 5
Number of pages, Annex A: 3
Number of pages, Annex B: 3
Approved: S. Pierrad Olsen

Test Method
Concrete
Strains from Creep and Early-Age Shrinkage

1. Scope and Area of application

This test method is applied for determination of creep strain and/or strain caused by early-age shrinkage of concrete. The method does not include determination of strains caused by desiccation shrinkage, nor does it cover creep strains caused by tension. The strains are determined as a function of the age of the concrete. The determination takes place during a period of 28 days unless other requirements are stipulated.

2. References

DS423.12 Testing of Concrete. Consistency of fresh concrete. Slump test.

DS423.15 Testing of Concrete. Determination of the content of airvoid in fresh concrete.

DS423.16 Testing of Concrete. Fresh concrete. Density.

DS423.17 Testing of Concrete. Fresh concrete. Hardening.

DS423.21 Testing of Concrete. Making and curing of moulded test specimens for strength tests.

DS423.23 Testing of concrete. Hardened concrete. Compressive strength.

ASTM - C1074. Standard Practice for Estimating Concrete Strength by the Maturity Method.

TI-B 101 Test Method. Thermal Expansion Coefficient.

TI-B 103 Test Method. Activation Energy for the Maturity Method.

3. Definitions

The following definitions are used in this method:

3.1 Shrinkage
Deformations caused by the hardening process of the concrete with the exception of deformations caused by temperature variations and exchange of humidity with the surroundings.

3.2 Creep
Deformations caused by action from an external load with the exception of initial elastic deformations.

4. Principle of Method

4.1 Shrinkage
The shrinkage is determined as the deformations that take place in a test specimen free from load after the hardening process has started and compensation is made for deformations originating from the temperature variations in the concrete. Exchange of humidity between the test specimens and the surroundings shall be prevented.

The compensation for temperature deformations implies knowledge of the thermal expansion coefficient of the concrete. It is assumed that the thermal expansion coefficient is independent of the age of the concrete during the relevant period. The thermal expansion coefficient may be determined in accordance with TI-B 101.

The determination of shrinkage is performed on the basis of measurements on at least 3 test specimens. The concrete temperature must be measured in the middle of at least 1 specimen.

4.2 Creep
Creep is determined by repeated loading and off-loading of a number of test specimens. Exchange of humidity between the test specimens and the surroundings shall be prevented.The measured deformations are compensated for the shrinkage of the concrete and the temperature variations caused by the hardening process by means of measurements on at least 1 unloaded reference test specimen. Also the initial elastic deformations of the concrete are compensated for.

Determination of creep is made on the basis of measurements on at least 3 test specimens, and at least 1 unloaded reference test specimen. In case shrinkage at early age is determined simultaneously, the shrinkage test specimens may be used as reference. The 3 creep test specimens shall not necessarily be exposed to the same load sequences. The concrete temperature must be measured in the middle of at least 1 loaded test specimen and 1 reference test specimen.

5. Test Specimens

The test specimens are made of concrete cast in such a way that humidity exchange with the surroundings is prevented from the time of casting. It must be ensured that the concrete is not exposed to unintentional external forces (for instance friction between the test specimen and the mould).

The test specimens are cylinders with a diameter of approximately 130 mm and a height of approximately 700 mm. The thermal boundary conditions shall be coordinated so that the temperature difference within the cross section is not higher than 1 °C.

6. Equipment

6.1 General

Equipment for casting of concrete and determination of the temperature of the fresh concrete, slump, air content and density.

Moulds made of a non-absorbent material that is diffusiontight and inactive to cement.

Climate Chamber that can maintain a temperature of 20 ± 2°C.

Thermocouples for determination of the temperature of the surroundings and the temperature in the middle of a test specimen. The accuracy shall be within ± 1 °C at the absolute level. Temperature variations shall be measured within ± 0.5 °C.

Deformation gauge to measure length changes. When creep is determined the length changes shall be measured with load applied. The gauge length shall be 400 - 600 mm. The gauge is fixed at the middle of the test specimen. The measurements are carried out on two opposite sides of the specimen. It shall be possible to compensate for possible temperature sensitivity of the deformation gauge. The strain shall be measured with an accuracy of ± $5 \cdot 10^{-6}$.

6.2 Creep

Additional equipment required for determination of creep:

Equipment for application of load. A load corresponding to at least 40 % of the expected compressive strength shall be applied. The load shall be kept constant in the range of ± 5 % during the desired measuring period.

Equipment for measuring the applied load. The accuracy shall be in the range of ± 3 %.

Equipment for determination of the compressive strength of the concrete in accordance with DS 423.23.

7. Measuring Procedure

7.1 Preparation of Test Specimens

If possible the test specimens shall be cast of concrete from same batch. If possible the temperature of the concrete should be the same as that of the climate chamber at the time of the casting (refer section 7.2.1).

Slump, air content and density are determined on the fresh concrete in accordance with DS 423. Furthermore the concrete temperature is measured. The casting shall be performed according to DS 423.21 for concrete to be vibrated. After casting the moulds are closed and placed vertically in the climate chamber.

7.2 Procedure

A measurement comprises correlated values of time, deformations, temperatures and possibly load.

7.2.1 Shrinkage

The measurements shall be started as early as possible and not later than when the heat development in the concrete starts. If the casting temperature of the concrete corresponds to that of the climate chamber, the time of initial heat development can be determined as the time where the rise in the concrete temperature exceeds the rise in the temperature of the surroundings by 1 °C. [1]

Measurements are made at least every 20 minutes during the first 72 hours, then at least every hour for the next 168 hours (1 week) and at least every 6 hours for the remaining test period.

7.2.2 Creep

The measurements are started not later than by the first application of load.

Prior to each application/increase of load the compressive strength is determined according to DS 423.23 on at least 1 test specimen made with the same concrete and hardening as the test specimens used in the creep test. This might be omitted in case the strength development of the concrete is known.

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1) If it has not been possible to cast the concrete at the same temperature as that of the climate chamber, it will be difficult to determine whether the temperature variations in the concrete have been caused by heat exchange with the surroundings or by heat development in the concrete. In that case the starting time may be fixed as the time where the penetration resistance determined according to DS 423.17 exceeds 3.5 MPa, and the starting time as well as the setting period determined according to DS 423.17 shall be stated in the report.

During each application and relief of load at least 5 correlated values of load and deformations are recorded. Measurements are made at least every 20 minutes during the first 72 hours after loading and off-loading, respectively, then at least once every hour during the following 168 hours (1 week) and at least every 6 hours for the remaining test period.

The application of load shall take place at a velocity where the initial elastic deformations do not significantly increase the creep process. This requirement will normally be met if the application of load takes place within a period of 5 minutes. The load should be applied centrally. The off-loading shall take place at the same velocity as the loading. The maximum load must not exceed 40 % of the compressive strength at the time of loading.

7.3 Test Result

7.3.1 General

The maturity is determined on the basis of the measured concrete temperature by means of Arhenius´ function as stated in ASTM - C1074 with the activation energy defined as in TI-B 103.

The strain of the concrete corresponding to the measurement on one side of a test specimen is determined as:

$$\varepsilon_m(t) = -\left(\frac{l_t - l_0}{l_D}\right) + \varepsilon_{T,G}(t)$$

where:

$\varepsilon_m(t)$	=	Measured strain at the time t, positive as contraction [m/m]
l_0	=	Length at the time t_0 [µm]
l_t	=	Length at the time t [µm]
l_D	=	Measuring length [µm]
$\varepsilon_{T,G}(t)$	=	Possible increase in strain caused by temperature sensitivity of the deformation gauge at the time t, positive as contraction [m/m]

The concrete strain $\varepsilon_{m,n}(t)$ measured on test specimen No. n is determined as average of measurements on two opposite sides of a test specimen.

7.3.2 Shrinkage

The shrinkage strain in test specimen No. n is determined as the measured concrete strain n in the test specimen corrected for contributions from the temperature deformations of the concrete:

$$\varepsilon_{s,n}(t) = \varepsilon_{m,n}(t) + \alpha_c(T_c(t) - T_c(t_0))$$

where:

$\varepsilon_{s,n}(t)$	=	Shrinkage strain in test specimen No. n at the time t, positive as contraction [m/m]
$\varepsilon_{m,n}(t)$	=	Concrete strain in test specimen No. n at the time t, positive as contraction [m/m]
α_c	=	Thermal expansion coefficient of the concrete
$T_c(t)$	=	Concrete temperature at the time t [m/m]
$T_c(t_0)$	=	Concrete temperature at the time t_0 [m/m]

The shrinkage strain of the concrete $\varepsilon_s(t)$ is determined as average of the shrinkage strains determined on the individual test specimens.

7.3.3 Creep

The stress applied to test specimen No. n is determined as:

$$\sigma_n(t) = \frac{1000 \cdot P_n(t)}{\frac{1}{4}\pi d^2}$$

where:

$\sigma_n(t)$	=	Stress in test specimen No. n at the time t [MPa]
$P_n(t)$	=	Load applied to test specimen No. n at the time t [kN]
d	=	Diameter of test specimen [mm]

The concrete strain caused by an external load to test specimen No. n is determined as:

$$\varepsilon_{l,n}(t) = \varepsilon_{m,n}(t) - \varepsilon_{m,ref}(t)$$

where:

$\varepsilon_{l,n}(t)$	=	Concrete strain caused by external load to test specimen No. n at the time t [m/m]
$\varepsilon_{m,n}(t)$	=	Strain measured in test specimen No. n at the time t [m/m]
$\varepsilon_{m,ref}(t)$	=	Strain measured in reference specimen at the time t [m/m]. In case of more than one reference specimen the average value is used.

At the time for each loading and off-loading the E-modulus of the concrete is determined by means of linear regression. The initial elastic deformations at the time of loading or off-loading, t^l are calculated as:

$$\varepsilon_i(t') = \Delta\sigma(t') \cdot E(t')$$

where:

$\varepsilon_i(t')$ = Initial elastic strain, positive as contraction [m/m]

$\Delta\sigma(t')$ = Change of stress applied at the time t′, positive as compression [MPa]

$E(t')$ = E-modulus at the time t′ determined by linear regression [MPa]

The creep strain $\varepsilon_{c,n}(t)$ in test specimen No. n is determined as the concrete strain caused by the external load minus the initial elastic strains.

8. Statement of Result

It applies to all graphs that the zero point for time shall correspond to the casting time, unless information to the contrary is stated on the graph.

The same figure can include several graphs.

8.1 Shrinkage

The result is stated as:

Graph with correlated values of maturity and the shrinkage strain of the concrete, $\varepsilon_s(M)$.

Further information:

Age at the start of the measurements given in both decimal hours and maturity rounded off to the next 0.1 hour.

The thermal expansion coefficient used for the concrete and description of how it was determined.

Graph with correlated values of time, concrete temperature and maturity.

Graph with correlated values of time and measured concrete strain, $\varepsilon_{m,n}(t)$.

Graph with correlated values of time and shrinkage strain for each test specimen, $\varepsilon_{s,n}(t)$.

Graph with correlated values of time and shrinkage strain of the concrete, $\varepsilon_{s(t)}$.

8.2 Creep

The result is stated as:

Graph with correlated values of time and creep strain for each test specimen, $\varepsilon_{c,n}(t)$.

Further information:

Age at the start of the measurements given in both decimal hours and maturity rounded off to the next 0.1 hour.

Graph with correlated values of time, concrete temperature and maturity.

Graph with correlated values of time and measured concrete strain, $\varepsilon_{m,n}(t)$.

Graph with correlated values of time and stress applied for each test specimen, $\sigma_n(t)$.

Graph with correlated values of time and concrete strain caused by external load for each test specimen, $\varepsilon_{l,n}(t)$.

Graph with correlated values of time and strain for the reference specimen, $\varepsilon_{m,ref}(t)$. In case more than one reference specimen is used, the correlated values of time and average strain for all reference specimens are also stated.

Table with correlated values of time, maturity and E-modulus determined during the loading and off loading.

Table with correlated values of time and compressive strength.

9. Test Report

A test report shall include at least the following information:

a. Name and address of testing laboratory.
b. Date and identification of the report.
c. Name and address of client.
d. Test method (No. and title).
e. Deviations from the test method, if any.
f. Identification of the concrete.
g. Fresh concrete (slump, air content, temperature, w/c-ratio).
h. Surface defects, if any.
i. Casting date.
j. Starting time for measurements.
k. Test result (refer section 8).
l. Further information of significance for the evaluation of the result.
m. Evaluation of the result, if included in the assignment.
n. Signature.

This annex is included only as a guide and does not form an integral part of the standard.

1. Area of Application

The present annex describes how the shrinkage development proces of concrete determined during and after the hardening process can be described so that the shrinkage is included into a stress calculation of hardening concrete.

It is expected that the annex will be revised as more experience is collected.

The measured shrinkage deformations can be observed by means of tests as described in TI-B 102 "Test Method. Concrete. Strains from Creep and Early-Age Shrinkage".

During the described tests the shrinkage of a concrete specimen without water evaporation is measured as a function of maturity.

2. Scope of Test

The shrinkage development is measured on 3 specimens as described in TI-B 102 "Test Method. Concrete. Strains from Creep and Early-Age Shrinkage".

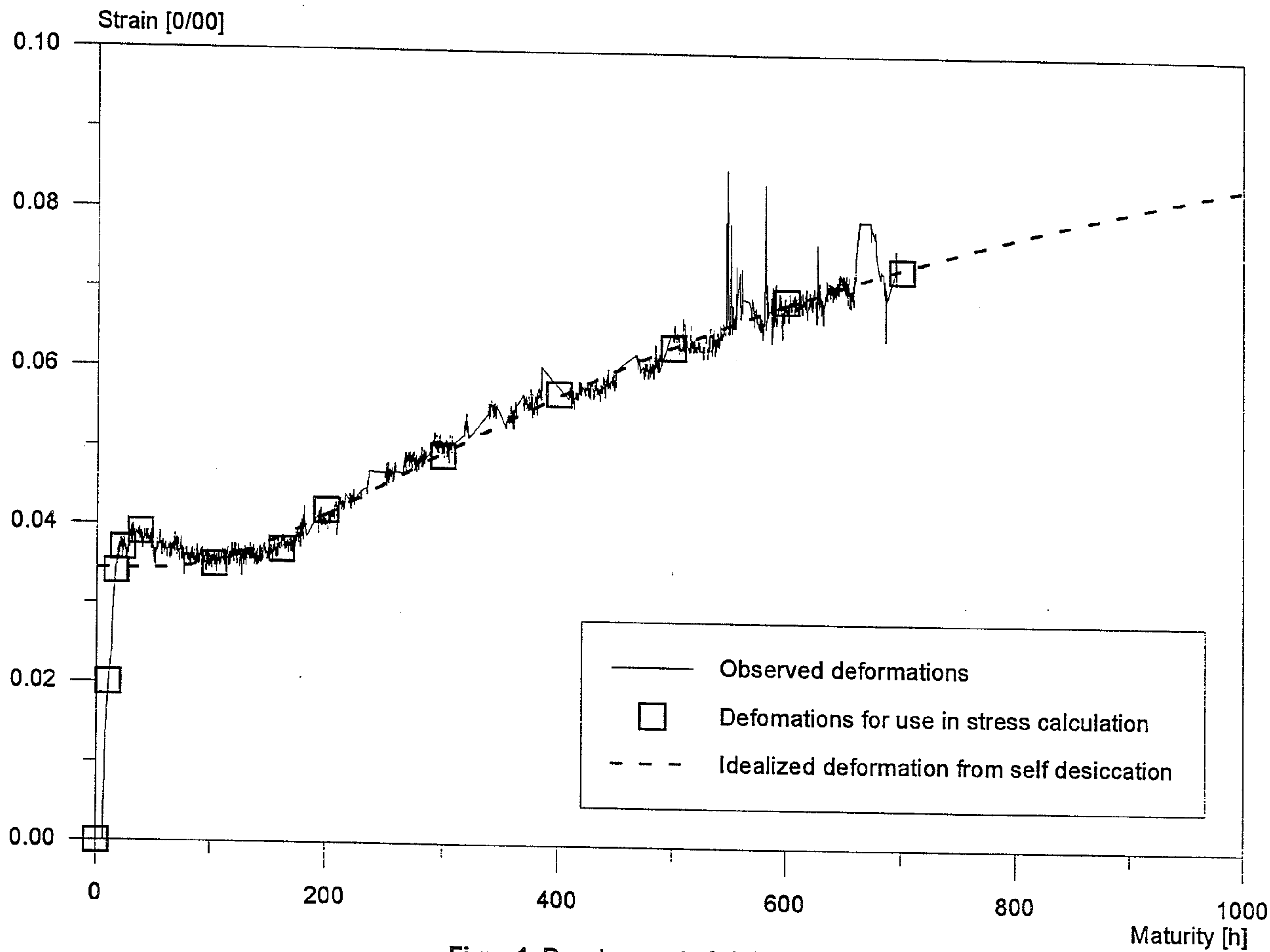
3. Test Results

Figure 1 shows observations from a shrinkage test. The shrinkage strains have been compensated for temperature fluctuations, cf. TI-B 102, by means of a constant thermal expansion coefficient.

For use in calculations of stresses in structures of hardening concrete, the observed deformations as a function of maturity can in principle be used directly. However, originating from the measuring device must be eliminated from the curve which describes the shrinkage development. This can for instance be done by selecting a number of points on the curve, so that the measured development is sufficiently described (figure 1).

The first point of the curve must correspond to the start of the measurement, as described in TI-B 102. Deformations which occur before this time, are assumed not to generate stresses because of the very low E-modulus.

If values of the shrinkage are needed longer than the period of measuring, this can be done in accordance with the theoretical considerations described in section 4.



Figur 1 Development of shrinkage.

4. Theoretical Considerations

The observed deformations can be divided into two groups:

1) When concretes with a low w/c-ratio are involved, the capillary water will be used up as water reacts with cement. This will result in a desiccation shrinkage corresponding to the shrinkage observed by desiccation of non-sealed concretes. Calculations based on w/c-ratios and the heat development curves show that shrinkage originating from self desiccation is observed only after 40 - 100 maturity hours depending on the concrete mix in question.

2) Deformations that are not related to self desiccation shrinkage can be observed in early-age concrete (figure 1). Reference to this type of deformations is found in the literature, but no other explanation is given than it might be a result of chemical shrinkage and/or of a thermal expansion coefficient that varies during the hydration stage.

The self desiccation starts when the capillary water V_k has been used up during the reaction with cement. From Powers phase conversion it is seen:

$$V_k = p - 1.4 (1 - p) \cdot R$$

where p is the specific volume of water before the reaction starts
R is the degree of reaction

The degree of reaction R_{max} corresponding to initial self desiccation is then

$$R_{max} = \frac{p}{1.4 \cdot (1 - p)}$$

The w/c-ratio is introduced by:

$$\frac{p}{1 - p} = \frac{\rho_c}{\rho_v} \cdot v/c \Rightarrow R_{max} = \frac{\rho_c}{\rho_v} \cdot \frac{v/c}{1.4}$$

where ρ_c and ρ_v are the density of cement and water, respectively.

The maturity is introduced by means of the adiabatic thermal development

$$R_{max} = \frac{Q}{Q_\infty} = \exp\left(- \left(\frac{\tau_e}{M} \right)^\alpha \right)$$

where Q_∞, τ_e and α are parameters from the heat development curve of the concrete.

The maturity corresponding to initial self desiccation is then

$$M_{max} = \frac{\tau_e}{(-\ln(2.22 \cdot v/c))1/\alpha}$$

The measured self desiccation shrinkage may be approximated by:

$$\varepsilon_{sd} = (\varepsilon_\infty - \varepsilon_0) \cdot \exp\left(- \left(\frac{\tau}{M} \right)^\alpha \right)$$

where ε_0 = The level corresponding to the zero point of the self desiccation shrinkage

ε_∞ = the level corresponding to total self desiccation

M = maturity

τ, α = curve parameters.

The values of ε_0, ε_∞, τ and α are determined on the basis of the temperature compensated shrinkage strains as a function of maturity (figure 1) by means of the method of least squares. Figure 1 shows the resulting curve. The total self desication shrinkage of the concrete is determined as $\varepsilon_\infty - \varepsilon_0$.

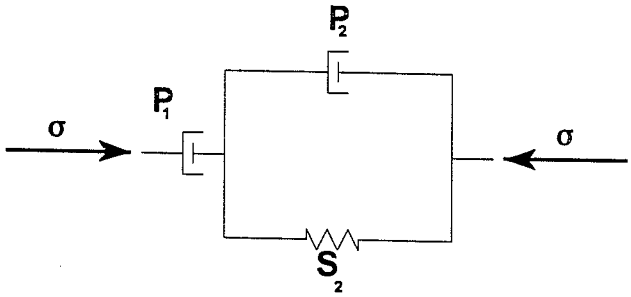
This annex is only included as a guide and does not form an integral part of the standard.

1. Area of Application

TI-B 102 describes the technical aspects of a method for determination of coherent values of load, deformation and time. The present annex describes how the planning of such test and the subsequent data processing may be carried out, when the objective is to establish a mathematical creep model for stress calculations of hardening concrete.

It is expected that the annex will be revised as more experience is collected.

It is assumed that creep deformations of concrete can be described by means of a rheological creep model as shown on figure 1. When a test specimen (see TI-B 102) is exposed to repeated loads and relief of loads, the properties of the viscous pistons and the spring can be determined, including the variation in time.



Figur 1 Rheological model for creep strains.

2. Scope of Test

Test setup and execution of test according to TI-B 102 "Test method. Concrete. Strains from Creep and Early-Age Shrinkage".

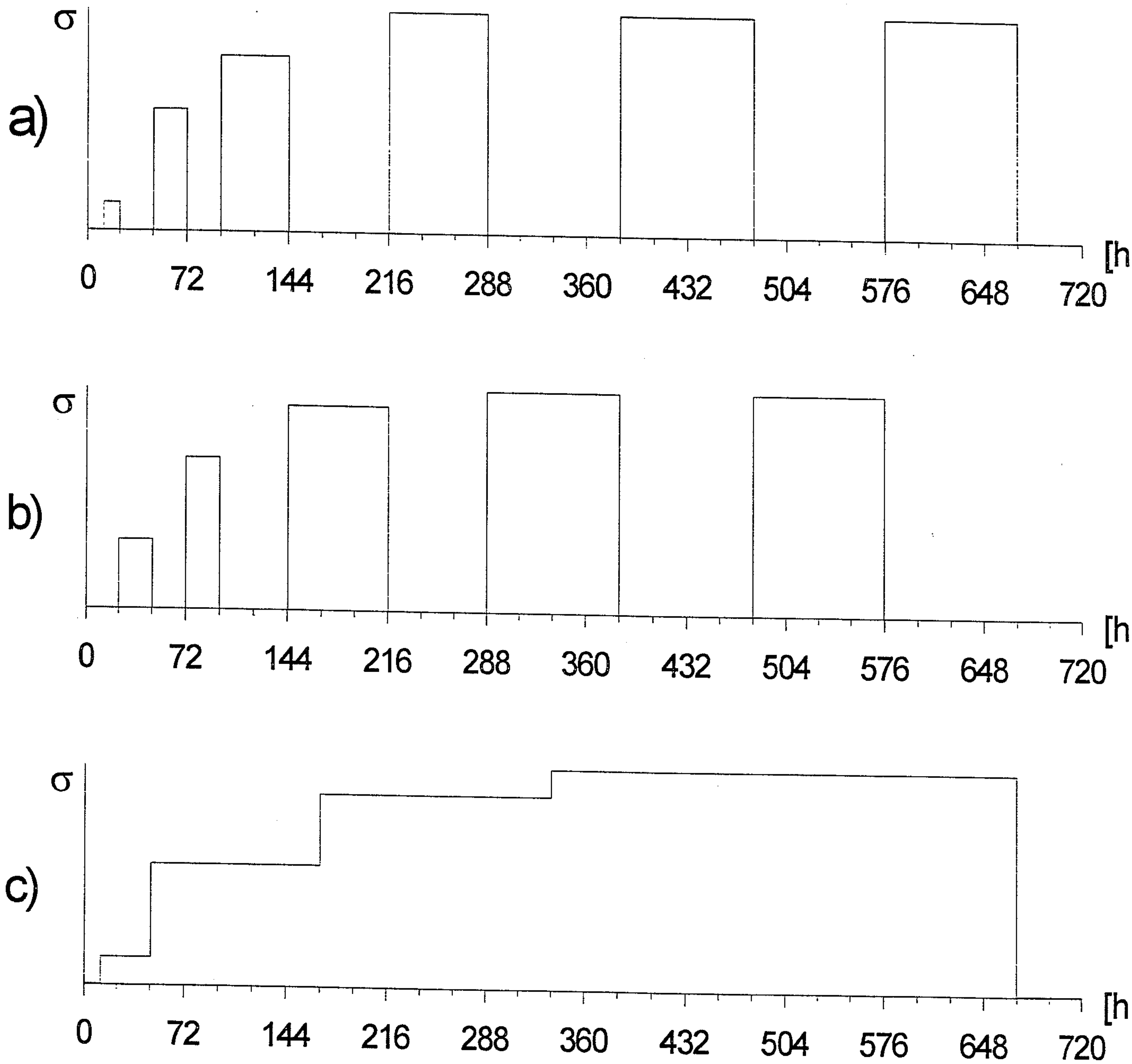
Tests are carried out on 3 test specimens the load periods and load levels are chosen so that 2 of the specimens are continously exposed to load and relief of load. The two specimens shall be exposed to the load and relief of load sequence alternatively - in the beginning rather short load periods and longer load periods as the concrete matures.

The exposure to load and relief of load shall take place alternatively between two specimens.

The third test specimen shall be exposed to load constantly, and the load is increased as the testing procedure progresses.

The maximum load is 40% of the compressive strength and the first load shall take place as early as possible. An example of a load sequence for three test specimens is shown in figure 2.

Moreover, the strains are measured on specimens not exposed to load. These measurements are used to compensate the measurements on the loaded specimens for shrinkage and temperature deformations.



Figur 2 Example of Load sequences.
Load-level = 40% of actual compression strength.
Time = 0: mixing.

The load sequences a) and b) primarily provide information for the determination of the properties of the parallel-coupled units, while load sequence c) provides information about the properties of the outer piston.

3. Processing of Test Results

The deformation measurements as a function of time are compensated in accordance with TI-B 102 for the shrinkage movements and temperature fluctuations of the measuring equipment. Furthermore the creep deformations are isolated from the initial-elastic deformations.

By means of the rheological model the rate of creep strains can be determined by:

$$\dot{\varepsilon} = \frac{\sigma}{\eta_2} - \frac{E}{\eta_2}\varepsilon_2 + \frac{\sigma}{\eta_1}$$

where
- $\dot{\varepsilon}$ = is the total rate of creep strains
- ε_2 = is creep strains in the parallel-coupled units (refer figure 1)
- η_1 = is the viscosity of the piston P_1
- η_2 = is the viscosity of the piston P_2
- E = is the spring constant for the spring S_2

It is assumed that the development of the viscosities and the spring constant can be expressed by:

$$\textit{property} = a \cdot \exp(b \cdot \textit{time})$$

The constants (a and b) of the development of the properties can be determined by the method of least squares performed on all the tests simultaneously.

By means of the development of the concrete temperature measured during the creep test, the creep properties are finally converted into a function of maturity instead of time.