Degree of capillary saturation : a tool for better evaluation of the moisture content in concrete

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1 Background

Relative humidities (RH) above 98% are difficult to use reliably when analysing the moisture conditions in a structure. A measurement of the moisture content by weight (u) is in this case, theoretical, a better way of discovering differences in moisture conditions between different points since the slope of the sorption isotherm is very steep in high moisture conditions.

The moisture content by weight is however difficult to determine accurately in concrete as the small samples taken out are usually not representative for the concrete quality in question, in this case the aggregate size is the determining factor. In a concrete structure the concrete is also differently compacted at different depths and the components may have separated to some extent. The same u at different depths can consequently mean different moisture conditions, and the opposite is also valid of course.

By determining the distribution of u in a structure which contains different materials or different material qualities it is of cours impossible to get any guidance by measuring the u only.

In high moisture conditions near 100% RH a measurement of RH is not always sufficiently accurate either. A measurement of the degree of capillary saturation (S_{cap}) gives greater possibilities of eliminating these problems.

In many case of damage in concrete slab on the ground S_{cap} measurements have given correct information about the real moisture source when other measuring methods and previous observations have arrived at other conclusions. The example in Table 1 illustrates clearly how the results can be and how the measurement results can be misinterpreted.

Table 1 Example of measurement results in a basement floor of concrete, Hammarkullen, Göteborg, Nilsson (1977).

Material	Depth (%)	u (%)	RH (%)	u after capillary saturation (%)	S_{cap} (−)
Mortar	0-2		100		
	0-3	6.7		7.6	0.88
Concrete	3-5	5.2		7.3	0.71
	6-7		100		
	7-10	5.6		6.8	0.82
	10-15	5.2	100	6.1	0.85
	15-20	4.4	100	5.0	0.88

RH is 100% in the whole concrete slab and gives no information from where the moisture comes. u has its higest value at the top and decreases downwards, which sometimes gives the impression that the moisture comes from above. If u is determined after the samples are filled with water through free capillary suction (u_{cap}) there is the same tendency, u_{cap} has its highest value at the top and decreases downwards.

S_{cap} in the concrete has its highest value at the bottom and decreases gradually upwards which shows that the moisture does not come from above; on the contrary should a further analysis definitely show that the moisture comes from below or that, by means of hysteresis, it is in equilibrium in the slab. Of course other results can be obtained in mortar, as this is a different material.

2 Definition of the degree of capillary saturation and the principle measurement

The degree of capillary saturation is defined by

$S_{cap} = u/u_{cap}$

Which can be written

$$S_{cap} = \frac{m_1 - m_2}{m_{cap} - m_2} \qquad (1)$$

Where m_1 is the initial weight, m_2 the dried out weight at 105°C and m_{cap} is the weight after free capillary suction.

The measurement is carried out in the following manner. The sample which is taken from the structure is cleaned from drilling dust and "loose particles" as fast as possible so the sample does not have time to dry. After weighing (m_1) the sample is placed in contact with a free watersurface and evaporation is prevented. After a few days when the surface is wet and the sample is capillary filled the weight (m_{cap}) is determined again. Afterwards the sample is dried out in an oven at 105°C and the dry weight (m_2) is determined. The procedure is shown in Fig 1.

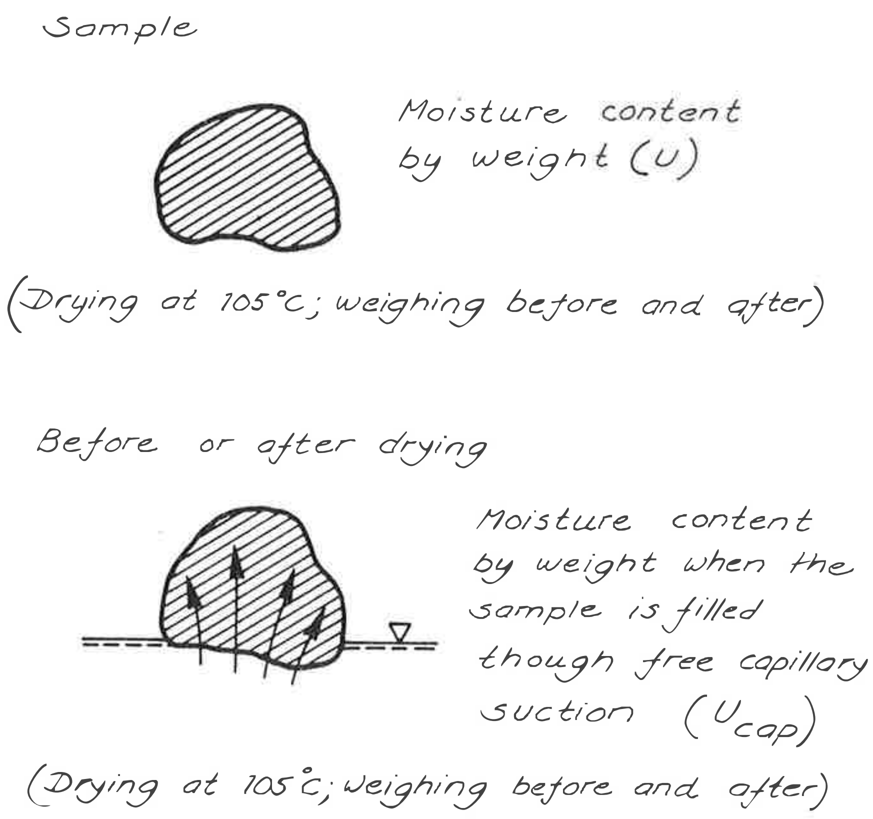

Fig 1 The procedure during the determination of S_{cap}

3 Laboratory experiment

Laboratory experiments have been made to show the advantage of measuring S_{cap} instead of only measuring u. The different parts of the measuring technic have also been studied, with extensive laboratory experiments, in order to improve the accuracy. Results have been obtained; among other things regarding the time for capillary suction, the dependence of the sample size and concrete quality on the drying time, influence of the oven temperature and other errors in measurement.

In Fig 2 some examples of results are given from a test series in concrete, where the influence of sample size was studied. The u-measurements show, as expected, that the smaller the sample the greater the deviation from the mean value. Even with samples greater than 300 grams the scatter turns out to be proportionately great.

The scatter when measuring S_{cap} was very small and the sample size has no influence on the result.

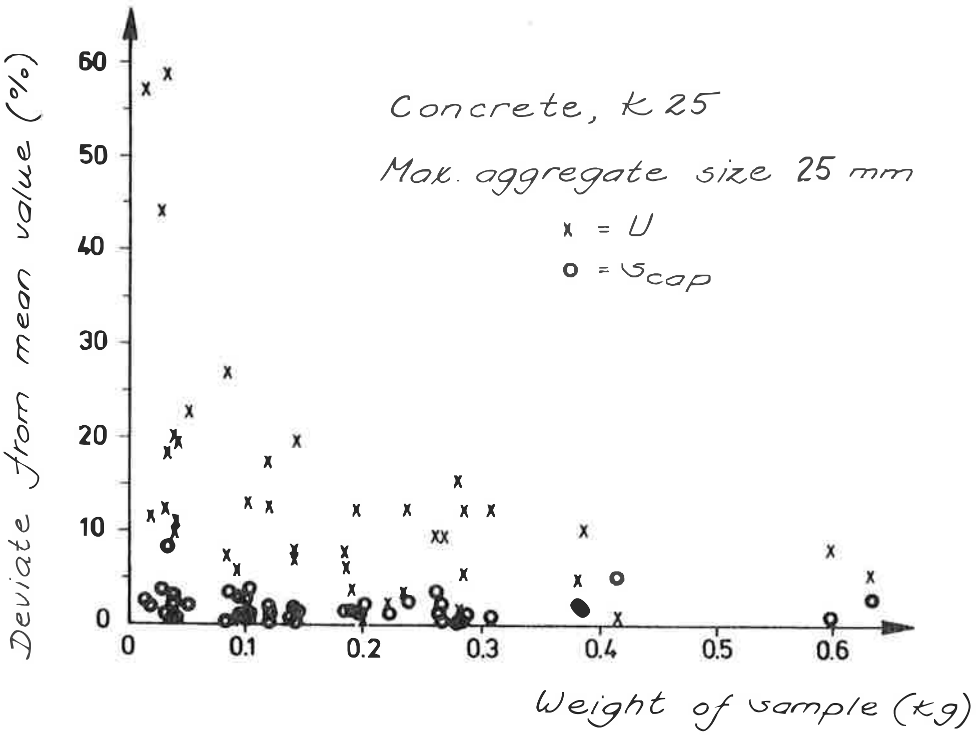

Fig.2 Deviations from mean value of u- and S_{cap} values of a concrete with the same moisture content.

In Fig.3 some examples of results are given, for a mortar, from a test series where the influence of the sample size was studied. The scatter in u- and S_{cap} values are the same size, which can be explained by the fact that there are only smaller aggregates present. For the u-measurements the deviation from the mean value is not so dependent on the sample size as in Fig.2. Observe that the scales in Fig.2 and Fig.3 are not the same.

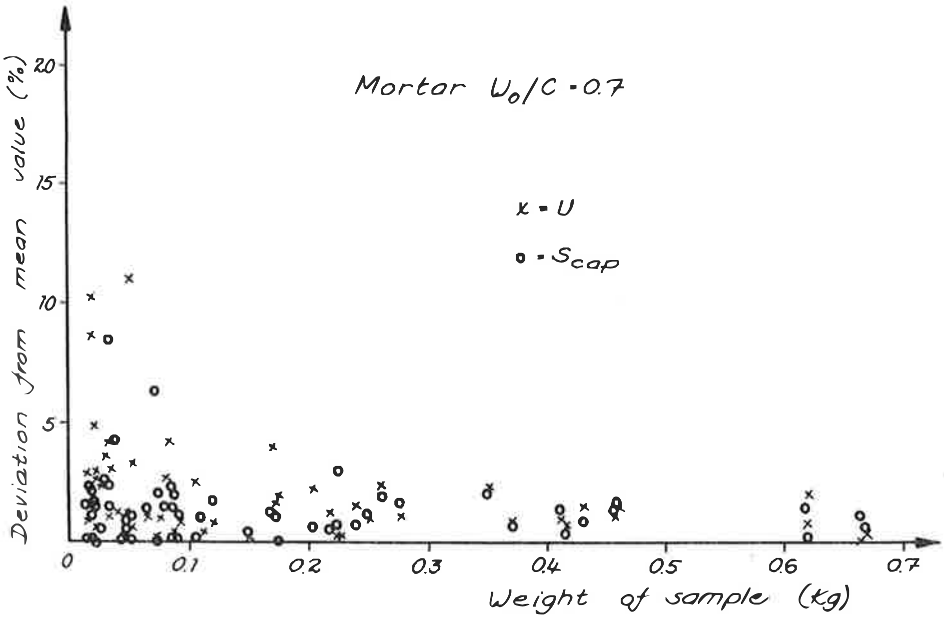

Fig.3 Deviations from mean value of u- and S_{cap} values of a mortar with the same moisture content.

In Fig.4 another example is given. In this case the influence of the separation in a concrete structure can be seen. The specimen is sealed directly after casting and consequently has the same moisture condition at different distances from the bottom. After curing u- and S_{cap} values are determined on samples taken at different heights. The distribution in the u-values shows a tendency to higher u-values at the top then near to the bottom, which could be interpreted as an indication that there is a moisture flow downwards. The S_{cap}-values show however that this is not true, instead the moisture condition could very well be the same in the whole specimen.

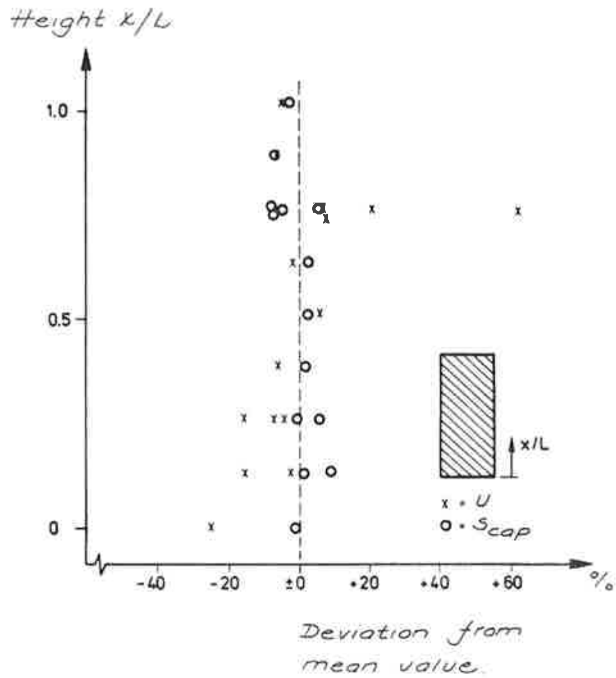

Fig.4 Example of distrubution of u-values in a concrete slab, where there is a u-gradient downwards without any moisture transport downwards. S_{cap} gives correct information.

The influence of an error in weight determination on u and S_{cap} can be estimated by writing

$$\ell n\ u = \ell n(m_1 - m_2) - \ell n\ m_2$$

$$\frac{\Delta u}{u} = \frac{\Delta(m_1 - m_2)}{m_1 - m_2} - \frac{\Delta m_2}{m_2} \qquad (2)$$

$$\ell n\ S_{cap} = \ell n(m_1 - m_2) - \ell n(m_{cap} - m_2)$$

$$\frac{\Delta S_{cap}}{S_{cap}} = \frac{\Delta(m_1 - m_2)}{m_1 - m_2} - \frac{\Delta(m_{cap} - m_2)}{m_{cap} - m_2} \qquad (3)$$

From (2) and (3) it can be seen that an error in m_1 gives an error of the same magnitude in $\Delta u/u$ and in $\Delta S_{cap}/S_{cap}$.

The influence of m_{cap} is only on S_{cap} , and if there are relative highly moisture conditions then m_{cap} is in the same order of magnitude as m_1, which means that an error in m_{cap} gives about the same influence as an error in m_1.
An error in m_2 has about the same influence as m_1 on $\Delta u/u$ because in (2) $\Delta m_2/m_2$ is small compared with $\Delta(m_1 - m_2)/(m_1 - m_2)$. An error in m_2 has little influence on $\Delta S_{cap}/S_{cap}$ as the two terms in (3) almost cancel out each other.

To exemplify the influence of the weight of the sample on $\Delta u/u$ and $\Delta S_{cap}/S_{cap}$ has in Fig.5 an error of 0.05 gram been estimated in m_1 only, m_2 only and m_{cap} only. From Fig.5 it can be seen that even relatively small errors in the weight has an essential influence when the weight of the sample is less than 0.1 - 0.2 kg. In practical measurements the weight of the sample is as a rule less than about 0.2 kg.

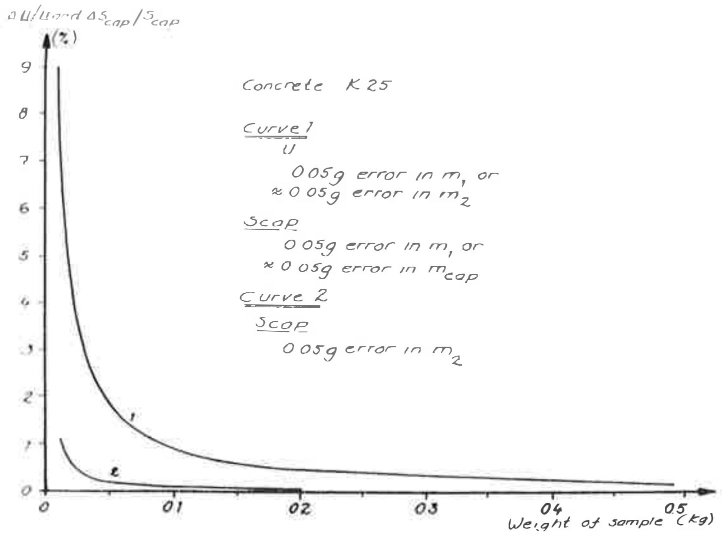

Fig.5 The influence of an error of 0.05 grams in different sample weights.

To study the influence of unintentional drying when taking out and treating the moisture samples, the drying of capillary filled samples were examined. The taking out and the treatment of a sample can take a relativly long time; the sample should be taken from the construction and cleaned from drilling dust and loose parts and then put in a plastic bag for transport to the laboratory, where it is taken out from the plastic bag and weighed. The evaporation per unit area of the sample was measured for different sample sizes and with different ratio area(A) - volumes(V). For concrete K 25 $\Delta u/u$ and $\Delta S_{cap}/S_{cap}$ are calculated for different times when RH around the sample is 40%, see Fig.6. In Fig.6 it is clearly shown that if the error in u and S_{cap} is not great then the time of handling for small samples should be less than about 1/2 minute and for larger samples maximum of 1 minute.

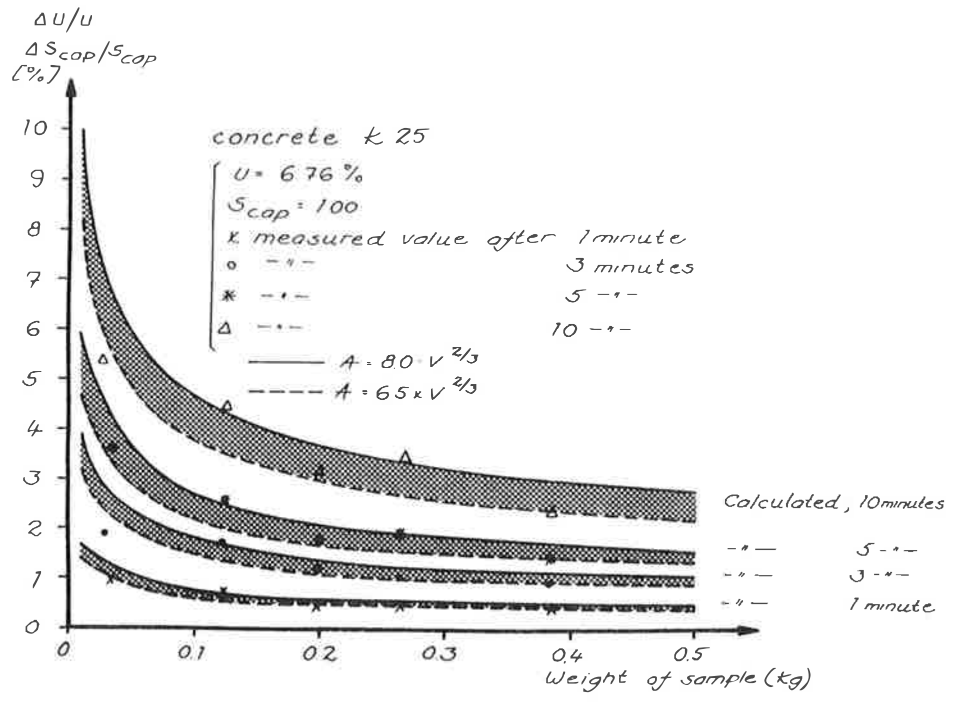

Fig.6 Influence of drying when handling the samples.

To study the influence of the oven temperature on u and S_{cap} mortar with $w_o/c = 0.7$ was examined. The samples were first dried out at 90°C after which the weight of the samples was stabilized the temperature was increased by 5°C, and so on upp to 115°C. From Fig.7 which is a mean value of the results it can be seen that the oven temperature has a considerably greater influence on u than on S_{cap}.

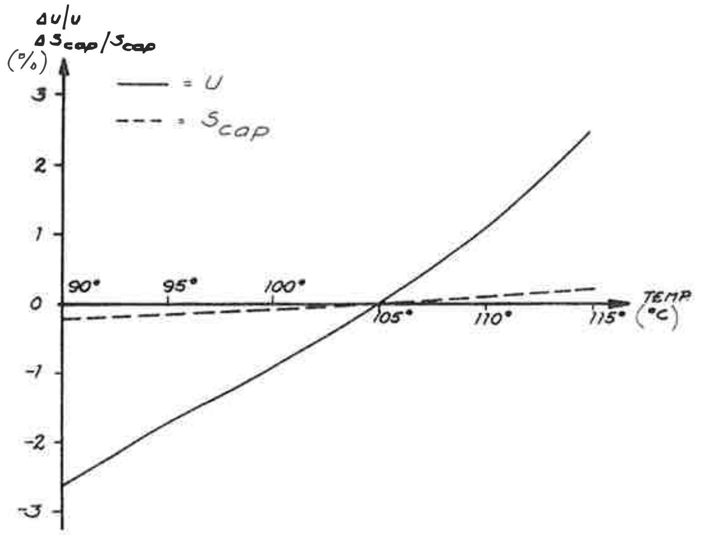

Fig.7 Influence of the oven temperature on u and S_{cap}.

4 Conversion to RH

With the knowledge of the shape of the sorption curve and the moisture history of the actual concrete, it should be possible to evaluate RH when S_{cap} is determined. In normal cases when only u is determined such a conversation is not possible because of the great uncertainty in determining u. When converting to RH this uncertainty can lead to errors of several percent, even if the sorption curve and the moisture history are well known.

When starting from points which lie on the desorption isotherm a conversion can be made from S_{cap} to RH with the assistance of desorption isotherms for concrete according to Nilsson (1980), see Fig.8, in the following manner.

$$u = \frac{W_e}{C+B+W_n} = \frac{W_e/C}{1+B/C+W_n/C} \qquad (4)$$

$$W_e = \frac{\text{weight of water evaporable at } 105^oC}{\text{total volume of the material}} \qquad (kg/m^3)$$

C = Cement content (kg/m^3)
B = Aggregate content (kg/m^3)
W_n = non - evaporable moisture content (kg/m^3)
At capillary saturation u_{100} can be written

$$u_{100} = \frac{W_o - 0.19\alpha C}{C+B+W_n} = \frac{W_o/C - 0.19\alpha}{1+B/C+W_n/C} \qquad (5)$$

W_o = mixing water (kg/m^3)
W_o/C = water - cement ratio
α = degree of hydration
From (4) and (5) one can obtain S_{cap}

$$S_{cap} = \frac{u}{u_{100}} = \frac{W_e/C}{W_o/C - 0.19\alpha} \qquad (6)$$

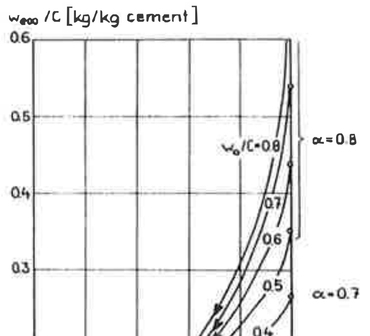

Fig.8 Desorption isotherms for concrete according to Nilsson (1980)

The accuracy in estimating which RH a certain S_{cap} corresponds to, is determined by how well you know the W_o/C and α .

In Fig.9 the desorption isotherms, expressed in S_{cap}, are drawn for the mortars which were used in the laboratory experiments. The degrees of hydration are not measured but estimated with the help of the age of the samples and according to literature. The deviations between calculated and measured RH are maximally 1 - 2% RH, with the eception of one point. The desorption isotherms could not be constructed and RH measured with such accuracy. This exellent coincidence should not be expected in practical applications.

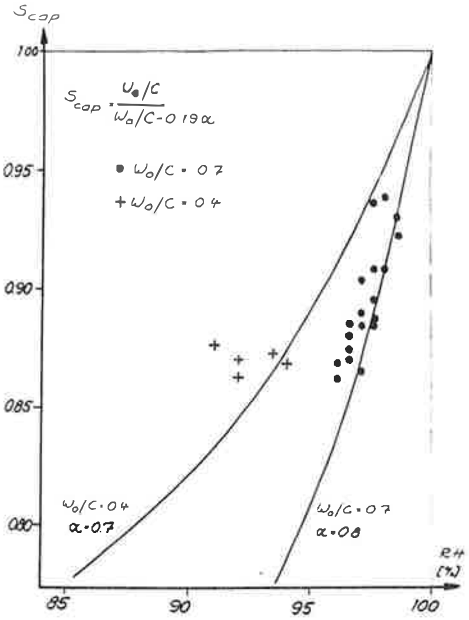

Fig.9 The upper parts of the calculated desorption isotherms for samples made of mortar which were used in the laboratory experiments.

5 Conclusion

The main conclusion of our experiments is that the the degree of capillary saturation, S_{cap}, is far more precise than the moisture content by weight, u , in the analysis of concrete.

6 Acknowledgement

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