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Some aspects of considering creep of concrete : a stochastical quantity

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Part 1

Some aspects of considering creep of concrete a stochastical quantity

Contribution to the RILEM colloquium "Creep of Concrete"
Leeds 20-21 April 1978

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Rapport M 78-5

Ir. H.A.W. Cornelissen

SOME ASPECTS OF CONSIDERING CREEP OF CONCRETE A STOCHASTICAL QUANTITY
(subject of a thesis)

LE FLUAGE DU BÉTON COMME QUANTITÉ STOCHASTIQUE. QUELQUES ÉLÉMENTS D'APPRÉCIATION.
(sujet d'une thèse)

session:
Advances in defining analytical laws for prediction of creep

Ir. H.A.W. Cornelissen
Eindhoven University of Technology
Department of Architecture
The Netherlands

Summary

Creep of normal weight, unreinforced concrete is considered a stochastical quantity, being a result of variations in the amounts of cement, water and aggregate, which occur in practice. The one-month laboratory creeptests are performed at three different temperature and relative humidity conditions:

1. constant temperature and relative humidity (25°C and 50% respectively);
2. an artificial so called winterclimate;
3. an artificial so called summerclimate;

These two artificial climates with alternating temperature and relative humidity (every 12 hours), are derived from the real conditions that occur in the Netherlands during a typical winter- and summermonth.

The results of the experiments, which were set up completely on a statistical basis, are compared with recommendations on the creep behaviour of concrete, and are a contribution in determining a confidence interval for creep-deformations in practice.

Since the research is not quite finished only preliminary results are presented.

Resumé

On peut considérer le fluage du béton de densité ordinaire, non armé, comme une quantité - stochastique, par suite des variations des quantités du cement, de l'eau et de l'agregat rencontrées dans la pratique. Les expériences sur le fluage (pendant un mois) ont eu lieu sous trois conditions différentes concernant la température et l'humidité relative:

1) une température de 25°C et une humidité relative de 50%;
2) un climat artificiel à savoir le climat d'hiver;
3) un climat artificiel à savoir le climat d'été.

Les deux climats artificiels comprenant une temperature et une humidité relative alternantes, sont déduits des conditions réelles qui se produisent aux Pays Bas pendant un mois d'hiver et d'été caractéristique.
Les résultats de l'experimentation sur une base complètement statistique ont été comparés aux recommendations relatives au fluage du béton, et constituent une contribution à la détermination d'un intervalle de confiance pour les déformations résultant du fluage comme elles se présentent dans la pratique.
Comme le programme expérimental n'est pas terminé on ne presente que des résultats préliminaires.

1. INTRODUCTION

Time - dependent deformations of concrete structures are caused by a relatively large number of uncertain factors such as environmental conditions, load and also the concrete composition. Therefore creep should be considered a stochastical quantity (1). This paper deals with a limited part of causes of random variations of the creep-deformations, namely variations in the amounts of water, cement and aggregate, which may occur in real concrete compositions at the building site.

The one-month laboratory creeptests are performed at a constant temperature of 25°C and a relative humidity of 50%, and two artificial climates related to the conditions of a typical summer- and wintermonth in the Netherlands.

To determine the effect of the different factors as well as the confidence of the results, it was necessary to perform a detailed testprogram on a statistical basis.

The results presented at this stage of the research are to indicate briefly the way of approaching the problem.

(1) Prediction of creep, shrinkage, and temperature effects in concrete structures ACI committee 209

2. EXPERIMENTS.

2.1 The concrete compositions.

This research is related to concrete compositions often used for pretensioned structures. Starting from a mix having a water-cement ratio (w.c.r.) of 0.45 and a aggregate-cement ratio (a.c.r.)of 5.0, the results of an analyses of 600 M^3 fresh concrete indicated that the realised mixes at the building site had water-cement ratios and aggregate-cement ratios in the range of 0.40 to 0.50 and 4.5 to 5.5 respectively. These results, having a limited validity, are used as an indication to determine the concrete compositions as shown in fig. 1

a.c.r. / w.c.r.	4.5	5.0	5.5
0,40	x	x	x
0,45	x	x	x
0,50	x	x	x

fig. 1 The concrete compositions in terms of water-cement ratios and aggregate-cement ratios.

This scheme is performed using three types of cement for every w.c.r. - a.c.r. combination:

- rapid hardening portland cement
- extra rapid hardening portland cement
- rapid hardening blast-furnace portland cement

All mixes had the same maximum aggregate size of 16 mm. and grading curve according to the Dutch recommendations.

2.2 Curing and Loading.

After two weeks curing in water (20°), subsequently one week at 25°C and 50% R.H., the prisms (100x100x500 mm^3) were loaded uni-axially during 4 weeks. The stress-strength ratio was about 35%.

The deformations were measured at two opposite sides parallel to the direction of the load (fig. 2).

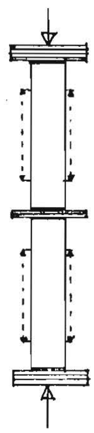


fig. 2 Way of loading and measuring deformations (schematic)

2.3 Artificial temperature and relative humidity conditions.

In the Netherlands during the period 1960 to 1970, the year 1961 showed average conditions in relation to temperature and relative humidity.

The data concerning a typical winter- and summermonth in that year, were translated in an artificial summer and winter climate with alternating temperature and relative humidity (every 12 hours).

The real as well as the translated conditions are shown in fig. 3 (see appendix).

2.4 Experimental scheme on a statistical basis.

The set up of the experiments was based on a 3^4 factorial design (4 parameters on 3 levels). Due to the capacity of the loading frame, at the two alternating T and R.H. conditions, one third of the involved combinations was performed at these conditions.

The experimental scheme is shown in fig. 4.

wcr.	acr.	T= 25°C RH= 50%			artificial summer climate			artificial winter climate		
		0	1	2	0	1	2	0	1	2
0,40	4,5	x	x	x	x					x
	5,0	x	x	x			x		x	
	5,5	x	x	x		x		x		
0,45	4,5	x	x	x		x		x		
	5,0	x	x	x	x					x
	5,5	x	x	x			x		x	
0,50	4,5	x	x	x			x		x	
	5,0	x	x	x		x		x		
	5,0	x	x	x	x					x

0 = rapid hardening portland cement

1 = extra rapid hardening portland cement

2 = rapid hardening blast-furnace portland cement

fig. 4 The experimental scheme. (x = experiment to be performed)

3. ANALYSIS OF SOME PRELIMINARY RESULTS

A linear equation was fitted to the data on the specific creep after 28 days under load at constant environmental conditions (25°C, 50% R.H.). The general form of the equation was:

$$\underline{y} = B_o + B_1 x_1 + \text{------} + B_k x_k + \underline{e}$$

$\underline{y}$ = the expected value of the respons (specific creep)

B_o ----- $_k$ = parameters (to be calculated)

x_o ----- $_k$ = independent variables, which represent the levels of the w. c. r., a. c. r., type of cement

$\underline{e}$ = random error

The equation is linear in the parameters B. The independent variables may be the original condition x_i or any function of x_i (for instance x_i^2)
With respect to extra rapid hardening portland cement, a result of the analysis is shown in fig.5
The measured as well as the fitted data and the 95% confidence-regions are presented. The random error is due to the performance of the experiments. It is shown that the resulting specific creep of a concrete mix having an avarage w.c.r. and a.c.r. of 0.45 and 5.0 respectively, may be in the range of about 2.3 to 5.6 (10^{-5} per N/mm^2) as a result of variations in the amounts of cement, water and aggregate.
More results will be presented during the colloquium.

4. SCOPE OF THE RESEARCH

Only a few important possible results are mentioned here.
The relation between the specific creep (28 days) and parameters partly determining the concrete compositions, for three types of cement and at three environmental conditions, as well as the confidence of this relation, will be obtained from the test results.
This relation will be useful in calculating the expected value of the creep deformations and the confidence-interval for a given chance-distribution of the concrete composition (within the limits) at actual conditions.
It is realised that the results are valid only within the limitation proposed in the research.

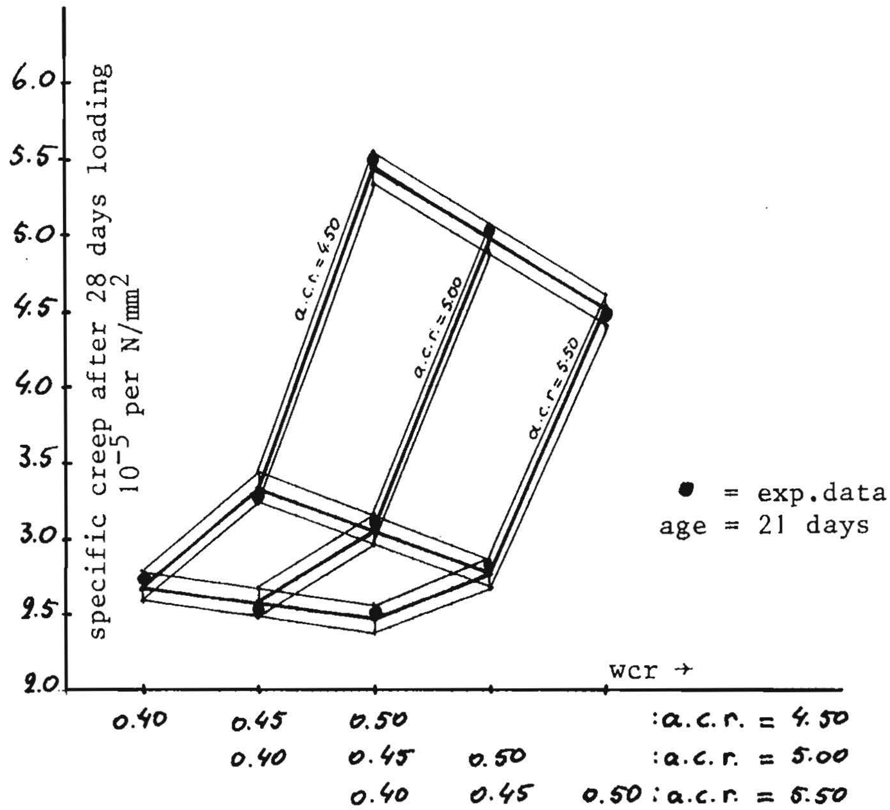


fig. 5

Relation between specific creep after 28 days under load and the water-cement ratio/aggregate-cement ratio of concrete with extra rapid hardening portland cement (the 95% confidence-regions are shown too).

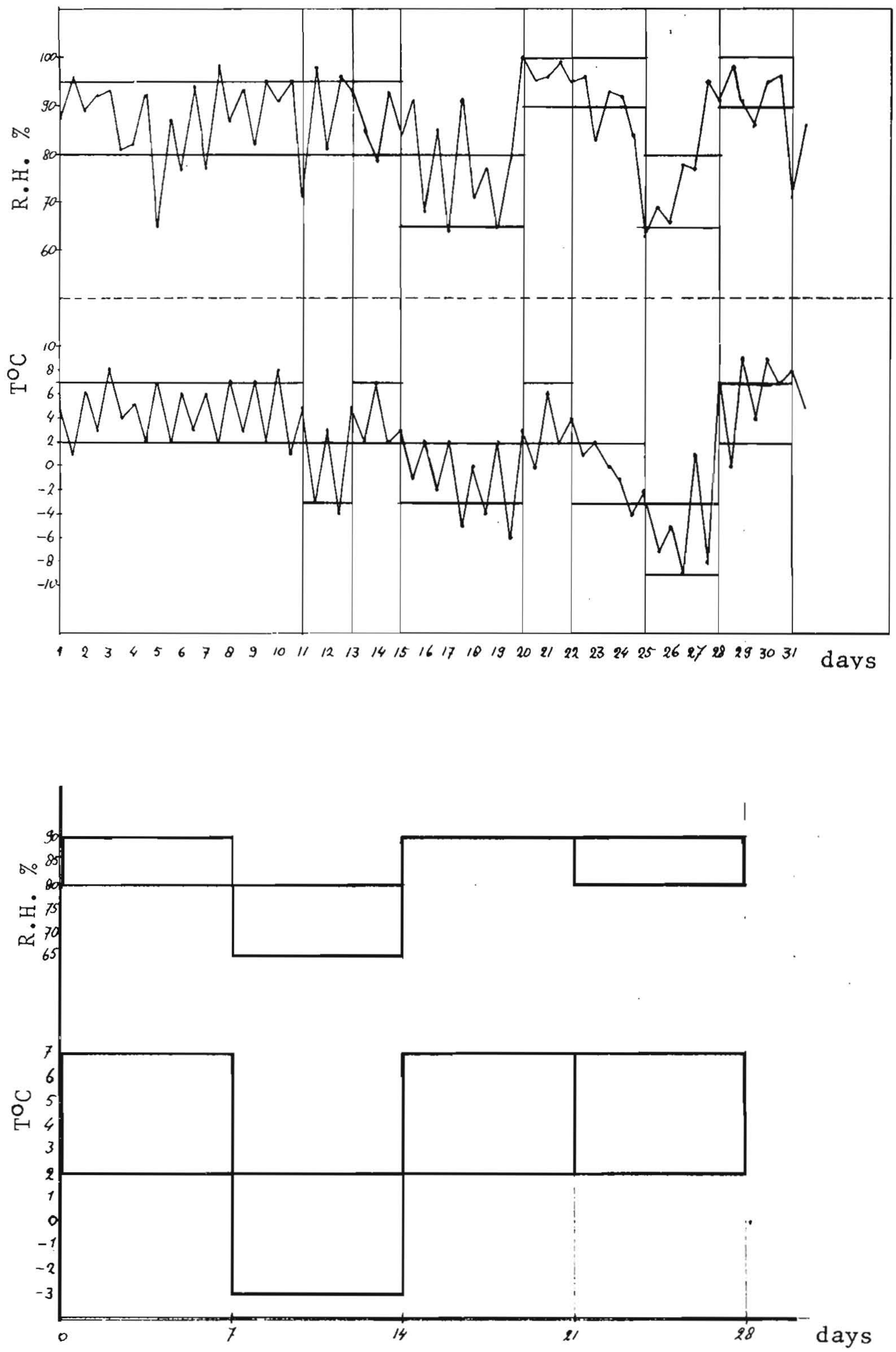
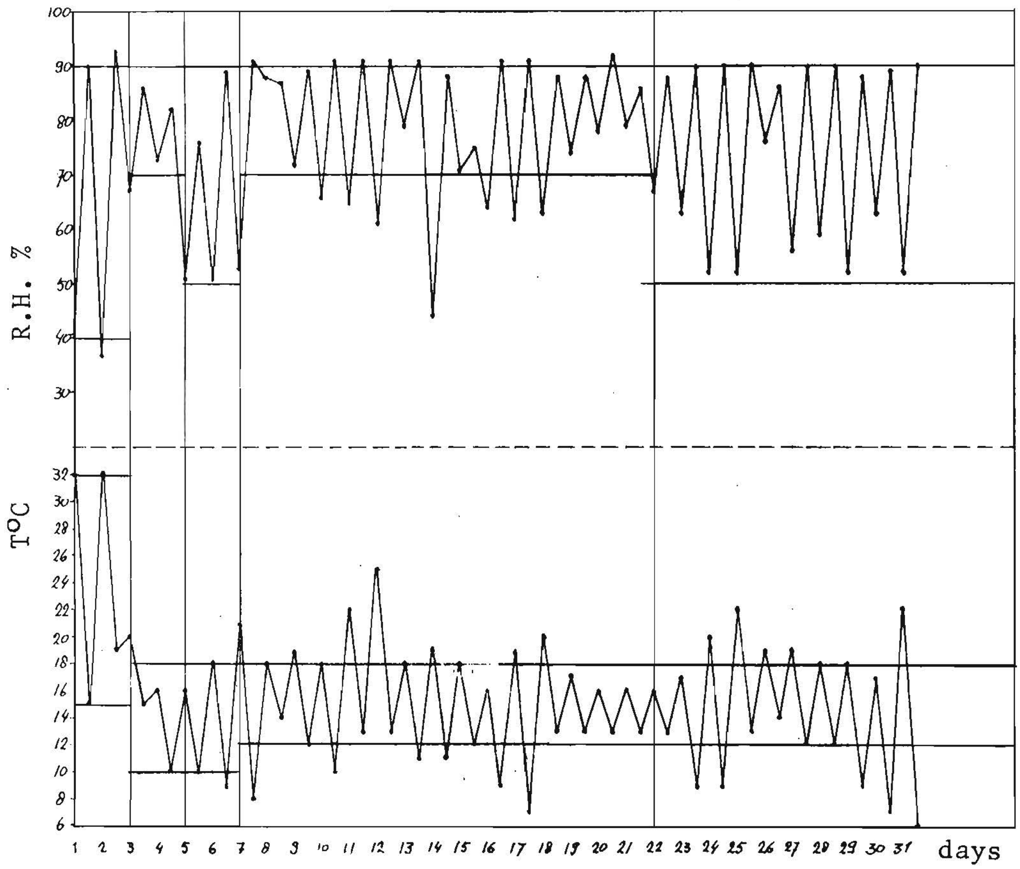


Fig. 3a. Real and artificial winter climate



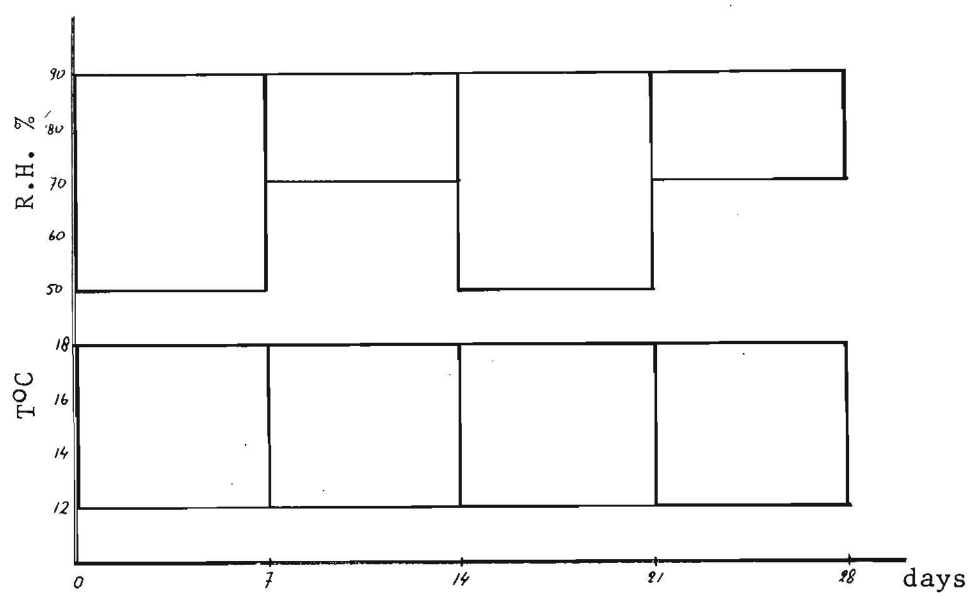


Fig. 3b. Real and artificial summer climate

Part 2

Text of the paper presented during the colloquium

"Creep of Concrete"

Leeds 20 - 21 April 1978.

Though still in a preliminary state, I am pleased to report you briefly on some aspects of the way of approaching creep regarded as a stochastic quantity, defined as a quantity dependent on random variables.
The research is performed under the supervision of Prof. Kreijger and Prof. Wittmann.
Because of random variations of important factors influencing the creep behaviour of concrete, the prediction of creep should be regarded as a stochastic procedure. The expected creep-value as well as the confidence-region are of interest.
This research deals with a limited part of causes of random variations of creep, namely the effect of random variations of the amounts of cement, water and aggregate, which may occur in practice as a result of dosing, mixing, a.s.o.
The relation between creep and these parameters, partly determining the concrete composition, will be useful in calculating the confidence interval of the creep deformations.
In fig. 1 the scope of the research is shown.
(figures in appendix)
The involved concrete mixes are often used for pretensioned structures in the Netherlands. To determine an actual range of concrete compositions as a result of variations in the amounts of cement, water and aggregate 600 m^3 fresh concrete, destinated for a presentioned cross-over, with an average w.c.r. of 0.45 by weight and an a.c.r. of. 5.0 by weight was analysed.
The results were used as an indication and led to an experimental scheme with concrete compositions in terms of w.c.r. and a.c.r. in wide ranges of 0.4 to 0.5 and 4.5 to 5.5 respectively.
see fig. 2.
The average amounts of cement, water and aggregate were 371, 166,9 and 1855 kg/m^3 concrete.
Referring to a paper by Brooks and Neville, published in Cement and Concrete Research of March 1975 a method is described to predict one year and longer time creep deformations from 28 days creep-tests.
This research is also based on 28 days creep-tests, which are performed at three different T and RH conditions, namely a constant T and RH of 25°C and 50%, and two artificial alternating T and RH conditions, related to the conditions of a typical winter- and summermonth in the Netherlands (more details are given in the paper).
see fig. 3.

These schematized artificial climats have been devided in 4 periods of 7 days. Every 12 hours the T and RH alternate between fixed limits (day-night-variations)

The dependence of the relation between concrete composition and creep upon these environmental conditions will be investigated.

To determine the confidence of the results a detailed testprogram is performed on a statistic basis.

The experimental scheme is given in fig. 4 of the paper "some aspects of considering creep of concrete a stochastical quantity". (first part of this report).

After two weeks curing in water of 200°C subsequently at 25°C and 50% RH the prisms with a cross-section of 100 mm x 100 mm and a length of 500 mm are loaded uni-axially during 4 weeks.

The stress-strength ratio is about 35%.

The creep deformations are measured at two opposite sides parallel to the direction of the load.

The shrinkage during the loaded period is measured on separate prisms.

The experimental data obtained up till now were transformed to specific creepdata, being;

$$\varepsilon_{sp}(t) = (\varepsilon(t) - \varepsilon_{inst.} - \varepsilon_{shr}(t))/\sigma$$

No correction was made for the increasing modules of elasticity.

These short-time test-results could be described with a power-function of the type:

$$\varepsilon(sp(t) = A.t^{B}$$

The correlation-coëfficient proved to be about 99%.

As an illustration fig. 4 shows the linear relation between the logaritm of the time and log $\varepsilon sp(t)$ for rapid hardening portlandcement concretes having a.c.r.'s of 5.5 and w.c.r's of. 4.0, 4,5 and 5,0.

The straight lines are nearly parallel and shifted along the Y-axis.

For sake of the statistical analysis a linear equation was fitted to the specific creep data after 28 days under load, as a function of the w.c.r. and the a.c.r.

With respect to the involved concretes loaded at constant T and RH the next equation was obtained,

$$\varepsilon sp(28d) = A + B.wcr + C.wcr^{2} + D.acr + E.wcr.acr$$

The average values of the parameters as well as the wanted standard diviation due to the performance of the experiments, were obtained from a regression procedure. For a w.c.r./a.c.r. combination both the expected value of the specific creep after 28 days under load and the confidence region can be calculated now.
This is shown in the figures 5, 6 and 7.
Also more evident conclusions can be given, for instance:

1. Compared with the two portlandcement concretes, rapid hardening blast-furnace cement concretes show lower creep values.
2. The effect on creep of the w.c.r. is more pronounced than the effect of the a.c.r..
3. Fig. 8 shows the specific creep results plotted as a function of the cementcontent per m^3 concrete. There is a proportional relation. At increasing w.c.r. the effect of the cementcontent increases too. Of course the effect is increased as a result of shrinkage.

It is remarked that the time-dependence of the creep and its change-distribution will be investigated.
At this stage of the research only a few results of the creep experiments at the alternating conditions can be given.
Moreover the results have not yet been analysed statistically.
As shown in fig. 9, extra rapid hardening portlandcement concretes exposed to the alternating summer-conditions (with an average temp. of 15°C), seem to show the same relation between the specific creep and the w.c.r. and a.c.r., as the same concretes exposed to the constant conditions, but the creep deformations have been decreased.
Important factors are the lower average temperature and the higher average humidity (decreasing of creep) and the alternating conditions (increasing of creep).
Summarizing, the intention of this research is to estimate on a statistic basis the relation between parameters partly determining the concrete-composition and specific creep deformations. Within the proposed range it will be possible to predict the 28 days creep as well as the confidence region if the change distribution of the concrete composition will be given.
This research is not intended to contribute to the mechanism of creep.
Besides this direct relation between concrete composition and creep behaviour the relation between creep and other relevant properties of concrete such as 28 days cube-strength, and the confidence of this relation will be investigated.

Well being incomplete, detailed results of the research cannot be presented yet, nevertheless it is hoped, that the way of approaching the problem of regarding creep of concrete as a stochastic quantity, has been indicated sufficiently.

appendix

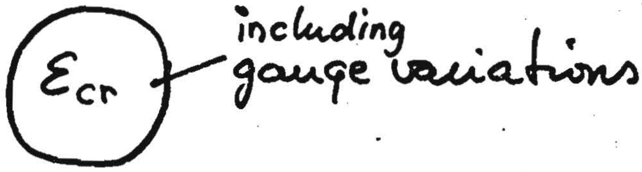
FIGURES

SCOPE OF THE RESEARCH

with respect to random variations of the creep-deformations three different levels are recognized

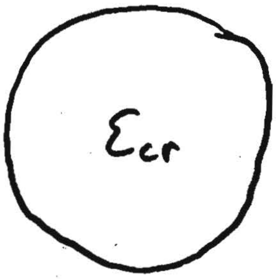
1. Constant T and RH conditions
Constant concrete composition

scatter



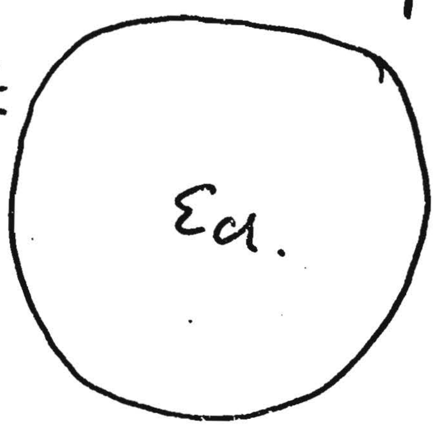
2. Constant T and RH conditions
Random variation of the concrete composition

scatter



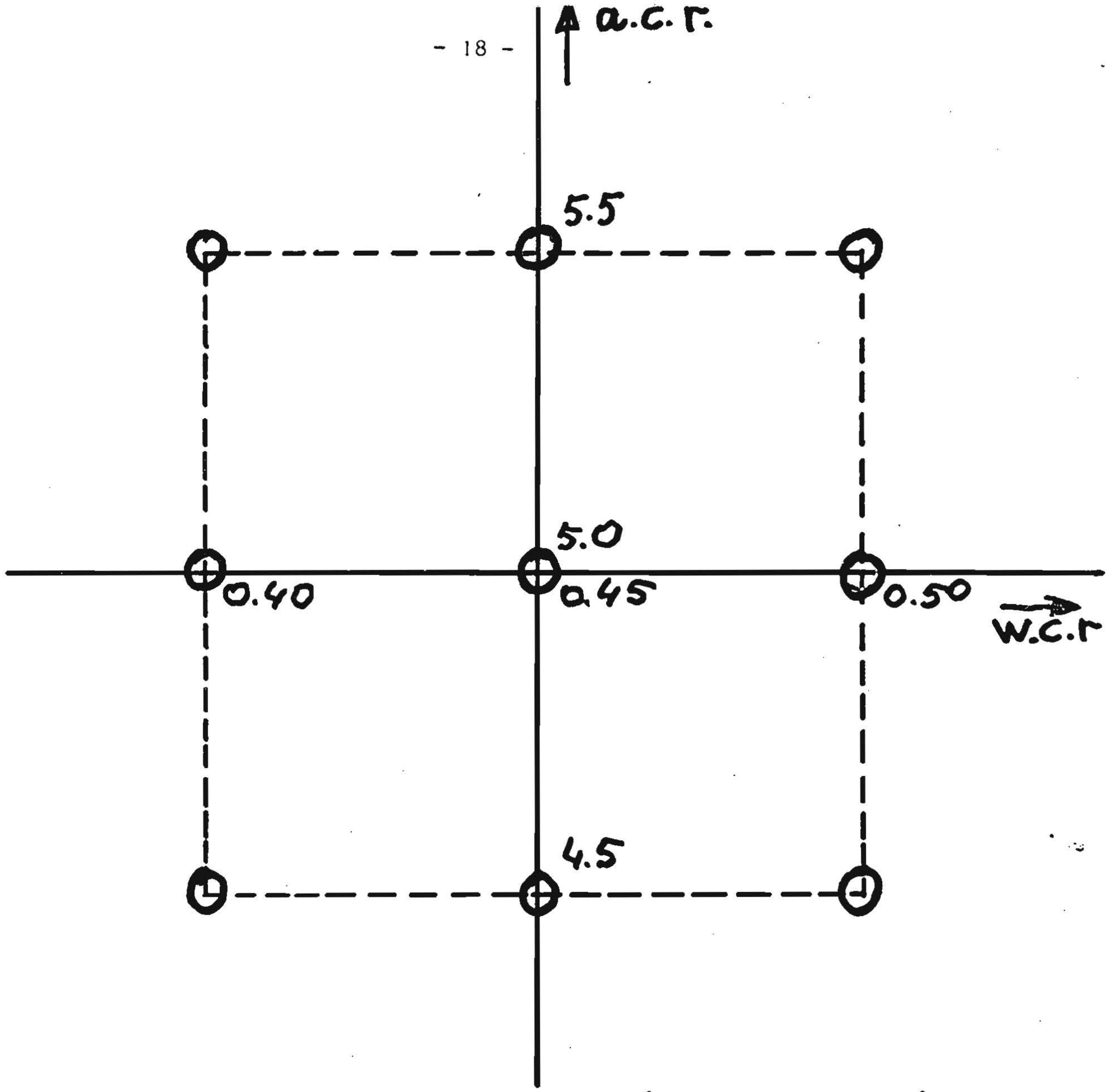
3. Actual T and R.H. conditions
Random variation of the concrete composition

scatter



The actual conditions have been translated in schematized artificial conditions

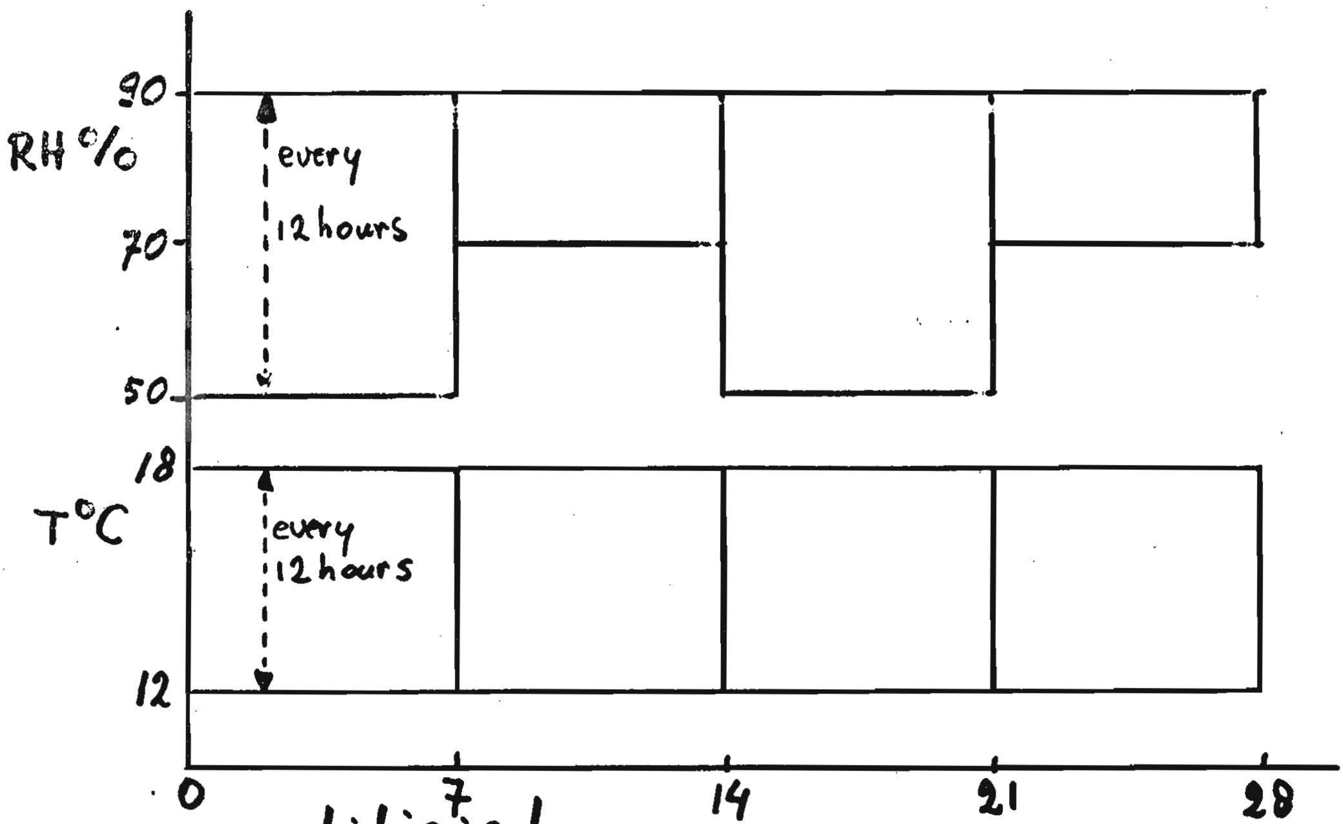
— The experimental scheme is related to these three levels.



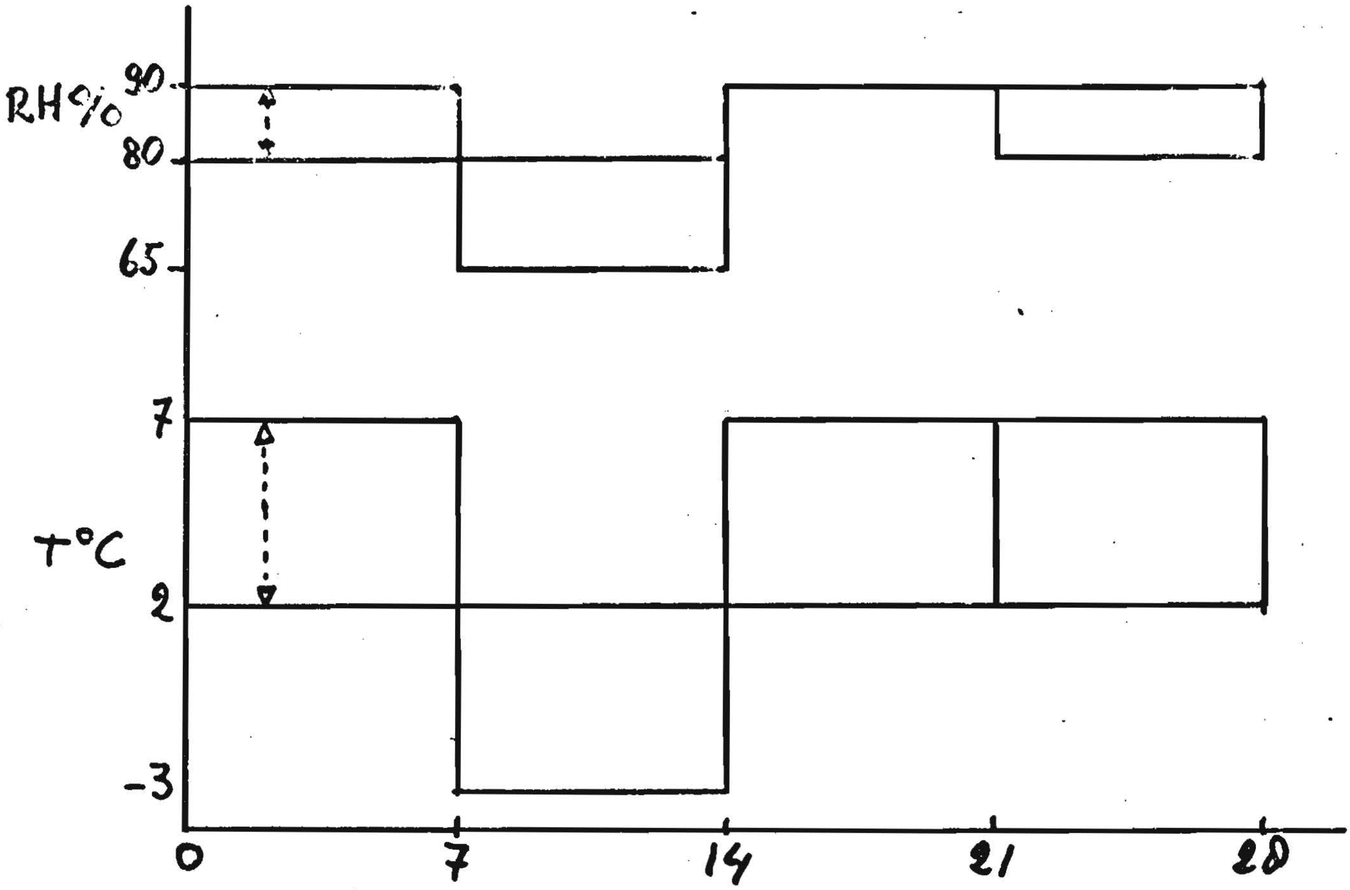
The experiments are performed with these wcr/acr combinations using 3 types of cement :

- rapid hardening portlandcement ($\sigma_{28} = 42.5\ N/mm^2$)
- extra rapid hardening portlandcement ($\sigma_{28} = 50.\ N/mm^2$)
- rapid hardening blast-furnace portlandcement ($\sigma_{28} = 42.5\ N/mm^2$)

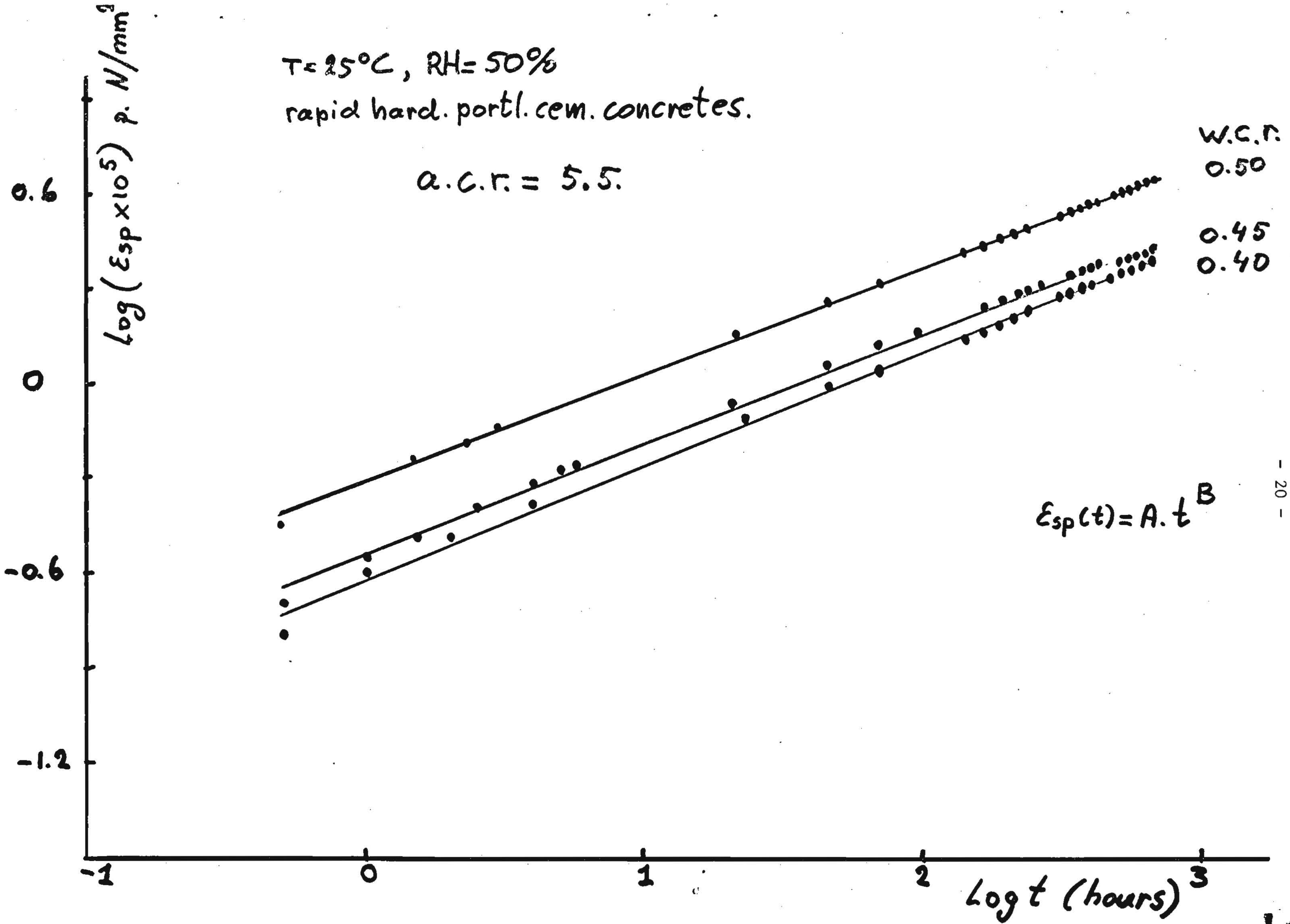
3



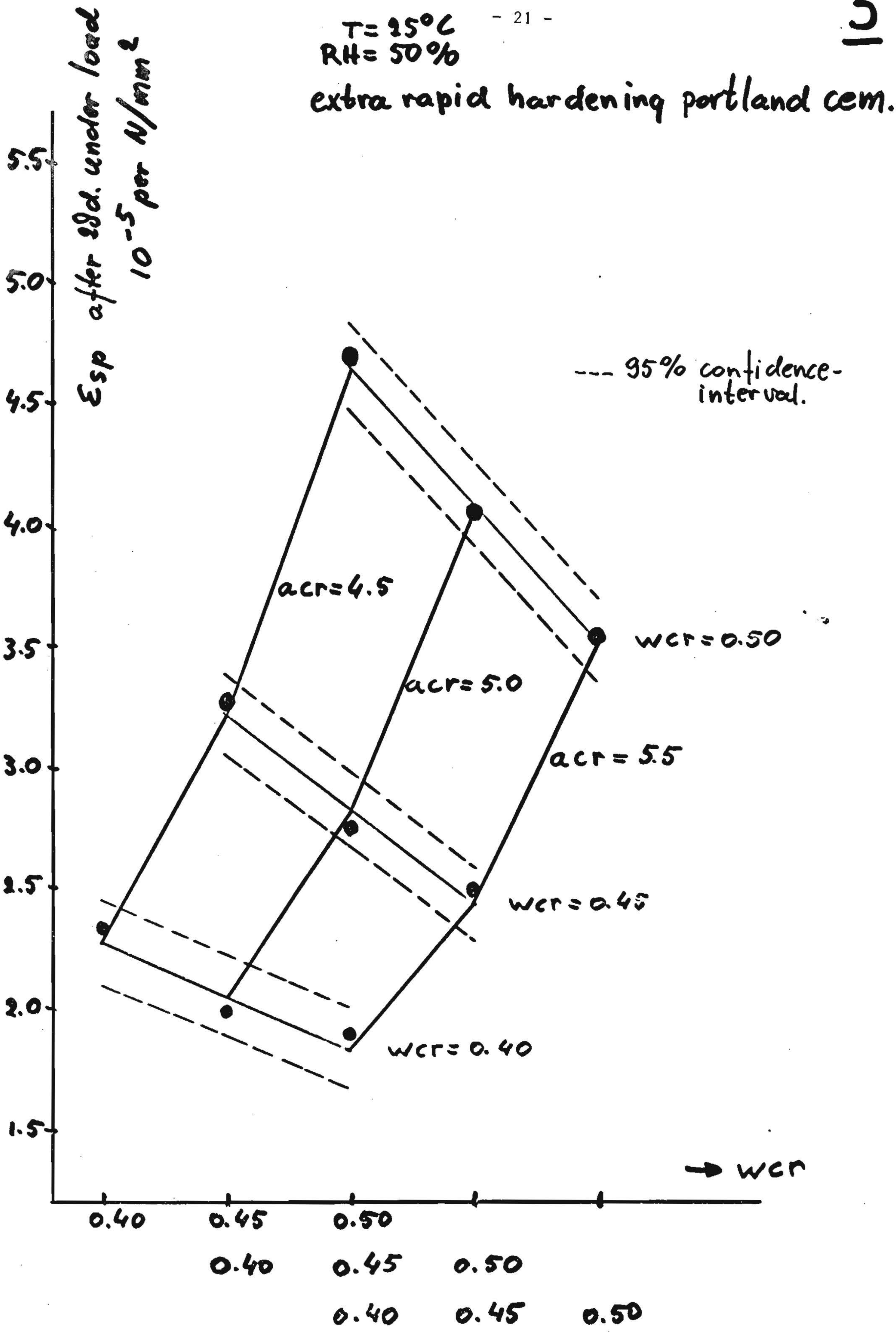
artificial
'summerclimate'

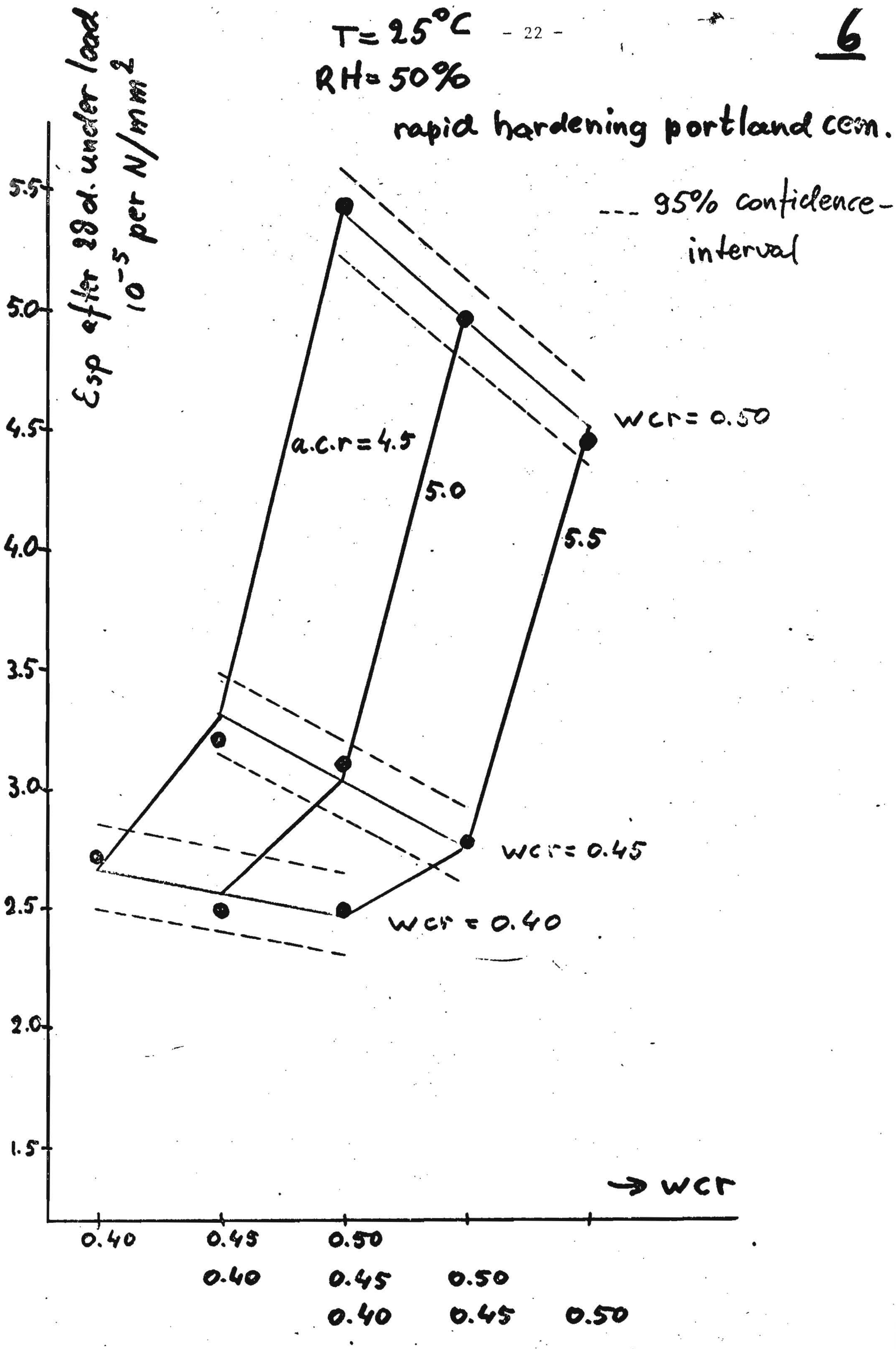


artificial
'winter climate'

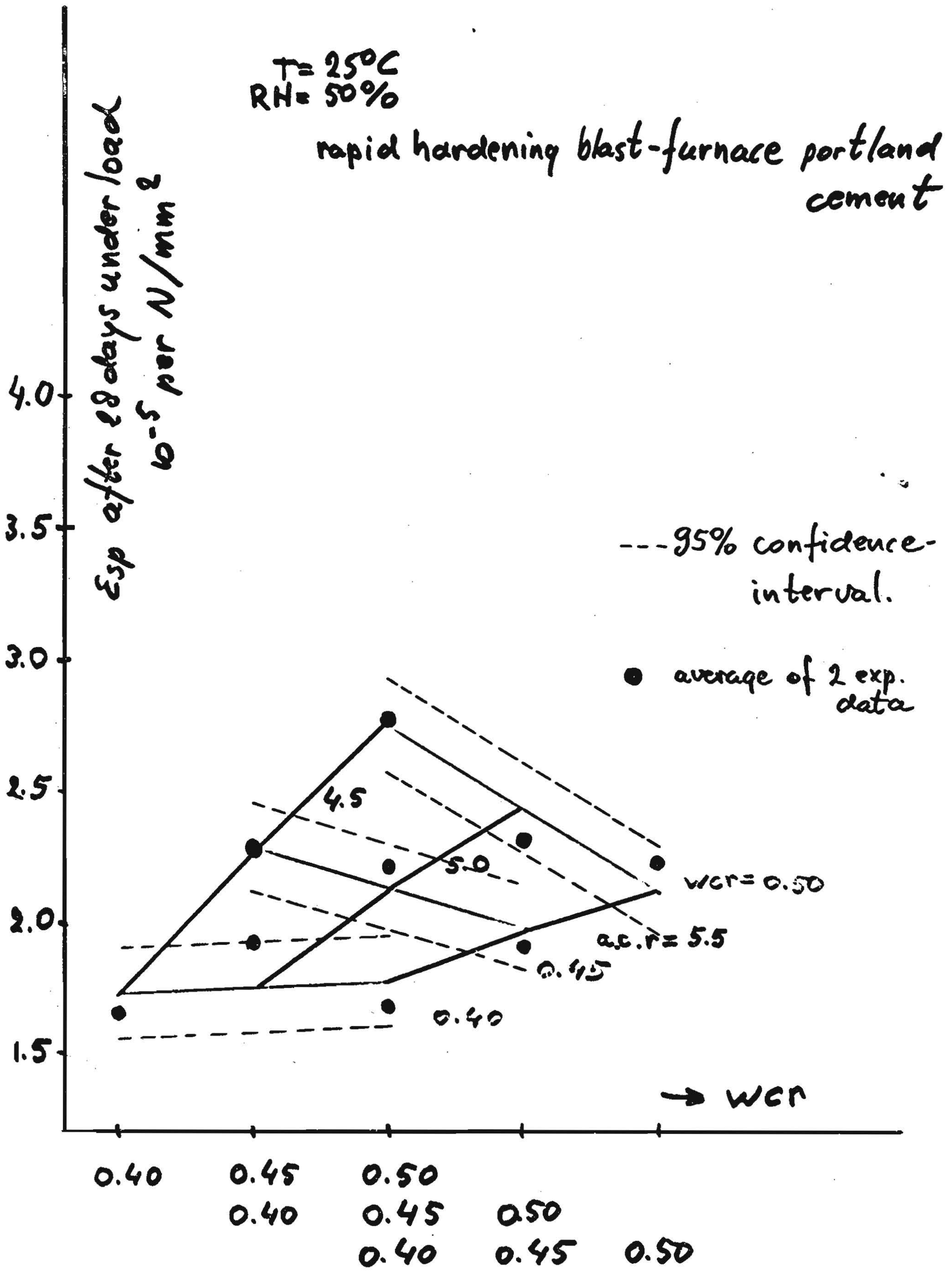

T= 25°C , RH= 50%
rapid hard. portl. cem. concretes.
a.c.r. = 5.5.
w.c.r.
0.50
0.45
0.40
Log (εsp x10^5) p. N/mm²
0.6
0
-0.6
-1.2
-1
0
1
2
3
Log t (hours)
εsp(t) = A. t^B

5

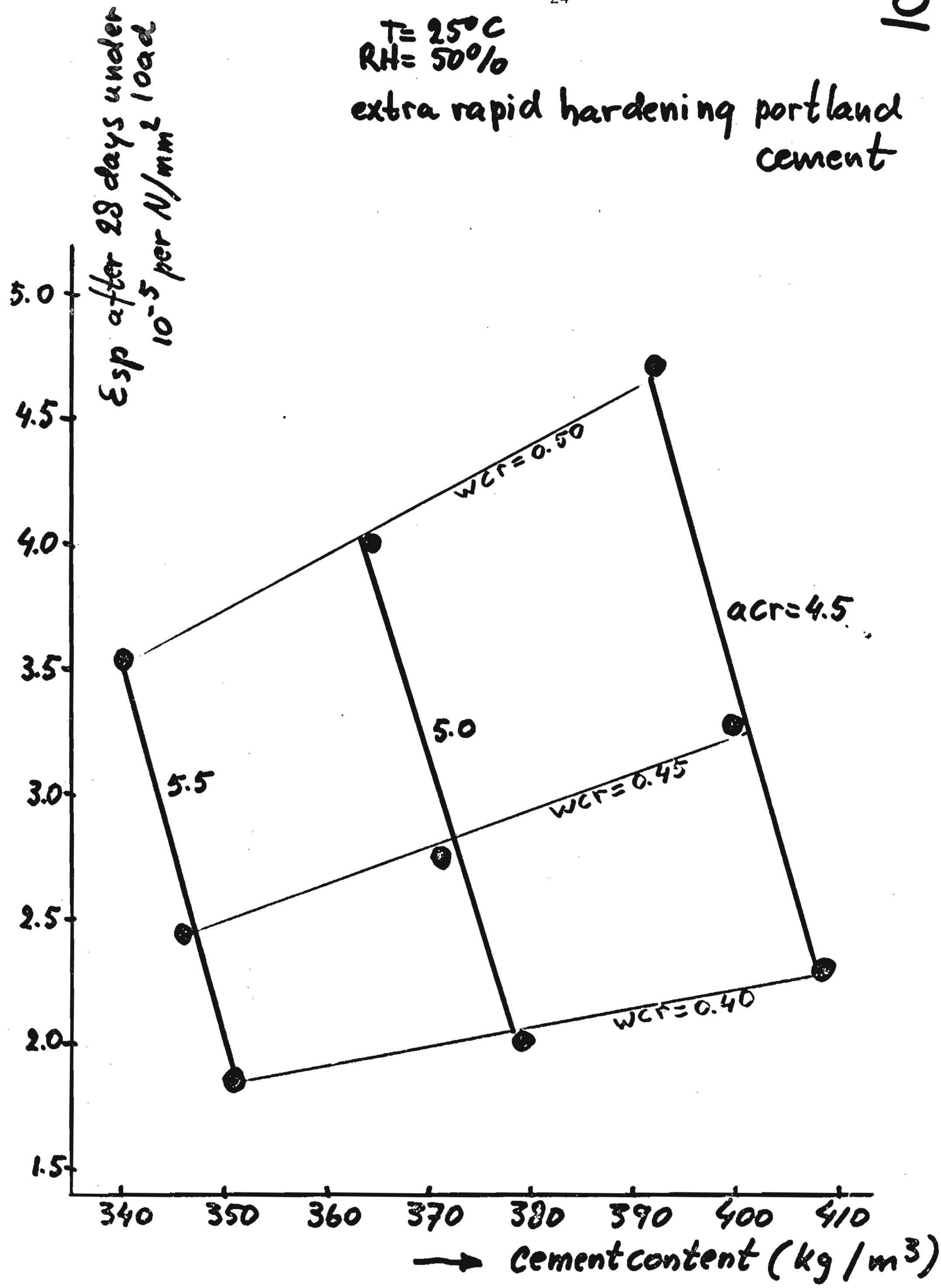

T= 25°C
RH= 50%
extra rapid hardening portland cem.
εsp after 28d. under load
10^-5 per N/mm²
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
--- 95% confidence-interval.
acr=4.5
acr=5.0
acr=5.5
wcr=0.50
wcr=0.45
wcr=0.40
→ wcr
0.40
0.45
0.50
0.40
0.45
0.50
0.40
0.45
0.50

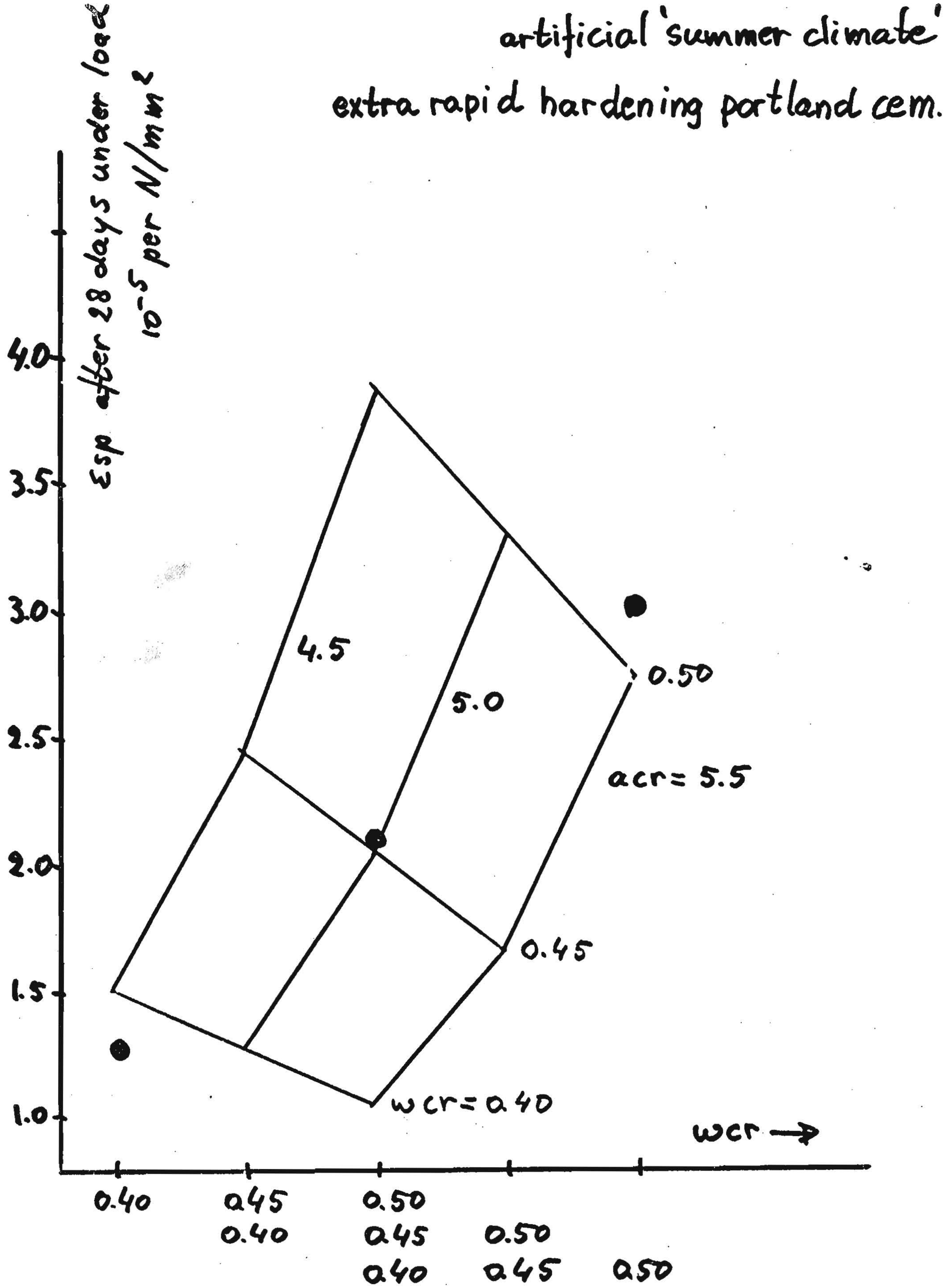

6
T= 25°C
RH= 50%
rapid hardening portland cem.
--- 95% confidence-interval
εsp after 28 d. under load
10^-5 per N/mm^2
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
a.c.r = 4.5
5.0
5.5
wcr= 0.50
wcr= 0.45
wcr = 0.40
→ wcr
0.40
0.45
0.50
0.40
0.45
0.50
0.40
0.45
0.50

7


T= 25°C
RH= 50%
rapid hardening blast-furnace portland cement
Esp after 28 days under load
10^-5 per N/mm²
4.0
3.5
3.0
2.5
2.0
1.5
---95% confidence-interval.
average of 2 exp. data
4.5
5.0
wcr= 0.50
a.c.r= 5.5
0.45
0.40
→ wcr
0.40
0.45
0.40
0.50
0.45
0.40
0.50
0.45
0.50

10


T= 25°C
RH= 50%
extra rapid hardening portland cement
Esp after 28 days under load
10⁻⁵ per N/mm²
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
wcr=0.50
wcr=0.45
wcr=0.40
acr=4.5
5.0
5.5
340
350
360
370
380
390
400
410
Cement content (kg/m³)


artificial 'summer climate'
extra rapid hardening portland cem.
Esp after 28 days under load
10^-5 per N/mm²
4.0
3.5
3.0
2.5
2.0
1.5
1.0
4.5
5.0
0.50
acr= 5.5
0.45
wcr= 0.40
wcr →
0.40
0.45
0.40
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0.45
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0.50