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IMPROVED TECHNOLOGICAL PROCEDURES FOR CONSTRUCTION OF HYDRO ELECTRIC POWER PLANTS

DP/YUG/87/003

SOCIALIST FEDERAL REPUBLIC OF YUGOSLAVIA

Technical report: Cracking in mass concrete structures *

Prepared for the Government
of the Socialist Federal Republic of Yugoslavia
by the United Nations Industrial Development Organization,
acting as executing agency for the United Nations Development Programme

Based on the work of Mr. H.N. Linsbauer,
expert on concrete production technology

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United Nations Industrial Development Organization
Vienna

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CONTENTS

1. INTRODUCTION

Quality of life and industrial development of a country are directly related to its energy production potential. During the last two decades a world-wide change in power generation policy took place. The limited supplies of coal and oil, which are extremely valuable primary materials for industrial and petrochemical products call for decreasing use in direct energy production. Nuclear power generation is hotly debated in a lot of countries. Further more the aspects of import costs and especially the environmental consequences are to consider.

For these reasons the importance of undeveloped water power resources has gained increased significancy and priority.

Yugoslavia is facing the problem of shortage of energy especially at the peak time, it utilizes appx. 50 % of available hydro electric potentials and is in need of increasing its hydro-power plants.

The electrical energy consumption is expected to increase particularly in the Socialist Republic of Slovenia, and will probably need additional 350 MW by the year 1990.

In view of above stated conditions it is well justified that necessary exploitation and assessments should be made in order to utilize the hydro-power potential of rivers in the Socialist Republic of Slovenia.

The experience gained through the construction of hydro-power plant dams on the rivers Soća and Sava have shown that constructing dams particularly their concreting process represents the most crucial point and one of the essential barriers for fast execution of work.

It has been proved that the reason for this obstacle is the limited size of the successive concrete blocks. The size of these blocks has been kept limited in order to avoid the danger of shrinkage cracks which appear during cement hydration, volume and temperature changes during the hardening period, and other reasons which cause appearance of cracks on the surface of concrete.

Considerable research has been carried out in other regions in order to control the shrinkage of concrete in the construction of dams, however, it is required to adopt particular steps concerning the specific conditions in the Socialist Republic of Slovenia in order to enlarge the sizes of concrete blocks which will result in a reduction of the power plants construction time to a notable extent.

2. CRACKING IN MASS CONCRETE STRUCTURES

The development of crack-like defects in mass concrete structures is a well known phenomenon and may be attributed to a multitude of effects such as:

Inadequate design and construction

Notches
Corners
Jagged dam-foundation-interface
Deformation restraint
Rock-dam bond of up- or downstream surface
Improper injection of joints
Insufficient preparing of construction joints

Volumetric change

Drying shrinkage
Creep under sustained load
Thermal stresses caused by heat of hydration
Chemically incompatibility of concrete components

Direct stress due to applied load or reaction

Unusual load cases
Earthquake
Excessive change of climate
etc.

The most important factor on cracking during the construction state is given by hydration process heat generation accompanied with uneven temperature distribution.

3. PREVENTION OF HYDRATION-PROCESS INDUCED CRACKING

The measures for the prevention of those volumetric-change-induced cracks may be listed as follows:

Conditions for prevention of cracking in mass concrete

Cement of low heat generation
Low cement content (permitted by low design stress)
Concrete with large strain capacity to failure
Low degree of restraint
Precooling of concrete components (low casting temperature)
Postcooling (embedded pipe system)
Short blocks
Insulation

- Low heat generation cement is obtained usually by additives as pozzolans (blast-furnace) and fly-ash. The optimum ratio of cement to additive volume should be determined by experiment . (Annex 1, page 6).

- The influence of cement-additive-admixtures content on the temperature rise during the hydration process is shown in Annex 1, page 17.

- Large strain capacity of concrete to failure reduces cracking sensitivity especially in regions of interfaces. The main factors for obtaining large strain capacity are shown in Annex 1, page 7. The influence of block-length to block-width ratio on restraint is documented in Annex 1, pages 8 and 9.

- The strongest influence on the avoidance of thermal cracking is the control of the concrete placing temperature by precooling (Annex 1, pages 12 and 13).

- Postcooling (Annex 1, pages 13 - 16) serves as temperature regulating system both in placing and final construction period.

- Insulations may be a sufficient measure to take precaution against cracking to reduce the temperature gap between the core and surface of the block.

The construction block size depends on the optimum combination of the above mentioned crack-prevention measures.

4. INVESTIGATION OF CRACKING

The design criteria DIN 19702 (FRG) and Bureau of Reclamation (USA) incorporate and regard potential crack formation in plain concrete structures. The proposed method rests on the rather suspicious assumption, that a horizontally oriented edge crack would propagate horizontally and extend into the strucutre up to the point of equilibrium between water pressure acting inside the crack and the compressive stress in the concrete section.

This procedure (called Lieckfeldt method), for assessment of the influence of cracking on bearing resistance of plain concrete structures is considered as a rough engineering method. With reference to the basic assumptions - planar crack extension, zero stress at the crack tip and linear shape of stress distribution - this method is not compatible with the principle of continuum (fracture-) mechanics.

Basic Principles of Fracture Mechanics

The procedure for investigation of cracking in mass concrete is based usually on the methods of linear elastic fracture mechanics (LEFM). The application of LEFM requires some fundmental attributes, as notch sensitivity, homogeneous material behaviour and a small fracture process zone compared to the dimension of the structure.

Concrete dams and associated hydraulic structures as weirs, lock walls, abutments etc. may be considered as perfect exemplars for the use of LEFM in case of cracking.

A topic of utmost importance is the formulation and testing of suitable and appropriate fracture criteria for crack extension. Crack initiation criteria base on a physical parameter (such as crack extension-force, stress intensity factor, J-Integral, T-Modulus, etc.) and compare an analytically calculated value for this physical parameter with an experimentally determined critical value of material. In linear-elastic fracture mechanics most often the stress intensity factor, K, is identified with the parameter in the fracture criteria, and one writes:

$$K_{\text{Ianalyt.}} = K_{\text{ICexper.}}$$

The stress field in the vicinity of the crack tip is given in the form

$$\sigma_{ij} = \frac{1}{\sqrt{2\pi r}} \cdot \sum_{n=1}^{3} K_n f_{ij}^{n} (\theta)$$

where the K_n are the stress intensity factors, n denotes the mode of fracture (n=1 : normal tensile fracture, n=2 : inplane shear fracture, n=3 : antiplane shearing), and the f_{ij}^{n} (θ) are functions of the coordinate θ.

The stress intensity factors K_n may be considered a measure of the intensity of the $r^{-1/2}$- singularity at the crack tip. The first basic relation of fracture mechanics then reads

$$K = \sigma \sqrt{\pi a} . Y$$

where σ is the nominal stress (stress at infinity or stress in the uncracked structure at the location of the prospective crack), a is the crack length and Y is a correction function which depends on the geometrical and loading configuration. The correction function takes into account the influence of finite dimensions, i.e., the effect of close boundaries on the state of stress in the crack tip region .

For application of fracture mechanics principles to hardening concrete a detailed analytical and experimental investigation concerning the time-dependent development of the Stress-Intensity-Factor K_I (K_{II}) and the time-dependent behaviour of material parameters including Fracture Toughness K_{IC} or Fracture Energy G_F is necessary.

The complexity of the hydration process is descriptive demonstrated by results of tests using the thermal stress testing machine (page 11 - Annex 1) where e.g. the influence of the relaxation of the "young" (green) concrete is demonstrated by the difference between the measured and calculated time-dependent stress distribution.

5. PROJECT ACTIVITIES

The previous project activities include a three days work session and an experimental investigation concerning temperature measurement in a hardening concrete cube.

WORKSESSION

Workschedule

Mo 07.03.88

Lectures at the Institute for Testing and Research in Materials (Doz. Dr. Linsbauer)

Participants

20 persons from ZRMK (Zavod za raziskovo materiala in konstrukci= Institute for Testing and Research in Materials and Structures, Ljubljana) , SCT (Slovenija cesta Tehnika Obnova = Slovenijia Roads and Construction Enterprise)
University of Ljubljana
IBE (Inženirski Biro Elektroprojekt = Power Engineering Enterprise)
GIB GRADIS - Civil Engineering Enterprise

Contents

A - Application of fracture mechanics principles to cementitious materials
B - Demonstration of case studies concerning cracking in Koelnbrein arch dam (Malta power plant Austria)
C - Mass concrete - special problems in mass concrete during hydration process
D - Fracture mechanics philosophy adapted to very young (green) concrete

Discussions

Intensive and detailed questions and discussions covering the field of the lectures

Tu 08.03.88

Meeting at SCT

Participants

SCT Andrej KERIN, dipl.civ.eng. , Project Manager - NPD
Alojz SEVER, mgr. tech.science, Laboratory Manager
Franc KAVCIC, dipl.civ.eng. , Laboratory staff member
Vlado ZERJAV, dipl.civ.eng. , Site Manager - Project Co-ordinator
Vladimir SOKOLOV, dipl.el.eng., Measurement Technics
Viljem CELCER, dipl.civ.eng. , Designer
Ivan KOCUVAN, dipl.eng., dr. , Cement Technology

University of Ljubljana
Aloijz KODRE, prov. of physics and mathematics

ZRMK Ada DE COSTA, dipl. civ. eng. , Concrete Technology
Jadran KORLA, dipl. civ. eng. , Concrete Technology
Jakob SUSTERSIC, dipl.civ.eng., Concrete Technology

UNIDO Doz. Dr. H. LINSBAUER - Expert

We 09.03.88

Meeting at SCT

Participants

SCT Andrej KERIN, dipl. civ. eng., Project Manager - NPD
Alojz SEVER, mgr. tech. science, Laboratory Manager
Franz KAVCIC, dipl.civ.eng., Laboratory staff member
Vlado ZERJAV, dipl. civ.eng., Site Manager - Project Co-orinator
Vladimir SOKOLOV, dipl.el.eng., Measurement Technics
Viljem CELCER, dipl. civ. eng., Designer
Ivan KOCUVAN, dipl.eng., dr., Cement Technology

IBE Savo JANEZIC, dipl.civ.eng., Designer dam construction

ZRMK	Edvard MALI, dipl, civ.eng., Concrete Technology Jadran KORLA, dipl.civ.eng., Concrete Technology Jakob SUTERSIC, dipl.civ.eng., Concrete Technology
UNIDO	Doz.Dr. H. LINSBAUER , Expert

Programme

A - Report of activities by members of SCT, ZRMK and associated institutions

- Preliminary tests for designing of concrete mixtures
- Concrete technology for dam constructions
- Description of the cube model - (2x2x2 m cube, cement heat generation 222 J/q - after 7 days - cement content 180 kg/m^3, Superplasticizer, 2,5% of cement content, 0.17% air entraining agent) see Annex 2
- Measuring system (cube geometry, temperature measuring system, location of measuring points, etc)
- Special problems (thermal coeficients of concrete - during hardening process)
- Methods of dam construction in Yugoslavia

B - Discussion of mass concrete problems on basis of papers

- Linsbauer (see Annex 1)

C - Report by Linsbauer concerning fracture mechanics material parameters testing - methods (comparison between RILEM - 3-point bending and Vienna-cube method)

D - Interim conclusions

E - Demonstration of Cube Model (MERILNI SERVIC SCT POLJE)

EXPERIMENTAL INVESTIGATION

The experimental investigation covers temperature measurements in a hardening concrete block with size of 2x2x2 m and special boundary conditions (insulation) accompanied by highly and user-friendly developed computer controlled data transfer and data processing system, which is implemented on a mini PC.

The experiment is running since December 1987. The concrete mixture is shown in pages 1 and 2 of Annex 2. The dimension of the cube with positions of the temperature measuring points is represented in page 3 of Annex 2. Temperature measuring data concerning the period 22.12.1987 are graphically shown on pages 4 - 10 Annex 2, for thermocouples 1 to 14.

6. CONCLUSIONS AND RECOMMENDATIONS

The activities within the worksession resulted in the following conclusions and recommendations.

F 1 Scientific engineering and laboratory potential covered by SCT, ZRMK, Faculty of Natural Science and Technology, Faculty of Civil Engineering, Architecture and Geodesy, University of Ljubljana, IBE.

- Cement technology
- Concrete technology

- Temperature measuring system
- Computer software concerning measuring data collection, input routines (data transfer) and software for heat transfer problems.

F 2 Support by UNIDO

F 2.1 Special training programme for strain measurements in concrete structures.

F 2.2 Laboratory visiting tour

- Zementforschungsinstitut Vienna (Dr. Sommer)
- Materials Laboratory - Tauernkraftwerke AG Strass (Dr. Huber)
- Technical University Munich - Prof. Springenschmid Demonstration and training advice Thermal Strain (Stress) - Testing Machine
- Laboratories Prof. Wittmann - ETH Zürich - Prof. Hilsdorf - University of Karlsruhe (young concrete)

F 2.3 Cooperation and exchange of experience between Prof. Kodre, Faculty of Natural Science and Technology and Prof. M. Saje, Faculty of Civil Engineering, Architecture and Geodesy on the project side, and Doz. Dr. Linsbauer on the UNIDO side concerning development of computer software for concrete hydration process problems.

F 2.4 Training support concerning test methods for fracture toughness and fracture energy of young and hardened concrete. Place: University of Technology of Vienna (Linsbauer, Tschegg.

F 2.5 Fracture mechanics materials testing for 15 test samples of different special concrete mixes produced by ZRMK at the University of Technology, Vienna.

F 2.6 Support in identifying specialists for determination of thermal constants of young and hardened concrete and sources.

F 2.7 Measuring and computer equipment (data acquisition station). Listing and firms (see Annex 3).

7. PROPOSED TIME SCHEDULE

The proposed time schedule according to the recommendations of part F2 is represented in pages 1 and 2 of Annex 4.

ANNEX 1 - LECTURE NOTES

ACI - DEFINITION OF MASS CONCRETE

MASS CONCRETE IS:

Any large volumen of cast-in-place concrete with dimensions large enough to require that measures be taken to cope with the generation of heat and attendant volume change to minimize cracking.

CRACKING CHARACTERISTICS AND CAUSES

INADEQUATE DESIGN AND CONSTRUCTION

Notches
Corners
Jagged dam-foundation-interface
Deformation restraint
Rock-dam bond of up- or downstream surface
Improper injection of joints
Insufficient preparing of construction joints

VOLUMETRIC CHANGE

Drying shrinkage
Creep under sustained load
Thermal stresses caused by heat of hydration
Chemically incompatibility of concrete components

DIRECT STRESS DUE TO APPLIED LOAD OR REACTION

Unusual load cases
Earthquake
Excessive change of climate
etc.

CONDITIONS FOR PREVENTION OF CRACKING IN MASS CONCRETE

Cement of low heat generation

Low cement content (permitted by low design stress)

Concrete with large strain capacity to failure

Low degree of restraint

Precooling of concrete components (low casting temperature)

Postcooling (embedded pipe system)

Short blocks

Insulation

Avoidance of stress raisers (galleries etc.)

CEMENT OF LOW HEAT GENERATION

CHEMICAL COMPOSITION OF PORTLANDCEMENT

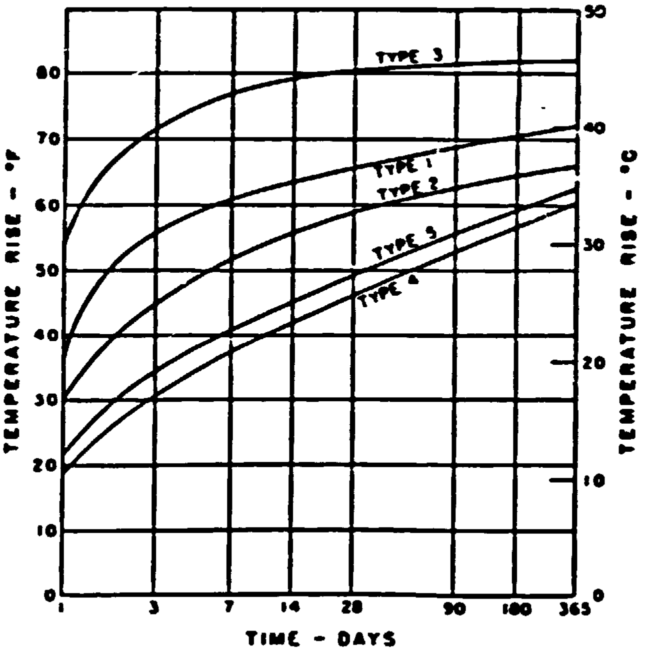
		%
Silica (Kieselsäure)	SiO_2	18-24
Alumina (Tonerde)	Al_2O_3	4- 9
Iron oxide (Eisenox.)	Fe_2O_3	1- 4
Lime (Kalk)	CaO	60-67
Magnesia	MgO	1- 5
Sulphurtrioxide (Schwefelsäureanhydrid)	SO_3	1- 2

CEMENT CLINKER MATERIALS

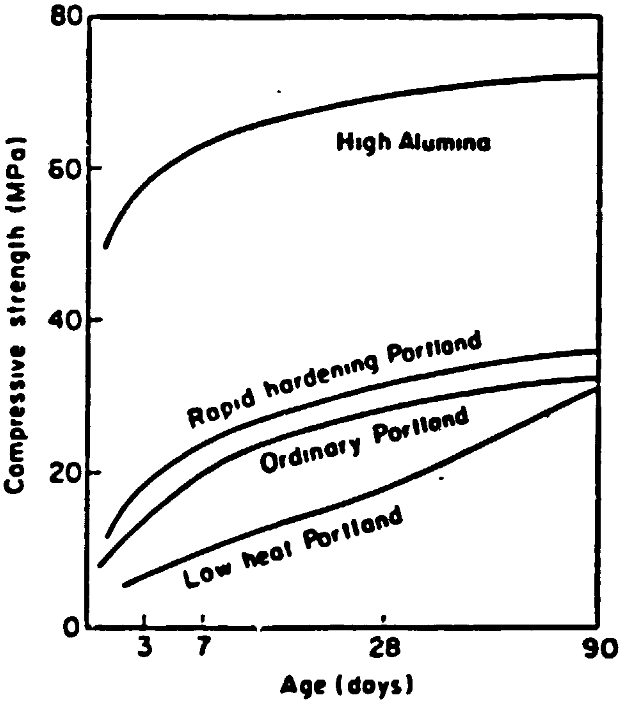
		Abbreviated
Tri-Calcium Silicate	$3CaOSiO_2$	C_3S
Di-Calcium Silicate	$2CaOSiO_2$	C_2S
Tri-Calc. Aluminate	$3CaOAl_2O_3$	C_3A
Tetra-Calc. Alumina-Ferrite	$4CaOAl_2O_3Fe_2O_3$	C_4AF

ASTM - TYPES OF CEMENT

		max C_3A cont.(%)
Type I	Regular - standard cement	15
Type II	Moderate heat of hydration Moderate sulfate resistance	8
Type III	High early strength	15
Type IV	Low heat of hydration C_3S max 35%	7
Type V	High sulfate resistance	5



Cement-type inluenced temperature rise of mass concrete (ACI)



Strength-age relationships for different cements (H. Thomas)

LOW CEMENT CONTENT : Special types of cement

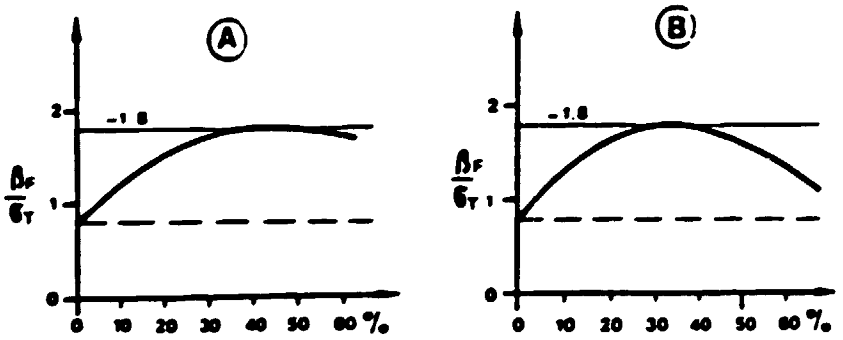
Blast furnace slag cement: Slag-cement is finely divided material consisting essentially of an intimate and uniform blend of granulated blast-furnace slag and hydrated lime.

Pozzolan cements : Pozzolan is defined as siliceous or siliceous and aluminous material which itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.

Characteristics : Saving of cement(Low heat development)

Reduction of water requirement

Slow strength development - design of mass concrete structures on the basis of 90-day to 1-year strength.



β_T Temperature induced tensile stress

β_F Flexural strength

Optimization of blast-furnace slag(A) and fly-ash (B) contents in case of Zillergründl arch dam (Widmann)

CONCRETE WITH LARGE STRAIN CAPACITY TO FAILURE

The strain capacity of concrete varies greatly with the composition of the concrete and the speed at which strain is applied.

Aggregates: The size of aggregates is a major factor - small maximum aggregate size allows a high tensile strain to failure but requires more cement for a given strength and vice versa causes more heat of hydration.

Coefficient of thermal expansion - low thermal expansion is favorable, for temperature change is the main contributor to tensile strain in mass concrete during the hardening process

Modulus of elasticity - regarding large strain capacity a low modulus of the aggregate material would be preferable.

Loading rate: The influence of loading rate on tensile strain capacity is shown in Fig.2.7

TABLE 2.3 — Linear thermal coefficient of expansion of concrete (ACI)

Coarse aggregate	Thermal coefficient of expansion Millionths/deg F	 Millionths/deg C
Quartzite	7.5	13.5
Siliceous	5.2-6.5	9.4-11.7
Basalt	4.6	8.3
Limestone	3.0-4.8	5.4-8.6

TABLE 2.7 — Tensile strain capacity (ACI)

Concrete components	Tensile strains (Millionths) (a) (b) Rapid test (Initial)	 Slow test	 Rapid test (Final)
Quartz diorite (natural) w/c 0.66 (c)	64 (89)	118 (102)	88 (78)
Quartz diorite (natural) w/c + p 0.63 (c)	52 (65)	88 (80)	73 (74)
Granite gneiss (crushed) w/c + p 0.60	86	245	110
Limestone (crushed) Quartz sand (natural) w/c + p 0.63	45 (70)	95 (89)	73 (75)
Limestone (crushed) Quartz sand (natural) w/c + p 0.47	62 (66)	107 (83)	80 (71)

(a) At 90 percent of failure [illegible]

(b) Mean values [illegible] in parentheses are from [illegible] at 7-days age. Values in parentheses are from [illegible] at 28 days or [illegible]

RESTRAINT : Definition - Hold back from action

Restraint acts to limit the the change in dimensions.

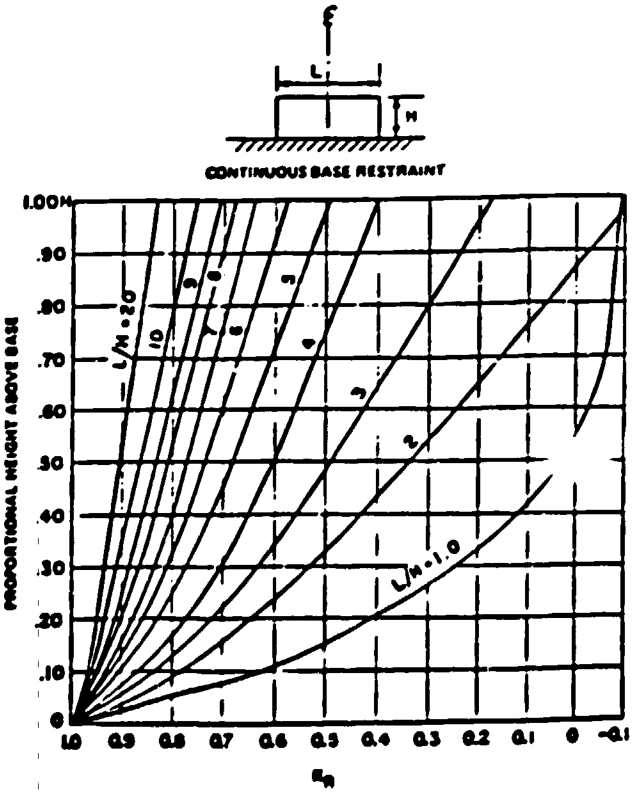
Continous restraint exists along the contact surfac of concrete and any material against which the concrete has been cast.

$$\sigma = K_R E_c \alpha \Delta T \lambda$$

σ	Temperature stress
K_R	Restraint factor
E_c	Modulus of elasticity of concrete
ΔT	Temperature difference
α	Coeff. of thermal expansion
λ	Multiplier regarding E_c/E_R
E_R	Modulus of elasticity of restraining mass

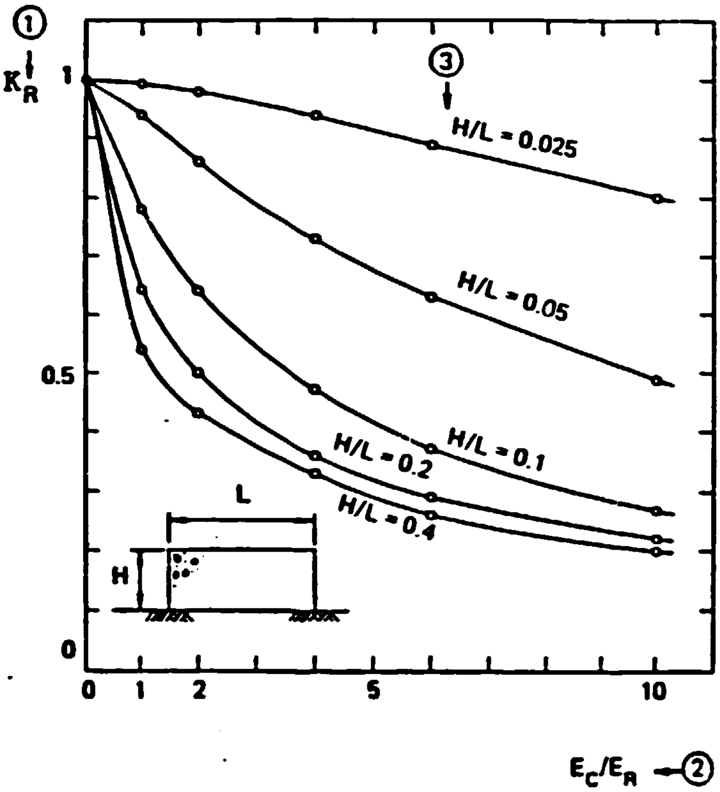
$\frac{E_R}{E_C}$	Multipliers λ
∞	1.0
2	0.83
1	0.71
0.5	0.56
0.2	0.33
0.1	0.20

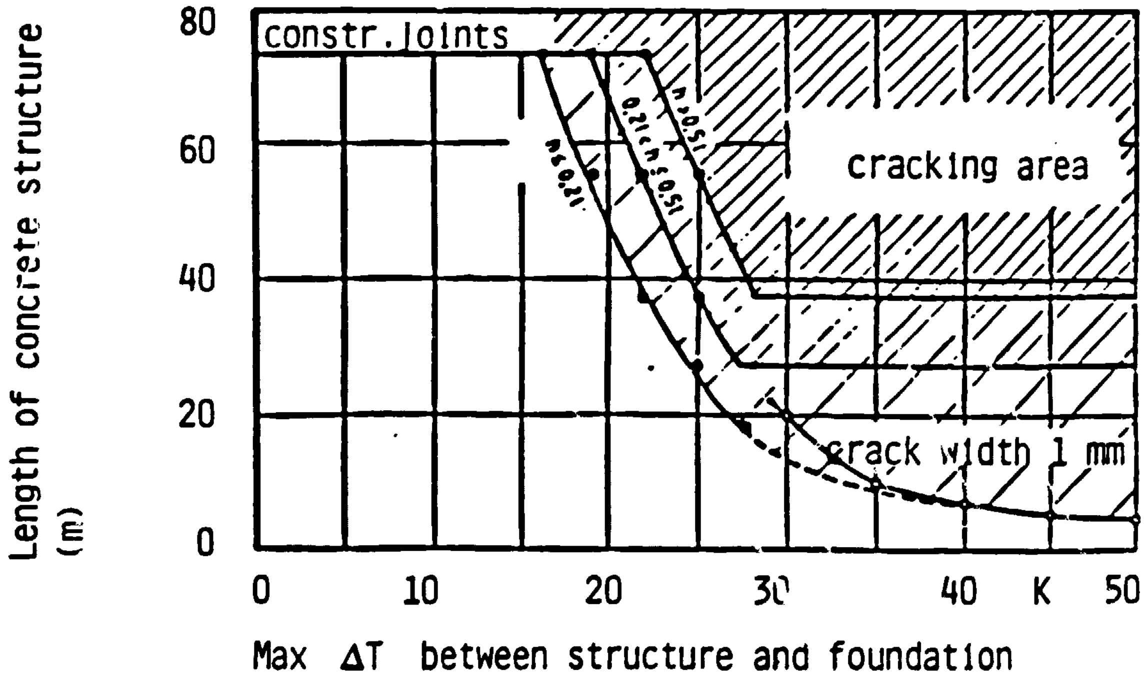
(ACI)



$$\sigma = K_R \, E_C \, \alpha \, \Delta T$$

(Fujigawa/Nagayama)





<u>Distance of construction joints</u> (Townsend)
(Wischers)

TABLE 3.1.3 — CONCRETE MIXES OF 23 DAMS AND RELATED INFORMATION (ACI)

No.	Name	Year completed	Type	Cement Type	Cement lb/cu yd. (kg/m³)	Pozzolan Type	Pozzolan lb/cu yd. (kg/m³)	Sand lb/cu yd. (kg/m³)	Coarse aggregate lb/cu yd. (kg/m³)	Coarse aggregate Type	MSA, in. (cm)	Water lb/cu yd. (kg/m³)	W/C	Entrained air, percent	Parts aggregate	Density lb/cu yd. (kg/m³)	WRA admixture used
1	Hoover	1936	Arch gravity	IV	380 (225)	—	0	931 (552)	2679 (1589)	Limestone and granite	9.0 (22.9)	220 (130)	0.58	0	9.5	4210 (2497)	No
2	Grand Coulee	1942	Straight gravity	II and IV	377 (224)	—	0	982 (583)	2268 (1345)	Basalt	6.0 (15.2)	226 (134)	0.60	0	9.4	4133 (2452)	No
3	Friant	1942	Straight gravity	IV	300 (178)	Pumicite	60 (36)	902 (535)	2636 (1564)	Quartzite, granite, and rhyolite	8.0 (20.3)	214 (127)	0.59	0	9.9	4136 (2454)	No
4	Shasta	1945	Curved gravity	IV	370 (219)	—	0	905 (537)	2721 (1614)	Andesite and slate	6.0 (15.2)	206 (122)	0.56	0	9.8	4202 (2493)	No
5	Hungry Horse	1953	Arch gravity	II	188 (111)	Fly Ash	90 (53)	842 (499)	3055 (1812)	Sandstone	6.0 (15.2)	130 (77)	0.47	3.0	13.2	4170 (2474)	No
6	Glen Canyon	1963	Arch gravity	II	188 (111)	Pumicite	94 (56)	777 (461)	2783 (1651)	Limestone, chalcedonic chert, and sandstone	6.0 (15.2)	153 (91)	0.54	3.5	12.8	3996 (2371)	No
6A	(0.27 percent admixture added)	1963	Arch gravity	II	188 (111)	Pumicite	90 (53)	800 (475)	2802 (1662)		6.0 (15.2)	140 (83)	0.50	3.0	13.0	4020 (2385)	Yes
7	Flaming Gorge	1962	Arch gravity	II	188 (111)	Calc. shale	94 (56)	720 (427)	2900 (1720)	Limestone and sandstone	6.0 (15.2)	140 (83)	0.53	3.5	12.9	4042 (2398)	No
8	Yellowtail	1965	Arch gravity	II	197 (117)	Fly Ash	85 (50)	890 (528)	2817 (1671)	Limestone and andesite	6.0 (15.2)	138 (82)	0.49	3.0	13.1	4128 (2449)	No
9	Morrow Point	1967	Thin Arch	II	375 (223)	—	0	616 (365)	2851 (1691)	Andesite, tuff, and basalt	4.5 (11.4)	196 (116)	0.52	4.5	9.2	4063 (2410)	Yes
10	Bartlett	1939	Multiple Arch	IV	466 (276)	—	0	1202 (713)	2260 (1341)	Quartzite and granite	3.0 (7.6)	270 (160)	0.58	0	7.5	4198 (2490)	No
11	Bonneville	1938	Gravity	Portland pozzolan	329 (195)	—	0	1094 (649)	2551 (1513)	Basalt	6.0 (15.2)	251 (149)	0.76	0	11.1	4225 (2506)	No
12	Detroit	1953	Straight gravity	II and IV	226 (134)	—	0	1000 (593)	2690 (1596)	Diorite	6.0 (15.2)	191 (113)	0.85	3.5	16.2	4107 (2437)	No
13	Norris	1936	Straight gravity	II	338 (200)	—	0	1304 (774)	2472 (1467)	Dolomite	6.0 (15.2)	227 (135)	0.67	0	11.3	4312 (2558)	No
14	Kentucky	1944	Straight gravity	II	338 (200)	—	0	967 (573)	2814 (1670)	Limestone	6.0 (15.2)	213 (126)	0.63	0	10.8	4138 (2455)	No
15	Hartwell	1963	Gravity	II	168 (100)	Fly Ash	57 (34)	797 (473)	3000 (1780)	Granite	6.0 (15.2)	182 (108)	0.80	6.5	16.8	4052 (2404)	No
16	John Day	U.C.	Gravity	II	148 (88)	Calc. shale	50 (30)	937 (556)	2970 (1762)	Nat. gravel	6.0 (15.2)	135 (80)	0.68	5.0	10.7	4200 (2492)	No
17	Salamonde (Portugal)	1953	Thin Arch	II	421 (250)	--	0	739 (438)	2837 (1683)	Granite	7.9 (20.0)	225 (133)	0.54	0	8.0	4005 (2376)	
18	Pieve di Cadore (Italy)	1949	Arch gravity	Ferric-pozzolanic	252 (150)	Natural	84* (50)	1180 (700)	3000 (1780)	Limestone	4.7 (12.0)	213 (126)	0.63	2.0	8.7	4316 (2560)	Yes
19	Rossens (Switzerland)	1948	Arch	I	421 (250)	—	0			Limestone	3.1 (8.0)	225 (133)	0.53	0			No
20	Chastang (France)	1951	Arch gravity	250/315	379 (225)			730 (433)	2785 (1652)	Granite	9.8 (25.0)	168 (100)	0.43		9.2	4072 (2416)	
21	Warragamba (Australia)	1960	Straight gravity	II	330 (196)	—	0	846 (502)	3045 (1806)	Porphyry and quartzite	6.0 (15.2)	175 (104)	0.53	0	11.8	4162 (2469)	No
22	Francisco Madero (Mexico)	1949	Round-Head Buttress	IV	372 (221)			882 (523)	2381 (1413)	Rhyolite and basalt	6.0 (15.2)	223 (132)	0.60		8.8		
23	Krasnoiarsk (USSR)	U.C.†	Straight gravity	IV and portland blast-furnace	380 (225)	—	0			Granite	3.9 (10.0)	213 (126)	0.56				Yes

*Pozzolan interground with cement (20 percent pozzolan for the summer months).

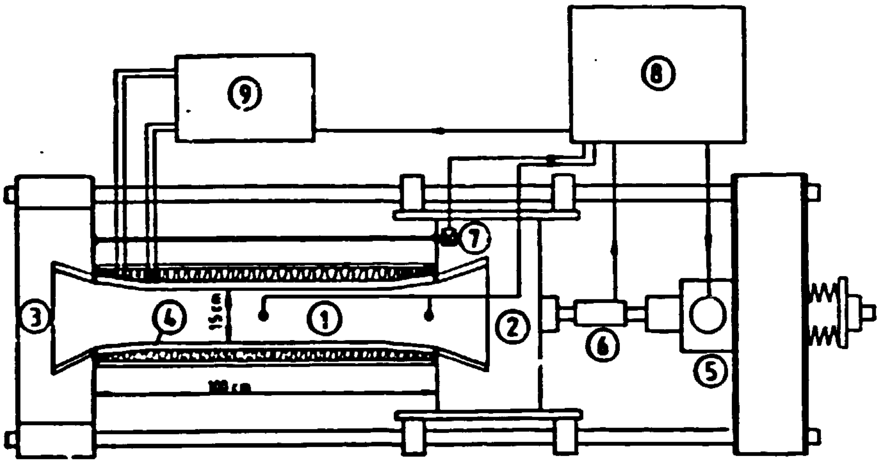
†Data gathered in 1958.

TABLE 3.7.1 — THERMAL PROPERTIES OF CONCRETE (ACI)

Structure	Coarse aggregate type	British units: Temperature, °F	British units: Coefficient of expansion,* 1/°F × 10⁻⁶, 1½ in. (3.8 cm) max	British units: Coefficient of expansion,* 1/°F × 10⁻⁶, 4½ in. (11.4 cm) max	British units: Thermal conductivity, Btu/(ft × hr × °F)	British units: Specific heat, Btu/(lb × °F)	British units: Density, lb/ft³	British units: Diffusivity, ft²/hr	Metric units: Temperature, °C	Metric units: Coefficient of expansion,* 1/°C × 10⁻⁶, 1½ in. (3.8 cm) max	Metric units: Coefficient of expansion,* 1/°C × 10⁻⁶, 4½ in. (11.4 cm) max	Metric units: Thermal conductivity, Kcal/(m × hr × °C)	Metric units: Specific heat, Kcal/(kg × °C)	Metric units: Density, kg/m³	Metric units: Diffusivity, m²/hr × 10⁻³
Hoover	Limestone and granite	50 100 150	5.3	4.8	1.70 1.67 1.65	0.212 0.225 0.251	156.0	0.051 0.047 0.042	10 38 66	9.5	8.6	2.53 2.48 2.46	0.212 0.225 0.251	2500	4.7 4.4 3.9
Grand Coulee	Basalt	50 100 150	4.4	4.8	1.08 1.08 1.09	0.219 0.231 0.257	156.1	0.031 0.030 0.027	10 38 66	7.9	8.6	1.61 1.61 1.62	0.219 0.231 0.257	2500	2.9 2.7 2.5
Friant	Quartzite, granite and rhyolite	50 100 150	—	—	1.23 1.23 1.24	0.216 0.230 0.243	151.0	0.037 0.035 0.033	10 38 66	—	—	1.83 1.83 1.84	0.216 0.230 0.243	2420	3.4 3.2 3.1
Shasta	Andesite and slate	50 100 150	—	4.8	1.32 1.31 1.31	0.219 0.233 0.247	158.6	0.038 0.036 0.034	10 38 66	—	8.6	1.96 1.95 1.95	0.219 0.233 0.247	2540	3.5 3.3 3.2
Angostura	Limestone	50 100 150	4.3	—	1.49 1.46 1.44	0.221 0.237 0.252	151.2	0.045 0.041 0.038	10 38 66	7.8	—	2.22 2.17 2.14	0.221 0.237 0.252	2420	4.2 3.8 3.5
Kortes	Granite, gabbros and quartz	50 100 150	5.2	4.6	1.61 1.60 1.59	0.208 0.221 0.234	156.6	0.050 0.047 0.044	10 38 66	9.4	8.3	2.40 2.38 2.37	0.208 0.221 0.234	2510	4.6 4.4 4.1
Hungry Horse	Sandstone	50 100 150	6.2	5.7	1.72 1.71 1.69	0.217 0.232 0.247	150.1	0.053 0.049 0.046	10 38 66	11.2	10.3	2.56 2.54 2.51	0.217 0.232 0.247	2400	4.9 4.6 4.3
Canyon Ferry	Sandstone, metasiltstone, quartzite, and rhyolite	50 100 150	5.4	5.2	1.63 1.61 1.59	0.214 0.226 0.238	151.3	0.050 0.047 0.044	10 38 66	9.7	9.4	2.42 2.40 2.36	0.214 0.226 0.238	2420	4.6 4.4 4.1
Monticello	Sandstone (graywacke), and quartz	50 100 150	5.2	—	1.57 1.55 1.53	0.225 0.237 0.250	151.1	0.046 0.043 0.040	10 38 66	9.4	—	2.34 2.31 2.28	0.225 0.237 0.250	2424	4.3 4.0 3.7
Anchor	Andesite, latite, and limestone	50 100 150	5.8	4.8	1.14 1.16 1.15	0.227 0.242 0.258	149.0	0.034 0.032 0.030	10 38 66	10.4	8.6	1.70 1.73 1.71	0.227 0.242 0.258	2390	3.2 3.0 2.8
Glen Canyon	Limestone, chert and sandstone	50 100 150	—	—	1.45 1.38 1.37	0.217 0.232 0.247	150.2	0.045 0.040 0.037	10 38 66	—	—	2.17 2.05 2.03	0.217 0.232 0.247	2407	4.2 3.7 3.4
Flaming Gorge	Limestone and sandstone	50 100 150	—	—	1.78 1.75 1.73	0.221 0.234 0.248	150.4	0.054 0.050 0.046	10 38 66	—	—	2.65 2.60 2.57	0.221 0.234 0.248	2411	5.0 4.6 4.3
Yellowtail	Limestone and andesite	50 100 150	—	4.3	1.56 1.53 1.49	0.213 0.228 0.242	155.0	0.047 0.044 0.040	10 38 66	—	7.7	2.31 2.28 2.22	0.213 0.228 0.242	2484	4.4 4.1 3.7

*1½ in. (3.8 cm) max and 4½ in. (11.4 cm) max refer to maximum size of aggregate in concrete.

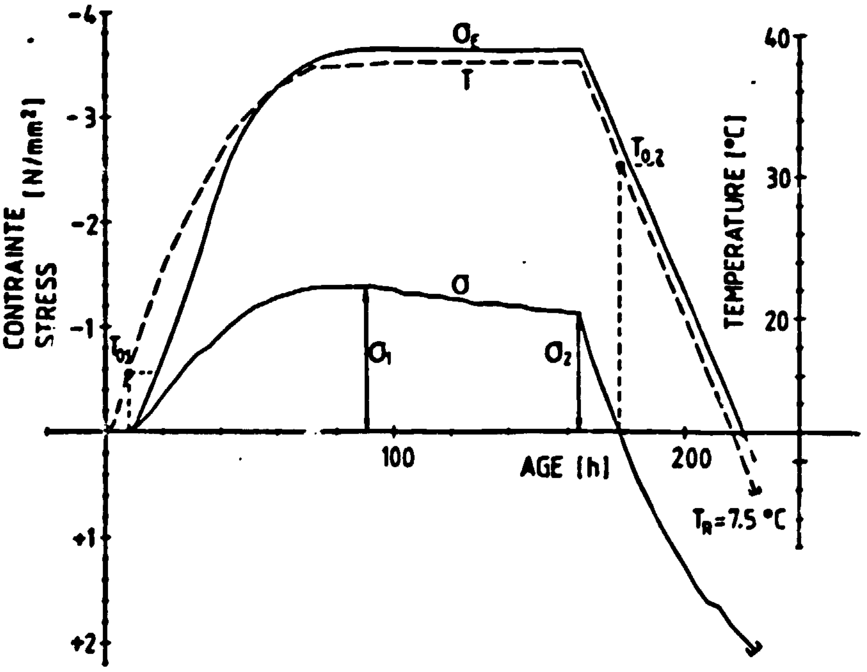
THERMAL STRESS TESTING MACHINE (Springenschmid,R.,Gierlinger,E.,Kiernozycki,W.: 15 th Icold, Lausanne)



Thermal-stress-testing-machine

Appareil d'étude des contraintes thermiques

1. Concrete specimen	*1. Eprouvette de béton*
2. Movable crosshead	*2. Tête d'ancrage mobile*
3. Fixed crosshead	*3. Tête d'ancrage fixe*
4. Temperature regulated mould	*4. Moulage tempéré*
5. Motor and transmission	*5. Moteur et engrenage*
6. Dynamometer	*6. Dynamomètre*
7. Length-measuring-system	*7. Dispositif de mesure des déformations*
8. Electronic control and recording units	*8. Equipement de contrôle et d'enregistrement*
9. Thermostat	*9. Thermostat*



Typical Result of a Test with the Thermal-stress-testing-machine (Cement E)

Résultats typiques d'une mesure avec l'appareil d'étude des contraintes thermiques (Ciment E)

T = Temperature	*T = Température*
σ = Thermal stresses	*σ = Contraintes thermiques*
σ_E = Computed elastic thermal stresses	*σ_E = Contraintes thermiques calculées*
$T_{0,1}$; $T_{0,2}$ = First — and second	*$T_{0,1}$; $T_{0,2}$ = Première — et deuxième*

PRECOOLING : The strongest influence on the avoidance of thermal cracking is the control of concrete placing temperatures.

$$T_p = T_f + C/(\alpha K_R) - \Delta T$$

T_p = Placing temperature

C = Strain capacity (10^{-6})

K_R = Degree of restraint

T_f = Final temperature

α = Coeff. of thermal exp.

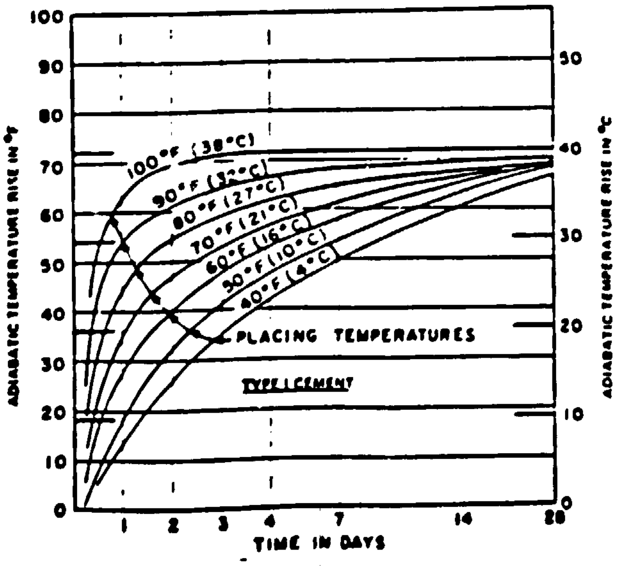
ΔT = Initial temperature rise of concrete

METHODS OF PRECOOLING

Mixing water:	Chilled mixing water Ice mixing water
Aggregate cooling:	Processing fine aggregate in chilled water Sprinkling of coarse aggregate stockpiles Immersion cooling of coarse aggregates Chilled water spray Vacuum cooling of aggregates
Cementitious materials:	Cooling unfavorable

Effect of placing temperature on temperature rise of mass concrete containing 225 Kg/m^3 of Type I cement

(ACI)



POSTCOOLING SYSTEMS

The principle of postcooling systems consists in circulating cool water through thin walled pipes embedded in the concrete.

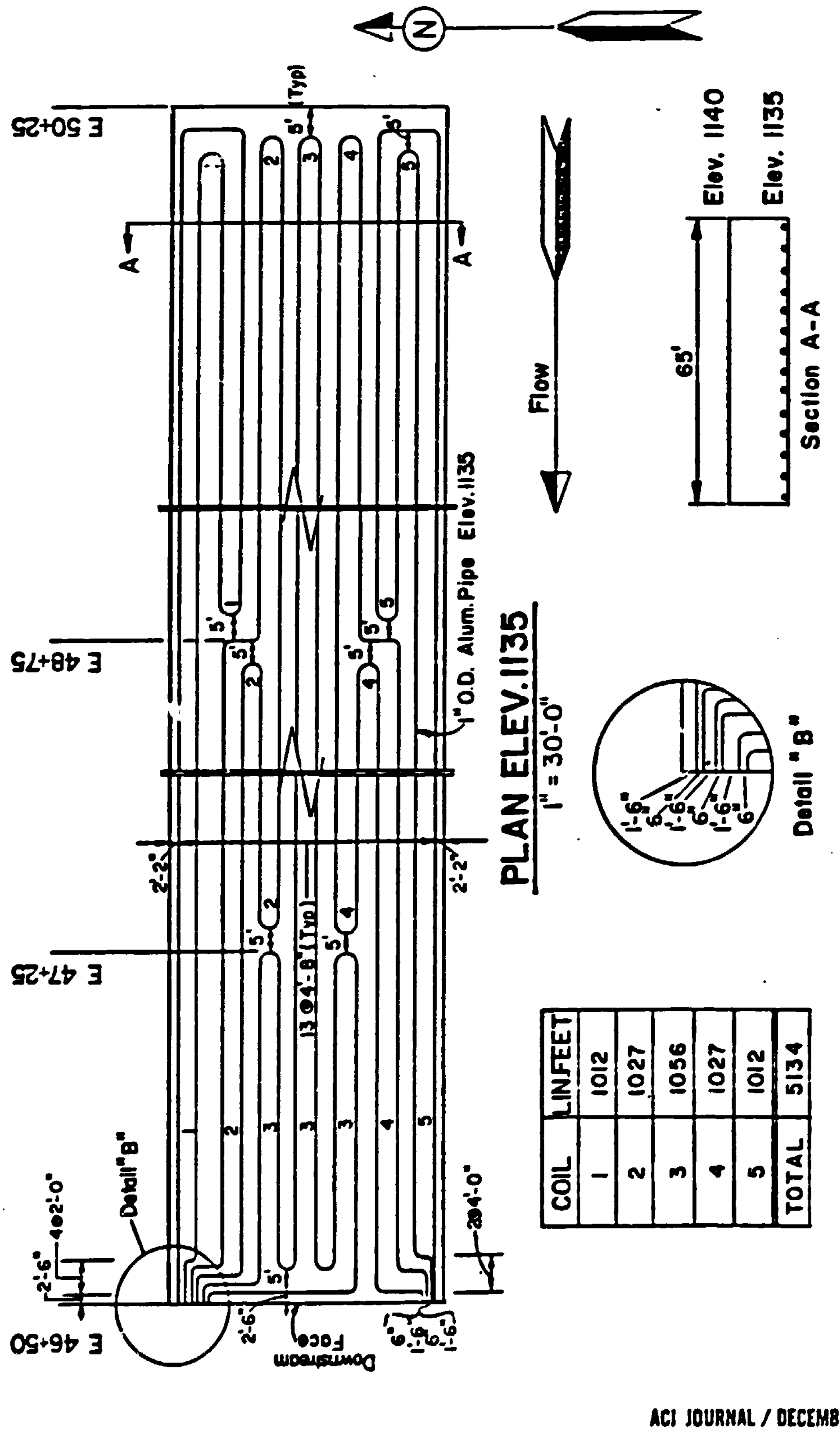
The heat removed during the first days following placement will reduce the initial peak temperature, but the primary purpose is to accelerate the subsequent heat removal during early ages when the modulus of elasticity is relatively low.

In the final construction period the cooling system is used for regulating the concrete temperature to gain full continuum behavior by (vertical) joint grouting.

Materials of pipes:	Aluminium or thin walled steel tubing, 25 mm outside diameter-1.5 mm wall thickness
Spacing:	Vertical pipe-spacing is due to the lift thickness. Horizontal spacing very often is the same as the vertical one
Pipe layout:	Max pipe length should be 250 m accordung to the heating of the cooling water during the process
Cooling rates:	The cooling rate for long time period should not exceed 0.6^{0} C - for short period of cooling 1.0^{0} C. (10^{0} to 20^{0} C within a 30 day period
Temperature monitoring	A perpetual monitoring of temperature situation is required (Resistance type thermometers)

Cooling water supply:

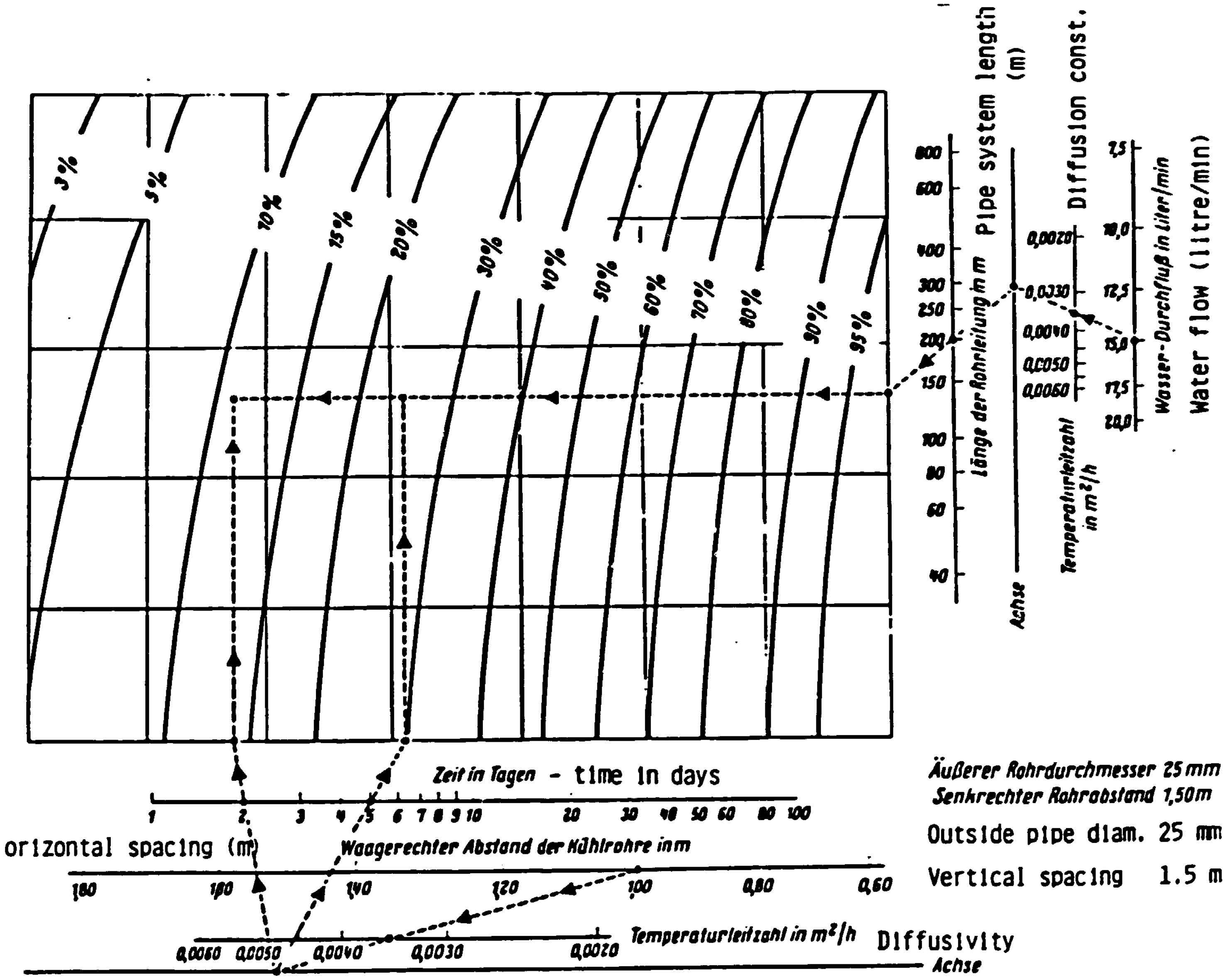
Refrigeration plant or natural water sources (glacier)



COIL	LIN.FEET
1	1012
2	1027
3	1056
4	1027
5	1012
TOTAL	5134

Fig. 7.4 — Typical cooling coil layout (Reference 7.4)

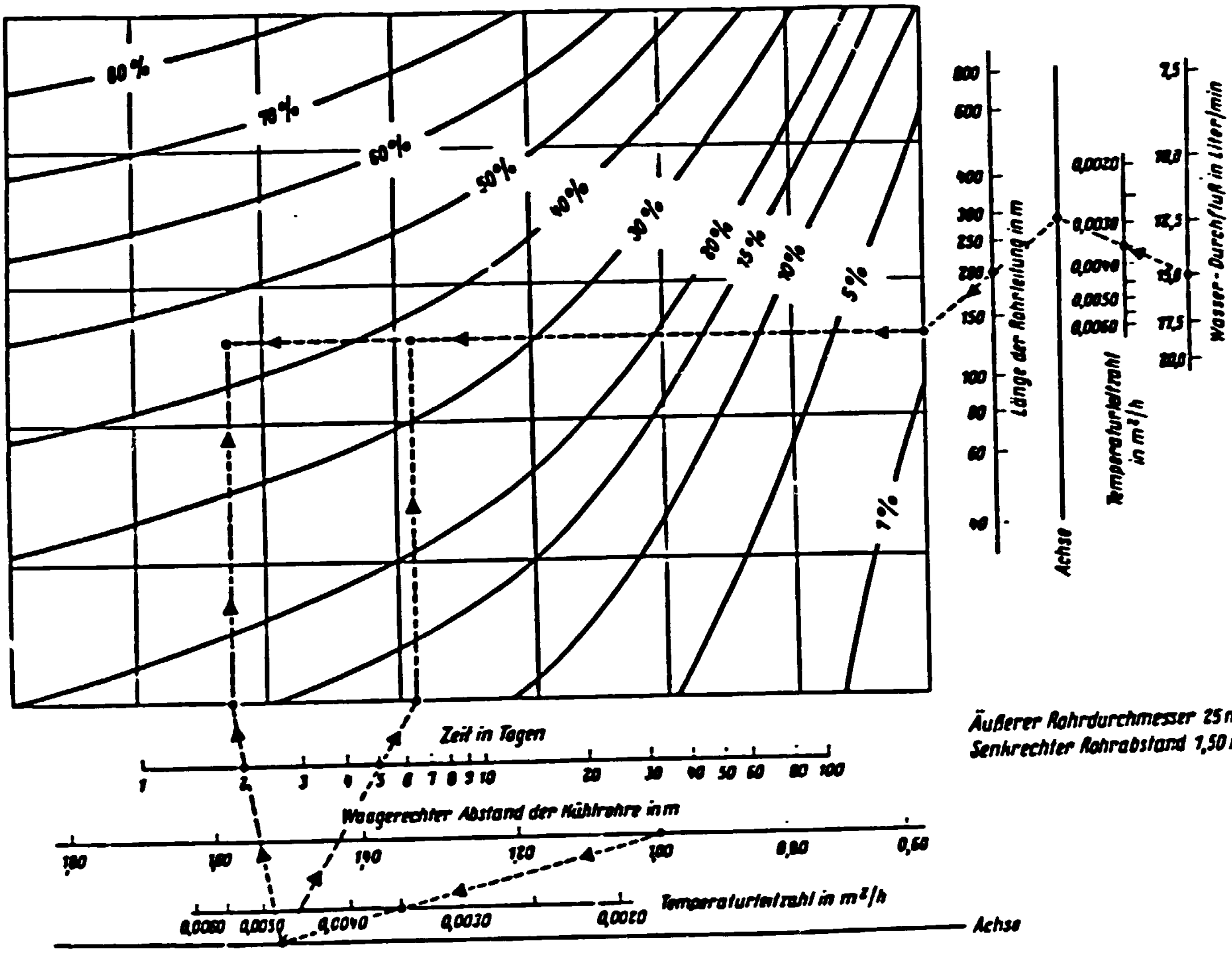
POSTCOOLING (PIPE) SYSTEM



Final mean temperature difference in percent per degree initial temperature difference (Rawhouser/Wischers)

Betonkühlung in Prozent des ursprünglichen Temperaturunterschiedes zwischen Beton und Kühlwasser

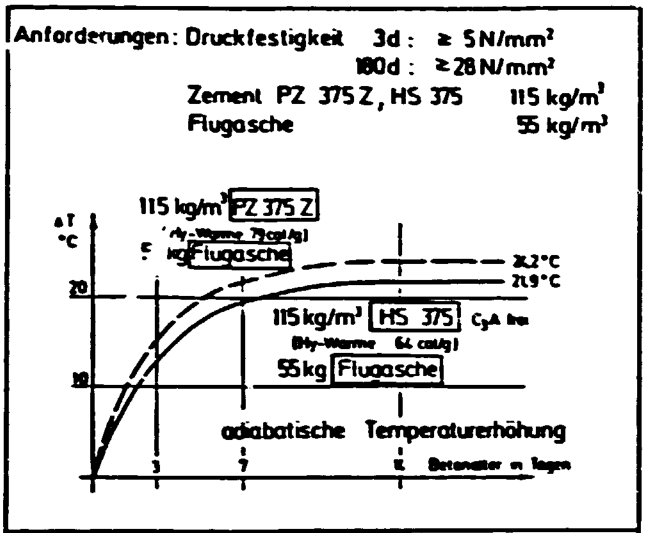
POSTCOOLING (PIPE) SYSTEM



Äußerer Rohrdurchmesser 25 mm
Senkrechter Rohrabstand 1,50 m

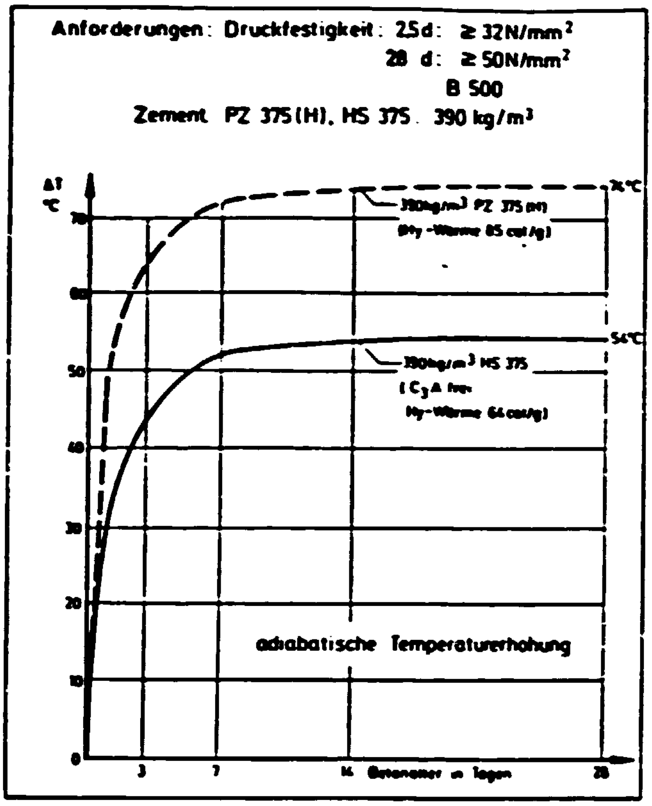
Temperature rise of water in pipes in percent per degree initial temperature difference (Rawhouser/Wischers)

Erwärmung des Kühlwassers in Prozent des ursprünglichen Temperaturunterschiedes zwischen Beton und Kühlwasser



	maximale Betontemperatur
Frischbetontemperatur 15°C, Lufttemperatur 16°C	
115 kg PZ 375 Z 55 kg Flugasche	40 °C
HS 375	−2 °C
Vorkühlung — Beigabe von 50kg Scherbeneis pro m³ FB	− 8 °C
Nachkühlung — Rohrinnenkühlung in jeder 3m – Zone	− 4 °C

a)



b)

a) Cement content and heat development of mass concrete

b) Cement content and heat development of construction concrete

(H.Huber - Zement und Beton 4, 1987)

Anforderung	Demand
Druckfestigkeit	Compressive Strength
Flugasche	Fly ash
Adiabatische Temperaturerhöhung	Adiabatic temperature rise
Betonalter in Tagen	Concrete age in days
Betontemperatur	Temperature of concrete
C_3A frei	C_3A free
Vorkühlung	Precooling
Nachkühlung	Postcooling
Rohrinnenkülung	Pipe cooling

Statements concerning the efficiency of different measures referring to the temperature development in mass concrete structures during construction

Quotation : Ukrainicyk,V.,Miculic,D.,Mekhile,Y.: Cracks in mass concrete at early ages in Haditha dam. 15th ICOLD, Lausanne

1) Influence of concrete placing temperature (T[illegible])

A 1° C increase of T[illegible] results in the increase of 1... 1.2° C of maximum temperature in the block.

2) Influence of lift height change (h)

Maximum lift temperature changes significantly by lift height change from 1 m to 2 m. In cements with low heat of hydration T_{max} increases by 4° C. The increase of maximum temperature with lift height change from 2 m to 3 m and 4 m is not so great. Maximum temperature gradient changes negligibly with lift height change.

3) Influence of period between pouring lift on lift

The change in the period between pouring lift on lift from one to three and seven days results in slight changes in maximum temperature (1... 3° C).

Maximum temperature gradient in a lift does not change numerically with regard to the days of placing considered.

4) Influence of cement quantity

In cements with low hydration heat an increase of 10 kg per cubic metre increases the maximum temperature by 1° C. Maximum temperature gradient increases with a greater quantity of cement used per cubic metre.

5) Influence of environmental temperature

Constant environmental temperature provides for a constant maximum gradient of 6... 7° C/25 cm for different lift heights and different days of pouring lift on lift. If the environmental temperature changes by 15° C, the maximum temperature gradient changes by 11... 12° C/25 cm for all heights and sequences of pouring.

COMPUTER PROGRAM FOR DETERMINING TEMPERATURE AND STRAIN (STRESS) SITUATIONS IN MASS CONCRETE STRUCTURES DURING CONSTRUCTION PERIOD

General remarks : (ACI - Control of cracking)

Tensile strain in mass concrete results mainly from the restraint of thermal contraction, and to lesser degree from autogenous shrinkage. The prediction of probable strain requires the prediction of temperatures to be espected. This prediction can be made quite reliably if the adiabatic temperature curve for the concrete is known, as well as the thermal diffusivity, boundary temperatures and dimensions.

The method is one of employing finite elements both as to space and time, and lends itself to solution for one, two and three dimensions by digital computer.

The determination of probable tensile strain was considered impossible until computer techniques of sufficient versatility became available. Even with the finite element method, the thorough analysis is laborious because of the time dependent variables.

The analysis must include many steps of time to properly account for the temperature, the creep (relaxation), the modulus of elasticity, varying boundary conditions etc.

The possibility of determining the influence of lift heights and lift placing time on the strain development has to be included in the program.

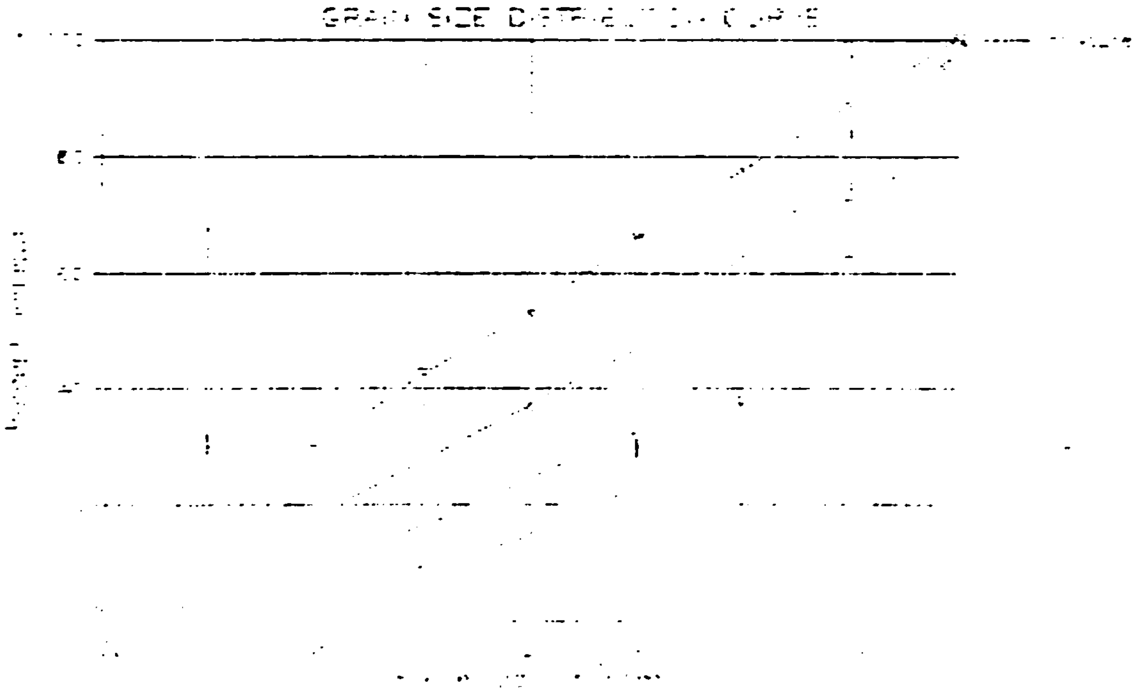
ANNEX 2 - TEST RESULTS

GRADATION OF AGGREGATE FRACTIONS

AGGREGATE FRACTIONS	Sieve size in mm .125	.25	.5	1.0	2.0	4.0	8.0	16.0	31.5
RIVER SAND	.0	.0	.0	.0	.0	.0	.0	.0	.0
0/4 HOTIC	7.3	15.5	30.9	45.2	66.3	85.9	99.0	100.0	100.0
4/8 HOTIC			.0	.0	2.3	10.8	99.2	100.0	100.0
8/16 HOTIC				.0	.6	3.1	26.0	96.5	100.0
16/31.5 HOTIC					.0	.0	.5	17.4	100.0

COMBINED GRADIATION FOR MIXTURE FOR CONCRETE 0/31.5 mm

AGGREGATE FRACTIONS	PERC. USED	Sieve size in mm .125	.25	.5	1.0	2.0	4.0	8.0	16.0	31.5
RIVER SAND	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
0/4 HOTIC	36.0	2.6	5.6	11.1	16.3	24.0	30.9	35.6	36.0	36.0
4/8 HOTIC	7.0	.0	.0	.0	.0	.2	.8	6.9	7.0	7.0
8/16 HOTIC	25.0	.0	.0	.0	.0	.2	.8	6.5	24.1	25.0
16/31.5 HOTIC	32.0	.0	.0	.0	.0	.0	.0	.2	5.6	32.0
SUM	100	2.6	5.6	11.1	16.3	24.4	32.5	49.2	72.7	100.0

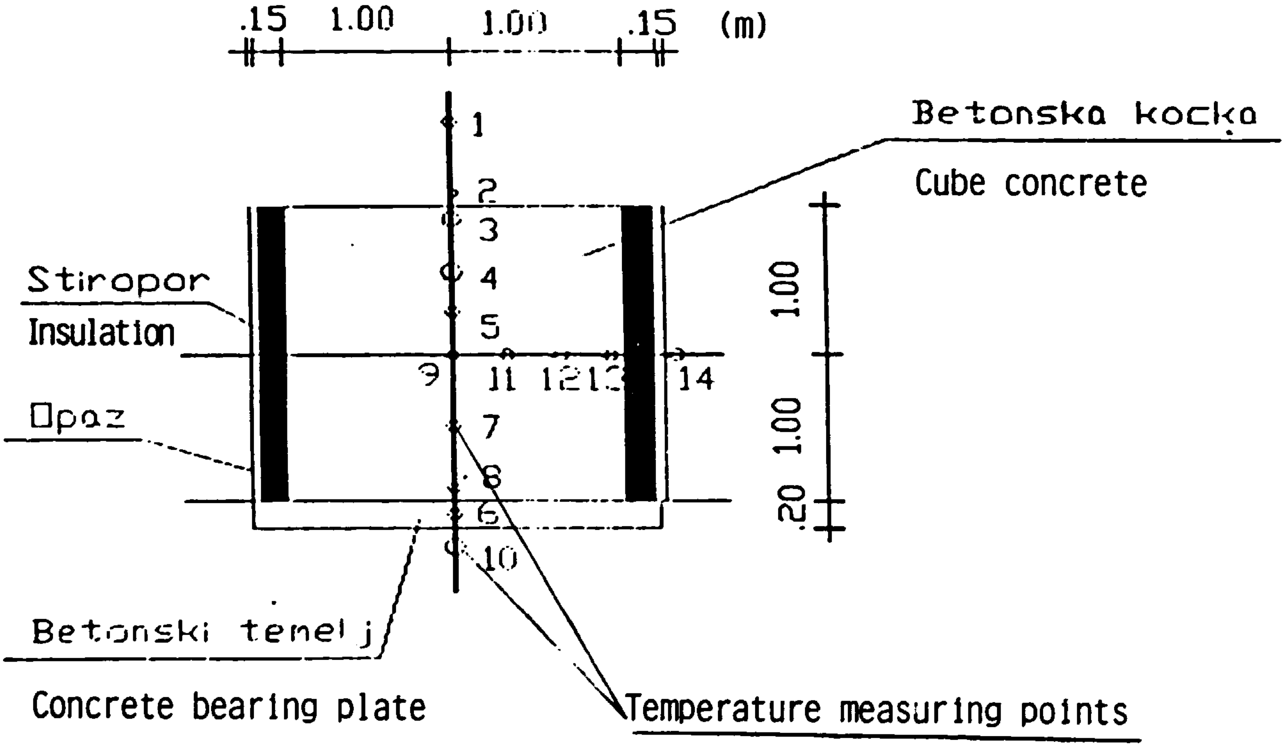


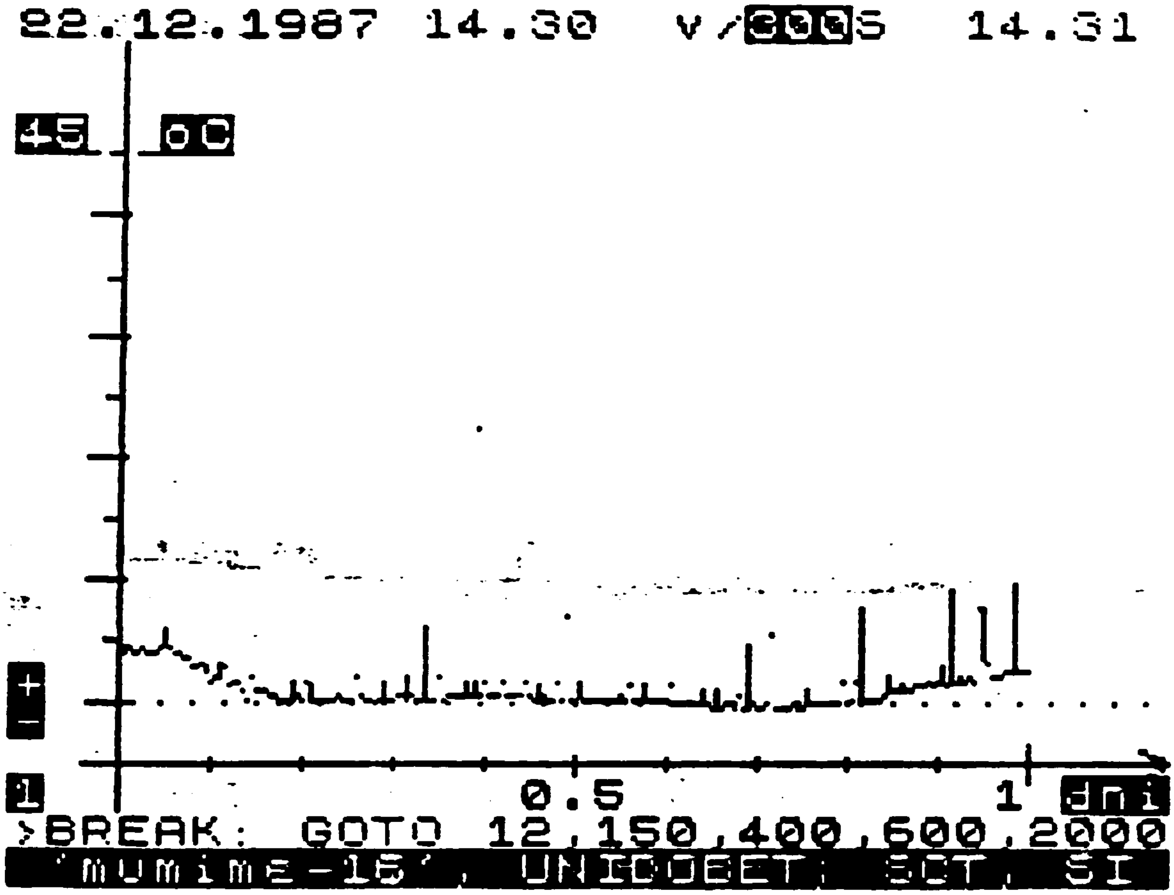
Propose of concrete: Cube
Mixture design: 200-1
W/C ratio : .69
Quantity of concrete: .555 m3 555 l

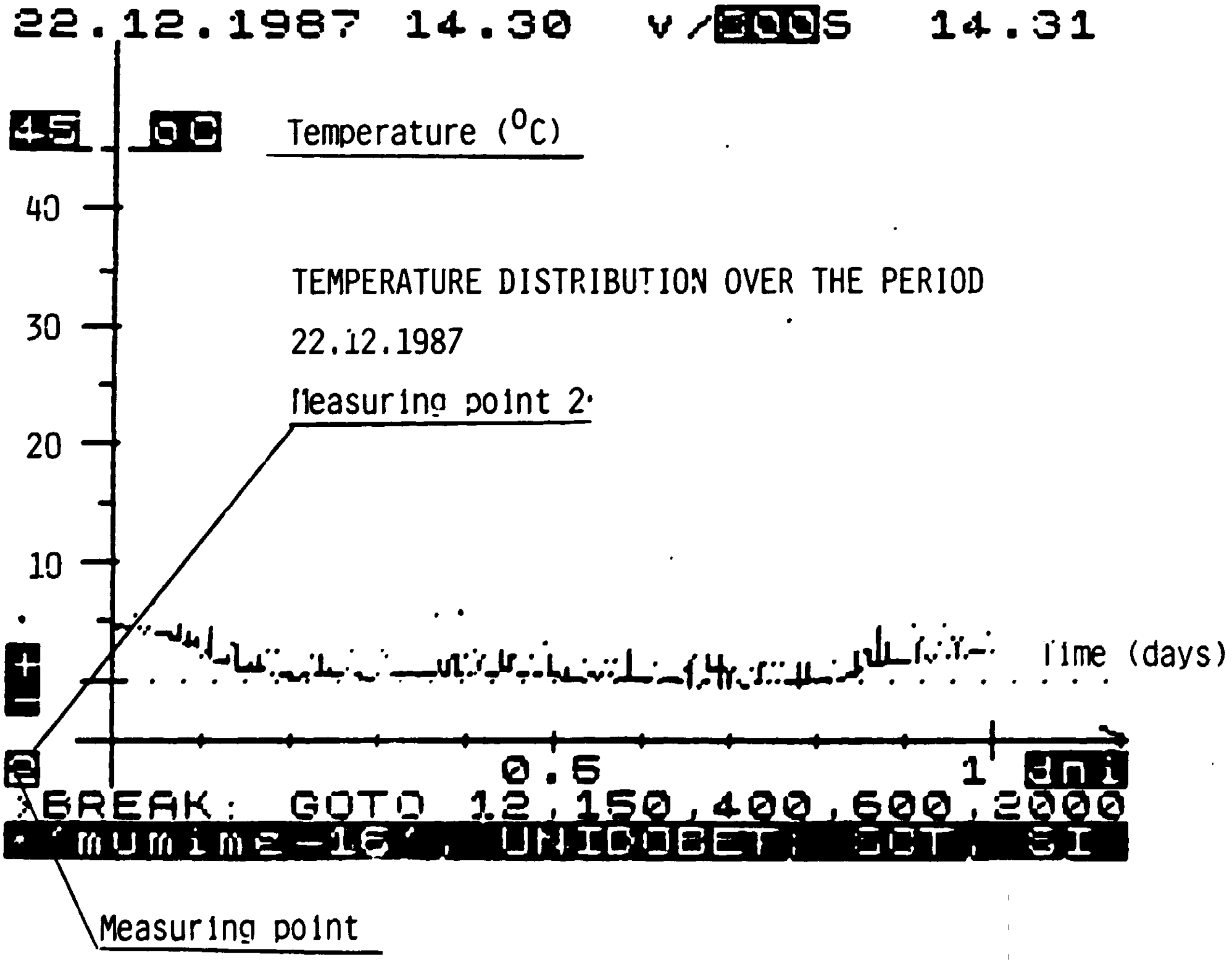
Date :02.12.87

Components of concrete	Perc. %	Content in kg	Specific gravity	Volume in litre	Mixture for 555 l
Cement :					
Anhovo Salodur NHC		180.0	3.10	58.1	99.9
Mixing water		118.5	1.00	118.5	65.8
Additives :					
1.Superplasticiz	3.0	5.40	1.13	4.78	3.00
2.Air-entriner	.17	.31	1.02	.30	.17
3.	.0	.00	1.00	.00	.00
Precent air pore	4.0			40.0	
Aggregate :		2131		778.4	
RIVER SAND	.0	0	2.73		.0
0/4 HOTIC	36.0	765	2.73	280.2	424.4
4/3 HOTIC	7.0	150	2.76	54.5	83.4
8/16 HOTIC	25.0	534	2.75	194.6	296.5
16/31.5 HOTIC	32.0	681	2.74	249.1	378.2
Sum		2435 kg/m3		1000 l	

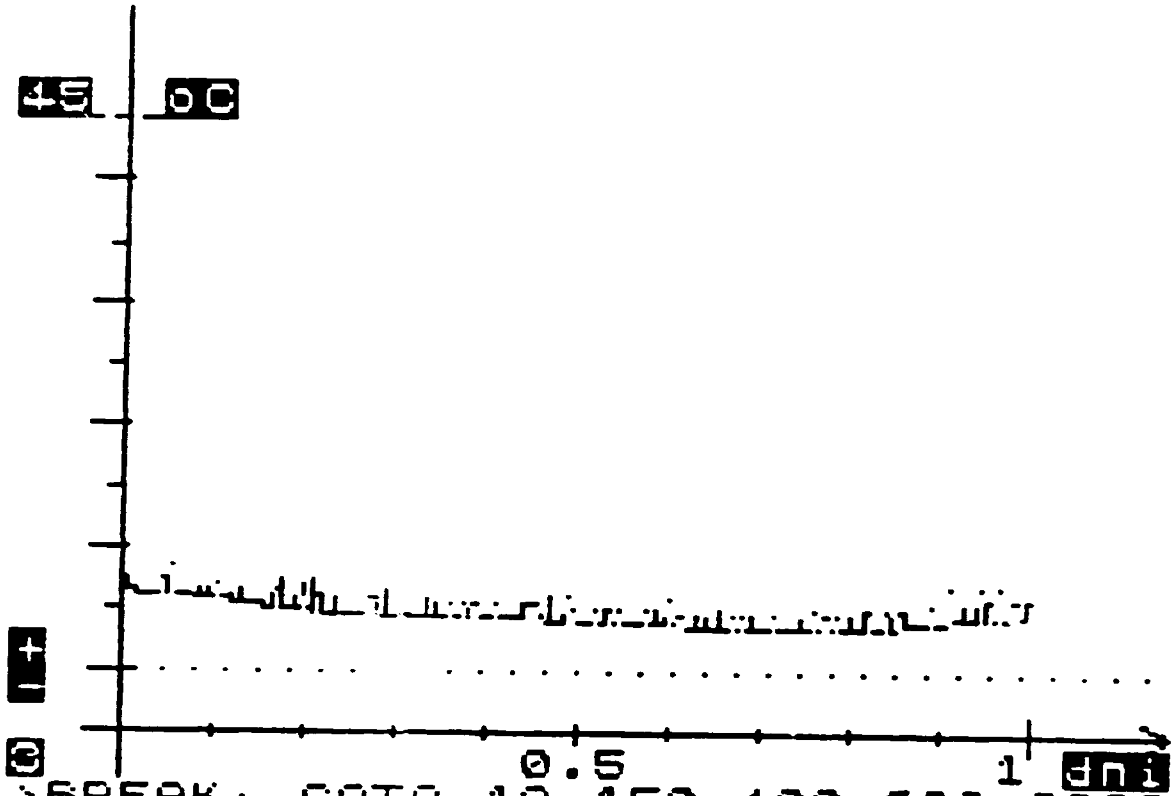
CUBIC TEST SAMPLE







TEMPERATURE DISTRIBUTION OVER THE PERIOD
22.12.1987
Measuring point 2



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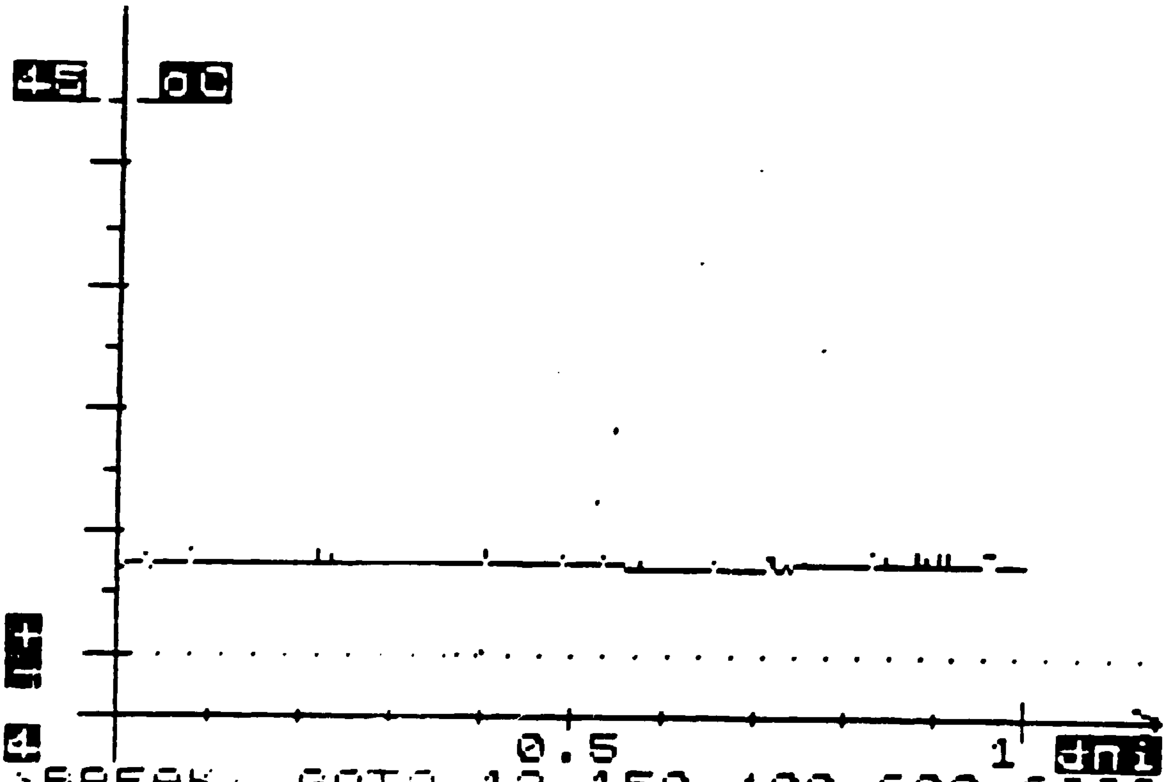
22.12.1987 14.30 v/0005 14.31



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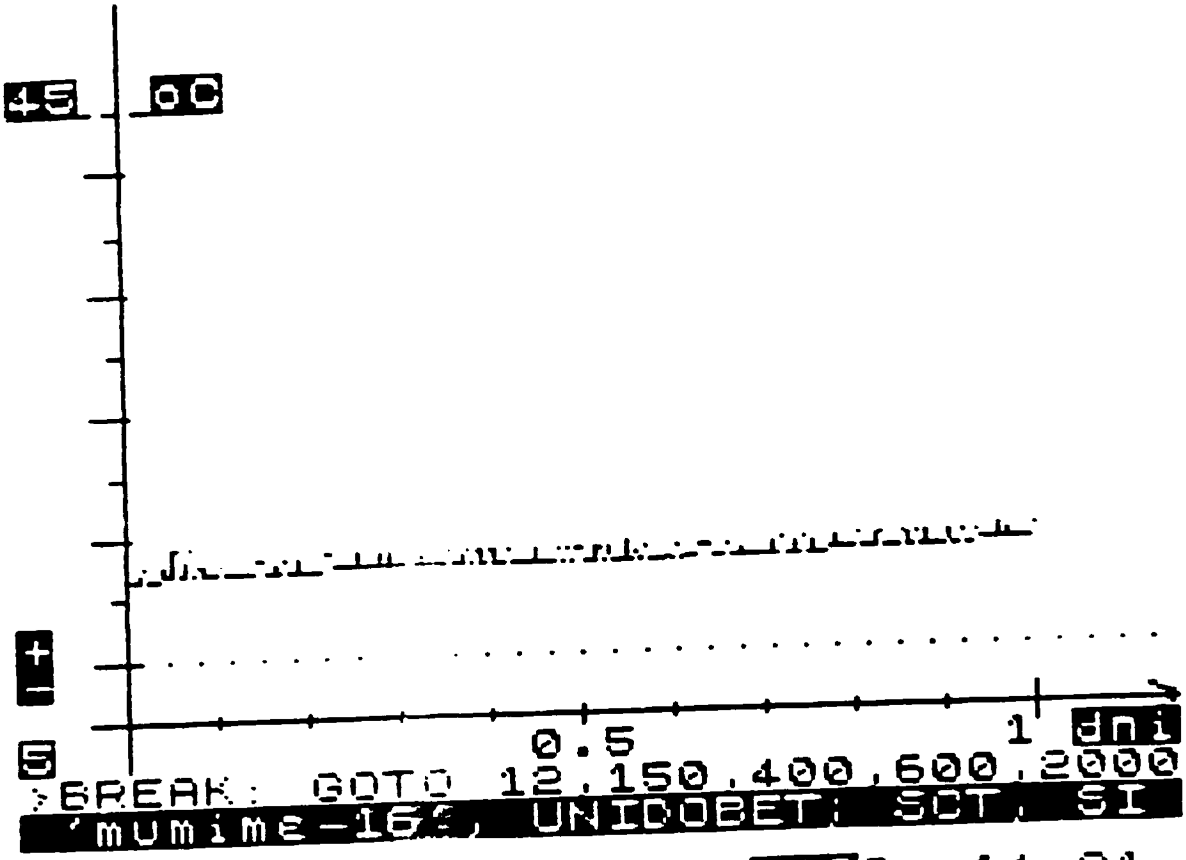

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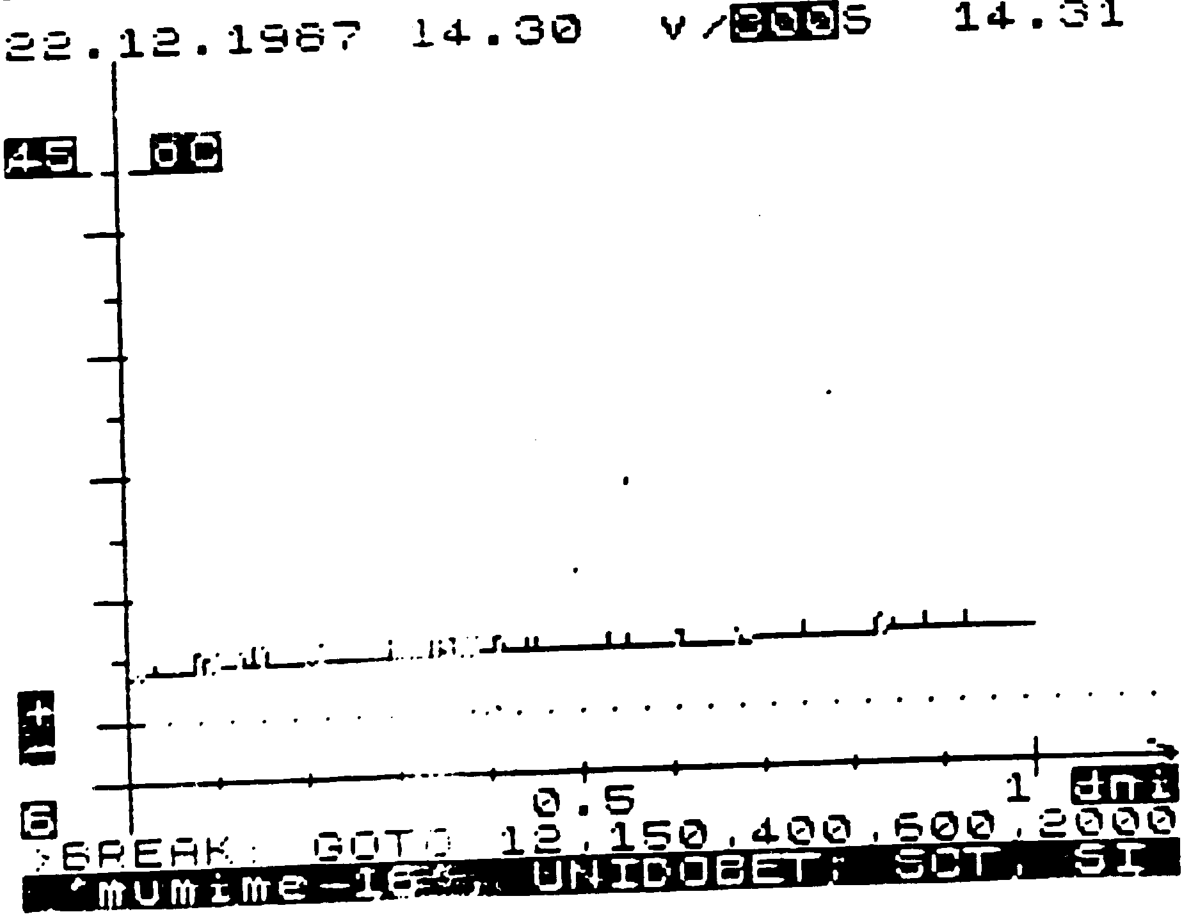

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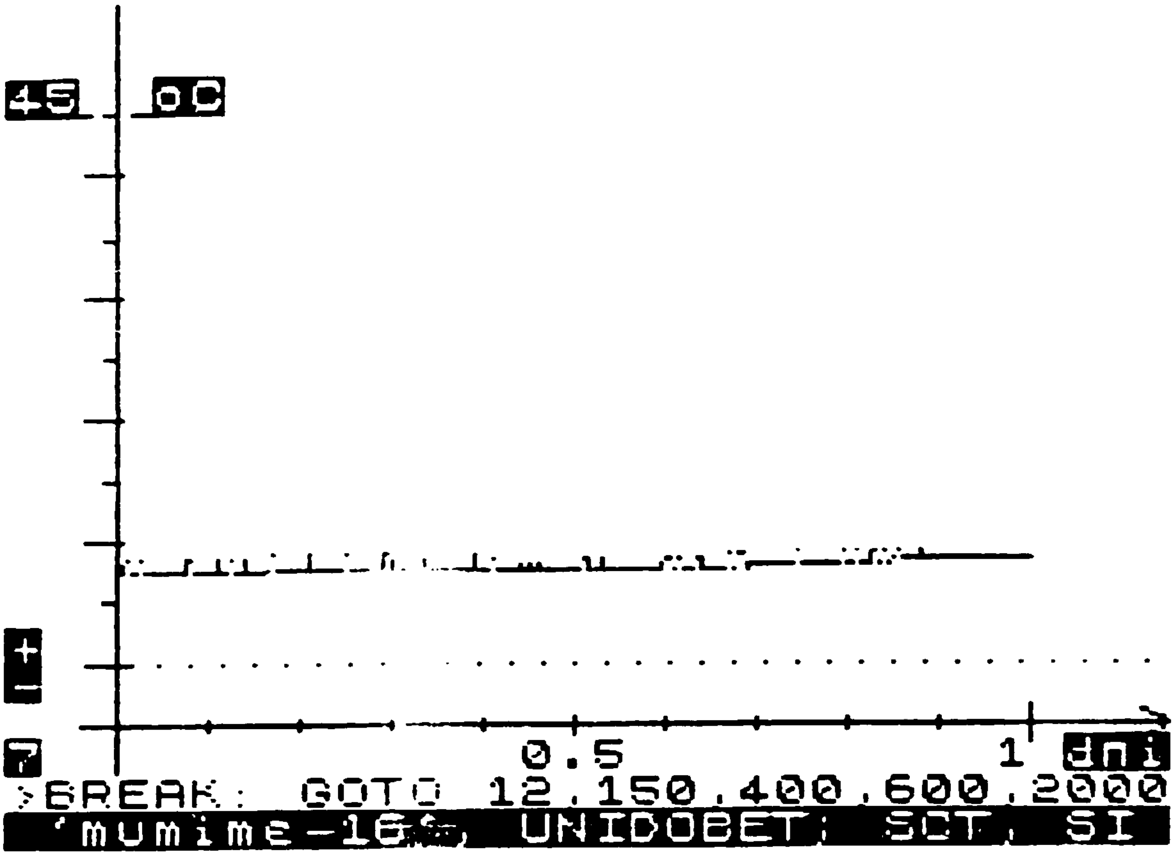

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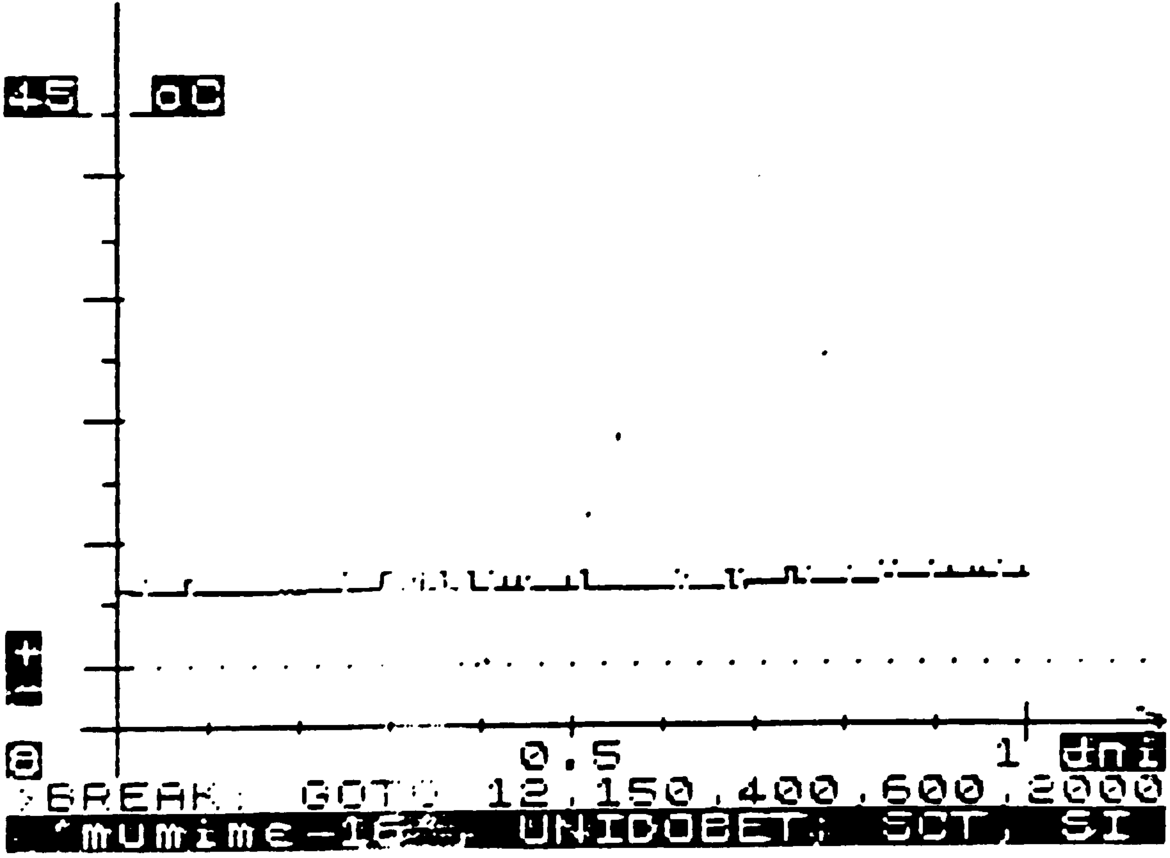

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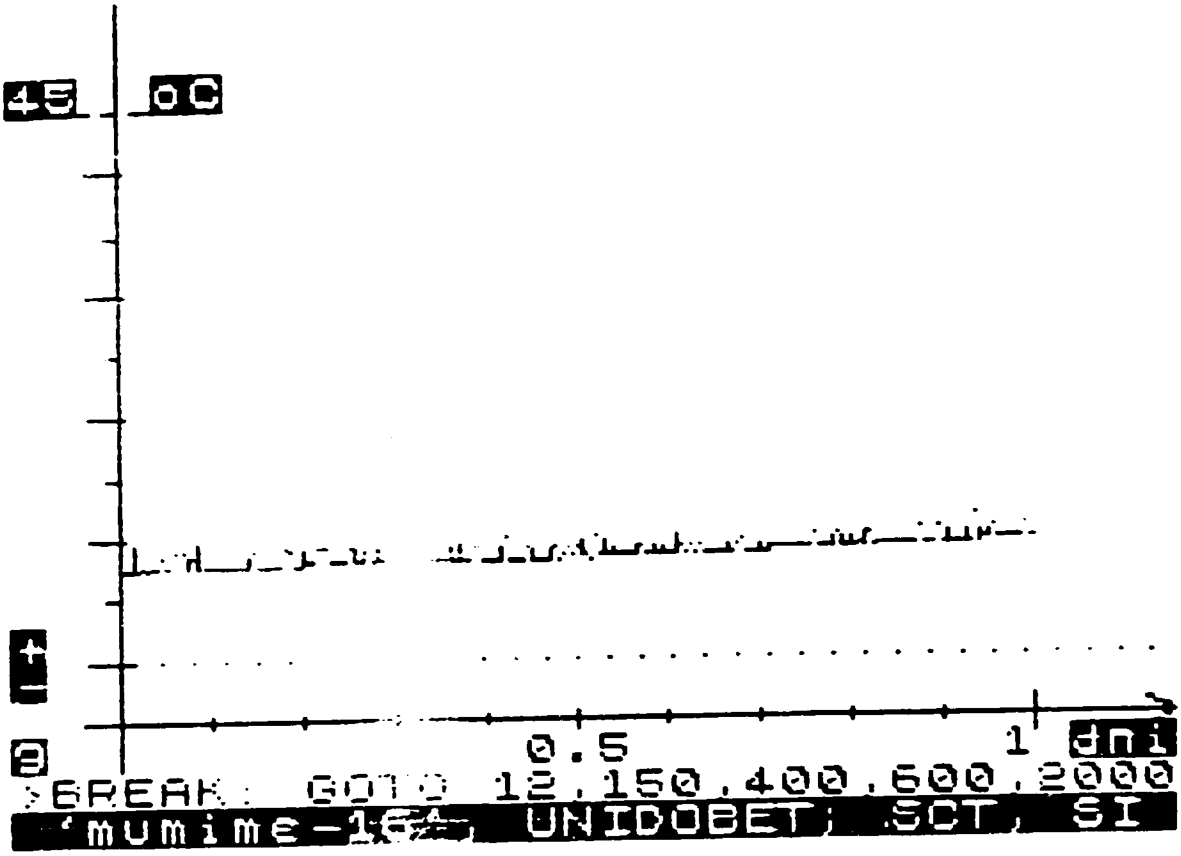

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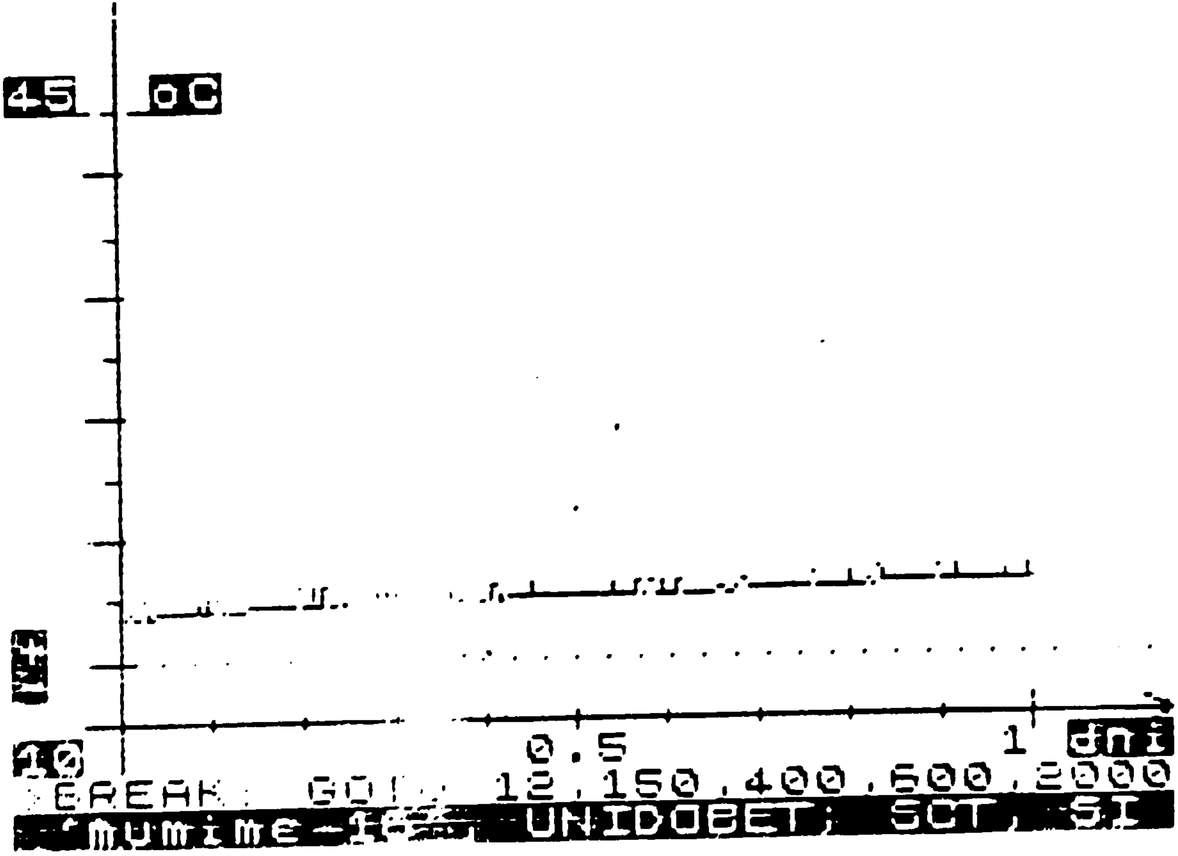
22.12.1987 14.30 V/0005 14.31



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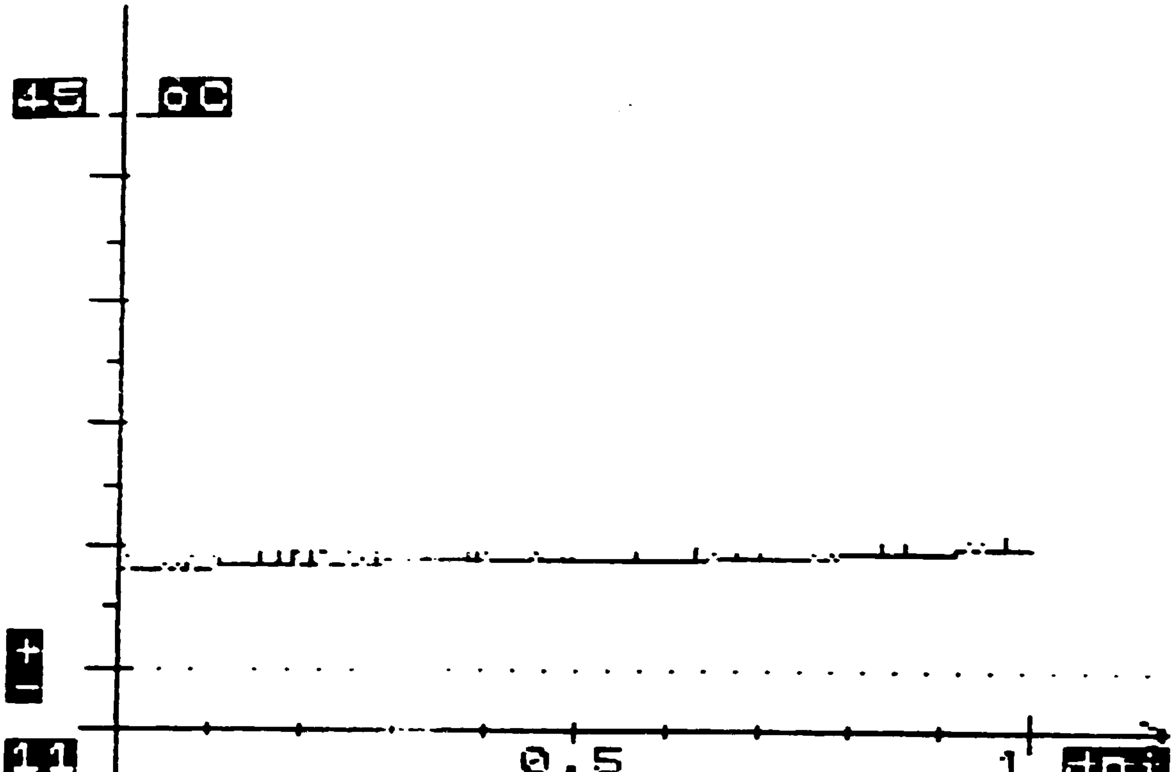

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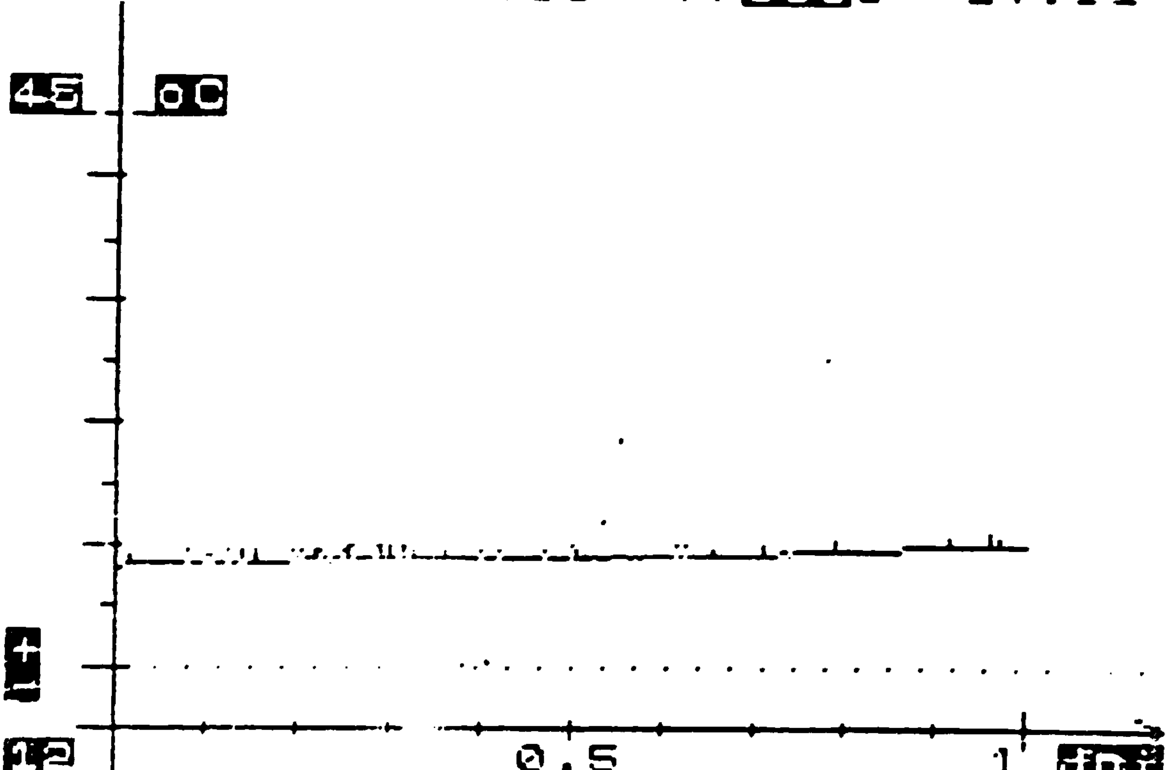

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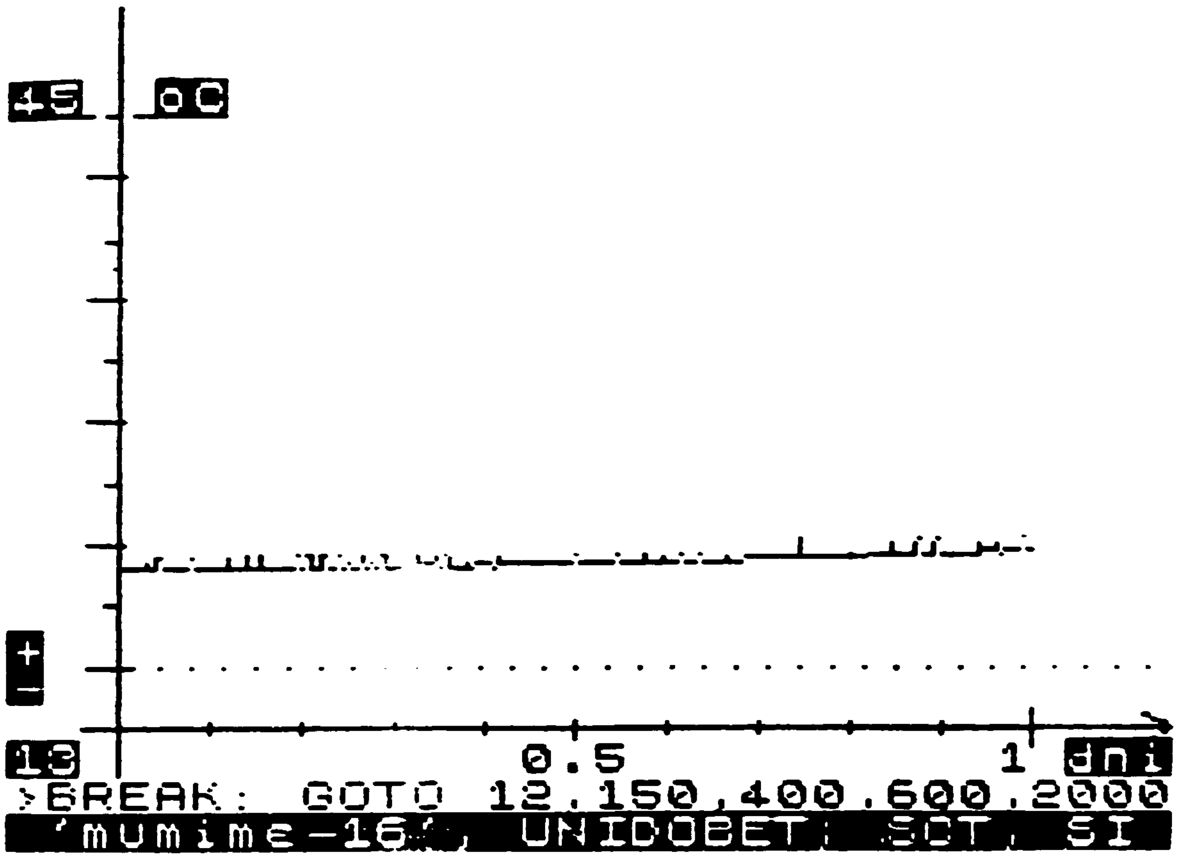

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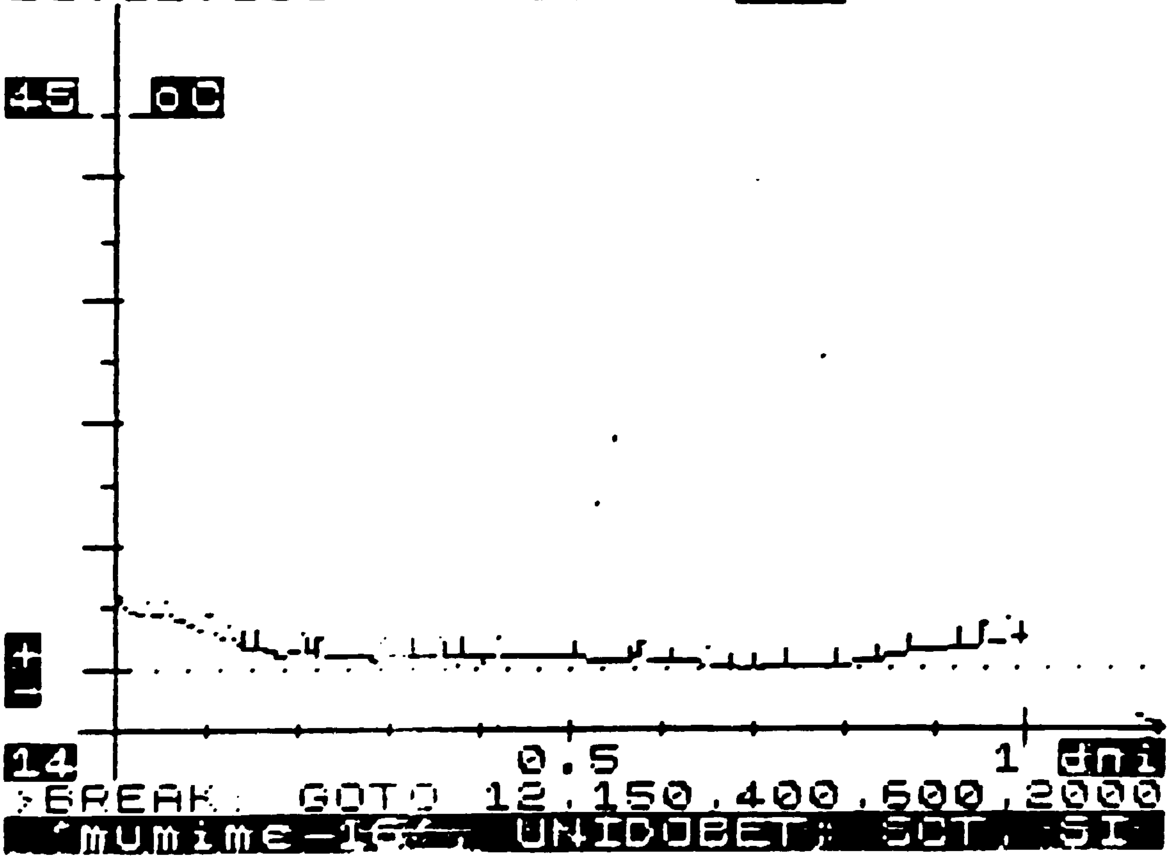
22.12.1987 14.30 v/300S 14.31



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>BREAK: GOTO 12,150,400,500,2000
 'mumime-16, UNIDOBET: SCT, SI
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ANNEX 3 - LISTING OF EQUIPMENT AND FIRMS

SCT. TOZD Strojni inzeniring
Kavciceva 66, 61000 LJUBLJANA
(from Mr. Sokolov Vladimir)
Tel.: (061)483211, tlx: 31753

ponPCATa/offix

________/sv.SV

(Prosim, odposljite tri telekse na naslednje tri naslove, ki pa imajo enak angleski tekst, naveden za znakom *** . . . . Hvala! Sokolov)

1. telex na naslov:
SOLID COMPUTER GmbH
8042 Oberschleisheim bei Muenchen, BRD
Bruckmannring 28
tel.: (9949 /0/89) 3151694
tlx.: 5213980
Attention Mr. Schnabl

(sledi tekst po *** ...).

2. telex na naslov:
HETRON COMPUTER GmbH
8032 Graefelfing, BRD
Lochhammerschlag 12
tel.: (9949 /0/89) 858060
tlx.: 5214372
Attention Mr. Wimmer

(sledi tekst po *** ...).

3. telex na naslov:
Intertrade, TOZD Zastopstva IBM
61001 Ljubljana, YU
Mose Pijadejeva 29
tel.: (061) 325461
tlx.: 31181
Pozor tov. DERENDA ali tov. TUMA

(sledi tekst po *** ...).

*** ...

Subject: SYSTEM PCAT & DATA AQVISITION STATION

A.00. PC AT

A.01. PC turbo AT 4/8 MHz with 1 MB memory, 360/1200 MB floppy=disk (5,25"), 40 MB harddisk, 2 parallel ports for printer and 4 serial ports RS232C, EGA for monitor, power supply 200 W, math coprocessor, VT220 like keyboard, mouse

A.02. NEC Multisync monitor or similar and monohromatic monitor conected on composite port of EGA card

A.03. Printer Fujitsu DL2600 or similar

A.04. Streamer for PC turbo AT, abel to be put in PC AT hausing

A.05. Roland plotter for A3 format, 8 pens and proper accesoire

A.06. Software: MS DOS 3.2, 'Borland' Turbo BASIC, Turbo PASCAL, Turbo C, good software for text and graphics processing, ACAD, Lotus 1-2-3, etc.

A.07. 12 boxes of floppydisks 5,25" for DSHD format and of good quality.

B.00. DATA AQVISITION STATION

B.01. Housing for DATA AQUISITION STATION

B.02. Power supply for data aquvisition station, 220 V, 50 Hz

B.03. 32 channel 12 bit A/D converter (4x)

B.04. Timer/counter

B.05. 2 channel D/A converter

B.06. 32 chennel digital I/O port (4x)

B.07. Interconection betven PCAT parallel port of PCAT and DATA AQVISITION STATION

B.07. Software, witch support working of DATA AQVISITION STATION if posibel in Turbo PASCAL.

Please, send Proforma invoice for abave konfiguration on following adress: UNIDO, Vienna International Centre, P.O. BOX 300 A - 1400 Vienna, Austria; PURCHAESE AND CONTRACT SECTION, attention Mr. LOGAN; Project signature DP/YUG/87/003; and offer one or two systems. Instaed of PCAT it is possible to offer equal sistem (f.e. PS/2) witch is compatibel to MS DOS software.

Please, be so kind and send us a copy from the abave Proforma invoice on ouer Adress SCT, TOZD SI, 61000 LJUBLJANA, Kavciceva 66, attention Mr. Sokolov, Thank You and best wishes.

Ljubljana, 19. 02. 1988 Sokolov Vladimir, dipl.el.ing.

ANNEX 4 - PROPOSED TIME SCHEDULE

ject: YUG/87/003

W O R K P L A N

date: 09/03/1988

li	Description	1988												1989				1990			
		1	2	3	4	5	6	7	8	9	10	11	12	I	II	III	IV	I	II	III	IV
	EXPERTS *																				
)1)2)3)4)5)6	CHIEF TECHNICAL ADVISER OR SHORT TERM CONSULTANTS (11-50,51...) as recomended by CTA			D= 3days Linsbauer			D=0,5m F 2,6				F 2,3				D=0,5m F 2,6			D=0,5m			
	TRAINING **																				
	Fellowships																				
)0	IN THE FIELD OF HYDRO-POWER DAM CONCRETE PRODUCTION AND CONSTRUCTION													D=4m P=1							
	Study Tours																				
)0	FOR TECHICAL PERSONNEL IN THE FIELD OF HYDRO-POWER DAM CONSTRUCTION				F 2,1		F 2,2 F 2,4 F 2,5								D=2W P=2						
	EQUIPMENT ***																				
	Expendable Equipment																				
)0																					
	Non-expendable Equipment																				
)0	PC DATA AQIUSITION STATION		R	F 2,7	ED																

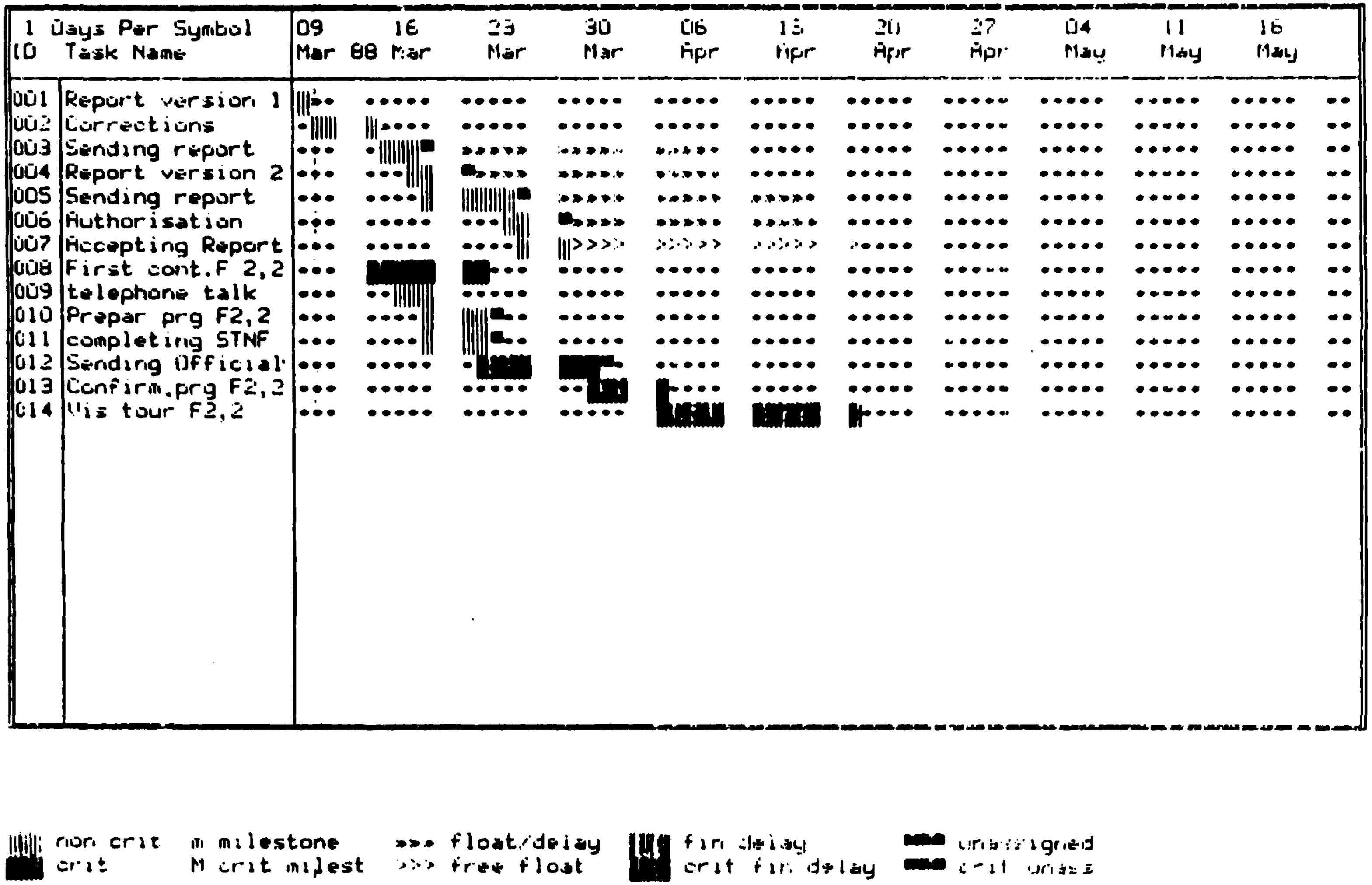
please draw a line and indicate on the line D= the duration of the expert's mission
please draw a line and indicate on the line D= the duration of the fellowship/study tour and P= number of participants
please indicate R= date of sending the requisition and ED= date of expected delivery

LEGEND: F2,... Activities according to Report No 1 (see page 3)

Task Gantt
09-03-88 22:50

Project: YUG87-00.PJ
Revision: 2

PROPOSAL FOR TIME SCHEDULE ACCORDING TO REPORT No 1



ID	Task Name
001	Report version 1
002	Corrections
003	Sending report
004	Report version 2
005	Sending report
006	Authorisation
007	Accepting Report
008	First cont.F 2,2
009	telephone talk
010	Prepar prg F2,2
011	completing STNF
012	Sending Official
013	Confirm.prg F2,2
014	Vis tour F2,2