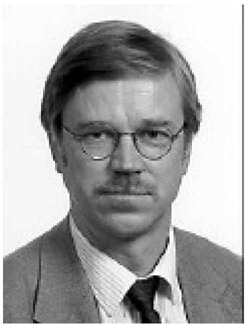
NORDIC CONCRETE FEDERATION MINI-SEMINAR "MOISTURE MEASUREMENT IN CONCRETE CONSTRUCTIONS EXPOSED TO TEMPERATURE AND MOISTURE VARIATIONS"



Heikki Kukko
Research Professor
Technical Research Centre of Finland, VTT Building Technology,
Concrete Materials
Kemistintie 3, Espoo, P.O.Box 1805, 02044 VTT, Finland
http://www.vtt.fi

Hemming Paroll
M. Sc., Research Scientist
Technical Research Centre of Finland, VTT Building Technology,
Concrete Materials
Kemistintie 3, Espoo, P.O.Box 1805, 02044 VTT, Finland
http://www.vtt.fi

ABSTRACT

Nordic Concrete Federation Mini-seminar "Moisture measurement in concrete constructions exposed to temperature and moisture variations" took place in Finland at Otaniemi, Espoo, August 22nd 1997. The mini-seminar was organised by Technical Research Centre of Finland (VTT). The main purpose of this mini-seminar was to discuss the benefits and weaknesses of measurement methods and to exchange experience of their utilisation. The mini-seminar gathered 24 concrete experts from three countries to delve into moisture measurement of concrete through presentations of papers and discussions including also the phenomena of self-desiccation and moisture measurement in high performance concrete and a presentation of a moisture sensor.

Key words: Moisture, moisture characteristics, humidity measurement, moisture meters

1 INTRODUCTION

This seminar was organised on August 22, 1997, in Espoo, Finland by VTT Building Technology. The seminar was a part in the series of Mini-seminars of the Nordic Concrete Federation.

The need to understand water transport and other humidity related behaviour of concrete arises from many practical reasons. The necessary drying time before surface coating is of vital importance in preventing deterioration and loosening of coatings. High humidity may give rise to health, aesthetic and durability problems during the service life of the structure. In controlling and estimating the existing humidity in concrete reliable and easy-to-use measurement methods are essential.

Concrete is a complicated material due to its porosity and hydraulic hardening. The increasing use of high performance concrete has increased the importance of phenomena like self-desiccation and temperature effects during hardening. The measurement of humidity in concrete in construction site is therefore a demanding task with various aspects to be taken into consideration. The understanding of the entity of aspects affecting the measurement results requires considerations of concrete hardening and micro structure, physical theories of water transport in porous material and way of functioning of the measurement apparatus.

The main purpose of this mini-seminar was to discuss the benefits and weaknesses of measurement methods and to exchange experience of their utilisation. The special topic of the seminar, humidity measurement in varying environmental conditions, is emphasized for practical reasons.

2 PRESENTATIONS

The main aspects in written reports of the contributions published in the seminar proceeding /1/ are summarised in this chapter.

Measurements on the moisture state in a heavily trafficked concrete flat slab repaired with a bonded concrete overlay by Jonatan Paulsson and Ali Farhang presents a research of a larger project which focuses on the effects of repairs on the remaining service life of repaired concrete bridge decks. This paper focuses on the moisture states in a repaired concrete bridge deck repaired with a bonded Steel Fibre Reinforced Concrete (SFRC) overlay without any isolation. The concrete overlay is therefore directly exposed to the environment. The measurement results are to be used in predictions of the service lives of concrete bridge decks exposed to de-icing salt etc.

Seven so called MS sensors (temperature and moisture gauges) were installed in the overlay and in the old concrete slab. The temperature and the relative humidity (resistance) were measured every hour and collected in data loggers. The structure is a heavily trafficked concrete slab deck built in 1944 and repaired with a bonded SFRC overlay in 1993. The structure is located just outside the central parts of Stockholm and de-icing agents (NaCl) are frequently used between October and April.

As a result of the measurements it was found out that the concrete slab clearly interacted with the environment. The RH in the concrete slab varied substantially during the winter and spring. There were several factors that seemed to affect the RH in the concrete slab. The number of precipitation occasions had a clear influence on the RH in the top part (overlay). The ambient RH did not affect the RH in the top part of the concrete slab. The measurements indicate that water transport may occur mainly at the outer 5 (10) mm. They also indicate that the RH in the interior parts of the concrete slab may increase during the spring due to the increased temperature. This released water may be transported to the outer parts of the slab during the spring/ summer. The measurements during the winter 1996-1997 indicate that the moisture state at the level of 35 mm from the wear surface and further down is not affected by diurnal changes of the relative humidity in the ambient air.

Measurements on seasonal and daily variation of temperature distribution across a concrete bridge slab due to a change of ambient temperature and solar radiation by Ali Farhang and Jonatan Paulsson presents a research related to Gullmarsplan traffic junction repair project in Stockholm. In order to present a relationship between environmental forces and the actual bridge response, a set of measurements have been conducted. The intention of this paper is to monitor the extreme events and correlate the environmental conditions with the recorded response such as temperature distribution and moisture transport.

A concrete bridge slab is permanently subjected to thermal action originating from the environment in which it is located. This thermal action depends on the environmental and climatic conditions at the site. Thermal action has a significant effect on the structural behaviour of a concrete slab, because these effects are of a comparable magnitude to the effect of mechanical loads. As the thermal action is permanent and cyclical, it may have a significant effect on the useful life of the concrete.

Beside above mentioned effects, the thermal action effects the durability of concrete. As it is known, all the chemical and physical process in concrete are temperature dependent. One of the most important process in concrete is the chloride uptake which is influenced by the environmental conditions such as drying and wetting, rainfall and sunshine, temperature distribution in concrete and ambient temperature and humidity.

The state of moisture in the concrete and the dynamics of moisture transport are of vital importance for concrete degradation, especially corrosion. Relative humidity and temperature measurements have been carried out on Gullmarsplan traffic junction using commercially available sensors located in sealed holes drilled into the concrete.

An experimental program was set up to study the thermal response of the concrete slab. The investigation included placement of 7 sensors within the concrete slab at different depths between 10 and 300 mm. MS sensors were used for in situ measurements of relative humidity and temperature.

In this research temperature and moisture profiles could be measured in situ and be monitored in order to establish some relationship between the environmental loads and structural response. The magnitude and distribution of extreme temperature gradients could be obtained using in situ measurement technique. The most important factors affecting the magnitude of temperature gradients are the daily variation of ambient temperature and solar radiation. The monitored extreme temperature differences is highly non-linear with a magnitude which is higher than the linear gradient value according to Swedish design code. The moisture content in the surface skin of concrete varies with the surrounding climate such as solar radiation and rain. However, the moisture state inside the concrete appears to be stable over time and increases with increasing ambient temperature.

Moisture measurements of concrete in practice (in Swedish*:* **Betongens fuktmätningar i praktiken**) by Tarja Merikallio and Pentti Lumme presents experiences of measurements of humidity in concrete in situ and some tests carried out in the laboratory. The background for this presentation is the insufficient knowledge of measuring moisture correctly in situ. It is important to reach a satisfying level of measurement results in order to lay on floor covering in proper time. To measure moisture in the concrete is not easy. Concrete is a difficult material considering moisture problems. One has to know well the measuring apparatus if reliable measurement results are wanted. The authors consider that it is important to rise the accuracy level of moisture measurements. But it is not necessary to get the absolutely correct value with much work in the measurements in practice.

A co-operative work has been carried out between the Technical University of Helsinki, Lohja Rudus, Vaisala and Humittest during the past three years to develop new sensors and additional equipment to measure the relative humidity especially in concrete but also in other building materials. These sensors have been tested in situ during varying circumstances and also in the laboratory.

Some tests have been carried out where the sensor has been cast in the concrete, with a tube cast in sensor and a sensor put in a drilled hole. The tested sensors have been the old HMP36 model and the new HM44 model, which was remarkably better than the old model. It is important to know that the alkali in the concrete can influence the sensor and cause a great variation in the calibration value of the sensor. The HM44 sensor have been tested in Stockholm in situ together with the Swedish Humi-Guard sensor. The results have been very similar.

Variations of temperature in constructions influence greatly the measurement results. It has been found out that both the decrease of temperature or a strong warming of a slab can cause condensation or a high moisture level in a drilled hole. It is difficult to test the influence of temperature on the concrete with reliable results. So far one can say that a rise of the temperature causes a rise in the relative humidity of the concrete. This can partly be a phenomena in the concrete but also some influence of the sensor under varying circumstances is possible. According to the tests the influence is significant if the temperature is lower than 20°C. In practice it is hopeless to carry out measurements if the temperature vary much during the measurements. After the heating of a concrete slab one has to wait for the stabilisation to get reliable measurement results.

In the beginning of this year a co-operation project has begun between YIT, Lohja Rudus, Vaisala and Humittest. The aim of this project is to develop moisture planning to avoid moisture problems in advance in the building process. The measurements are carried out with HM44 equipment with the drilled hole method or with a sensor remaining in the concrete connected to a data logger.

Measurement of relative humidity and temperature in new concrete bridges by Hemming Paroll presents the results of relative humidity and temperature measurement carried out on three new bridges. Three sensors were compared at first to elucidate their applicability in measuring the relative humidity (RH) in outdoor conditions. For the further measurements the cast-in-place MS Sensor with data logger was used. The other sensors were not used because the applied isolation was insufficient.

To check the isolation it is recommended to check the RH and temperature curves during a minimum measurement period of 24 h. These measurements can be made either with a data logger or manually which is laborious. If the isolation is good the RH curve will parallel the temperature curve.

The increase of relative humidity with temperature inside the concrete could be explained by the fact that the moisture content in concrete is almost sealed and with the rise of the average temperature at each level the ability of the air uptaking humidity strongly increases. But this uptake is less than the released humidity from the concrete microstructure into the interior sealed air volume of the concrete. This event can also be seen when examining the effect of temperature on equilibrium moisture curves of concrete.

The cast-in-place MS Sensor with data logger was chosen because the temperature of the sensor was assumed to be the same as the temperature of the concrete in the demanding outdoor measurement conditions. This was tested by comparing the RH curves with their corresponding temperature curves. All the RH curves are not temperature compensated.

Before waterproofing the RH curve from the sensor at the depth of 20 mm decreased trying to reach hygral equilibrium with the environment (the ambient air) while the RH curve from the sensor at the depth of 50 mm increased with increasing temperature. This showed different RH behaviour of the surface layer at a test bridge (Oulu). Also at other bridges the concrete surface layer clearly interacted with the environment: the rain, ambient air temperature.

On one occasion at Oulu bridge the 20 mm RH curve of the MS sensor changed its behaviour and followed the increase of the 50 mm RH curve. This happened when the bridge was waterproofed causing a moisture isolation at the concrete surface. Soon after this RH rise the sensors documented almost the same high values and blistering of the waterproofing membrane was reported.

The measurement results indicate self-desiccation when the w/c = 0.4 - 0.5 during a period of about 2-3 weeks after casting of the concrete and that after this the RH in the interior parts of the concrete increase due to ambient temperature rise. It seems that this moisture is transported to the surface layers during summer which in turn evaporates to the ambient air.

The concrete surface RH dropped during summer and rose during the autumn.

Measurements of the moisture states on laboratory samples vs. measurements on new concrete bridges by Esa Nykänen presents a study where results from self-desiccation measurements carried out in laboratory of concrete samples with MS sensors are compared with values in the literature and measurement results from bridges.

The sensors were cast in two laboratory samples which were then stored in a climate room with 95% RH and 23 ^{o}C for 180 days. The types of concrete used had a w/c of 0.43 and 0.59.

Both the laboratory specimens (w/c 0.43 and 0.59) showed self-desiccation. The concrete “LAB” K 60 with w/c of 0.43 had a moisture of 82 RH% and the “LAB” K 40 with w/c of 0.59 had a moisture of 91 %RH at the age of 28 d. Both the time-RH % curves drop (dry) further to the age of about 56 d and the slowly begin to come up again. After the age of 180 days the curves still go up and there seems not to be any major difference between the upward slopes of the two curves.

The curves achieved in the laboratory were compared to the values in the literature. The correlation to the RH % values presented in the literature was mainly good. This actually means that the self-desiccation effect was measured, being naturally stronger with the concrete with lower w/c.

Secondly, the curves were compared to the same curves achieved with same kind of sensors in bridges. The compared sensors were located at the bottom side of the bridge to avoid the weather dependent part of effect (sun radiation etc.). The sensors in the bridges, located about the same depth from surface as in laboratory, showed quite identical curves compared to the laboratory ones. The similarity only took place for 2-3 weeks.

The use of cast-in sensors (MS-sensors) to detect relative humidity in both laboratory and outdoor is possible. The values are in good correlation to the ones presented in the literature.

Measurements of self-desiccation and shrinkage on hardening concrete by Hans Hedlund and Jan-Erik Jonasson presents a research on measurement of humidity and shrinkage concrete. A general presentation of the measurement of humidity and shrinkage in high performance concrete (HPC) and normal performance concrete (NPC) is given. At laboratory tests of self-desiccation and shrinkage under sealed condition were carried out with high performance concrete (HPC) and normal performance concrete (NPC).

In this research it was found out that:

- If the measurements of shrinkage are not isothermally performed, correction of the measured strain due to temperature rise in the specimen have to be regarded.
- Shrinkage under sealed conditions may be assumed as a homogenous deformation over the cross section. In the case of a drying homogenous deformation can not be assumed as there will be moisture and shrinkage differences influencing the movements in the surface zone.
- In high performance concrete, under sealed conditions, a nearly uniform decrease of relative humidity due to self-desiccation has been observed. Measurements of drying indicates a uniform decrease in RH, like sealed conditions, up to 28 days after casting. 90 days after casting effects of drying have been measured.
- Different shrinkage and self-desiccation behaviour have been observed between different cement fabricates.
- Sealed shrinkage can be described with decrease of relative humidity by piece-wise linear curves in the humidity level from saturation to about 70% RH (Method 1). Shrinkage under sealed conditions can also be described as a time dependent deformation (Method 2). Using method 2 based on a short term measurements gives high level of accuracy for long term prediction of sealed shrinkage.

Measurement of concrete humidity by the Humi-Guard system by Henry Lundberg, Nordisk Industrifysik AB, presents the Humi-Guard humidity measuring system. For concrete humidity measurement the company has developed a complete system based on an instrument for measuring conductance and temperature. The system includes everything needed for accurate and reliable measurements, such as measurement tubes with seals to be used in drilled holes, measurement tubes that can be cast in concrete, RH-sensors, sensor contacts, temperature sensors, tube plugs and covers, data sheets and computer programs for transforming the values from conductance and temperature readings to RH. In the system also some tools are implemented. In the Humi-Guard-system the measurements of temperature and conductance always are related to measurements of conductance of one or more reference sensors over cells producing known RH. This concept of measurements related to known RH-values and identical sensors means that no calibration against other measurements of against other instruments is needed.

Measurement of moisture in high performance concrete by Göran Hedenblad summarises some results from RH-measurements, as presented in newer Swedish literature. Results from the author’s own measurements in high performance concrete (HPC) are also presented. Two different types of RH-meters and two different HPCs have been used. The overall conclusion is that RH-measurements in HPC are much more difficult to do than in ordinary concrete. This paper shows that it is possible, but requires knowledge, to measure the relative humidity in HPC. The paper presents the following recommendations that can serve as a first base of knowledge:

- When measuring RH in drilled holes, check that redistribution of moisture cannot occur in the measurement hole and also check that the measured depth is well defined, that is, that the distance between RH-sensor and the concrete is minimised. Further the evaporating surface of the concrete against the RH-sensor should be big.
- Measure RH only when the house is built in and has a constant temperature.
- Let enough time elapse between measurements in the same measurement hole (at least one week). Also let the measurement continue enough (at least two days). Check that the RH-sensor including its filter has dried to a lower RH than that measured afterwards. It is probably easier for concrete to emit moisture than to take up moisture (in the vapour phase).
- When measuring RH in a test tube, do so only with test tubes which contain a relatively large amount of material. Measure only one or two times within a short period. After the sample is taken out of the construction, let it be conditioned for a few days in the test tube before the RH-measurement is made.

3 CLOSING WORDS

The papers presented at the seminar covered a the whole field of measuring the RH in concrete. That is, measuring RH of concrete in-doors and out-doors as well as measuring the self-desiccation after the casting and measuring RH in high performance concrete (HPC). In addition to the traditional way of documenting measurement results a new way of documenting results with data loggers were presented as well as the use of new sensors for long term measurement.

The experts who participated in the discussions following the presentations had deep insight in the problems of moisture measurement in concrete. In the discussions it was noted that there exist varying opinions on the reliability of the results of in-situ measurements and some uncertainty about the validity of the existing measurement procedures when temperature varies. The opinions about the reliability of various methods seem to be a matter of discussion, too.

The main conclusions were:

- Temperature and moisture profiles can be measured in situ. According to the measurement results the concrete surface layer interacted with the environment: the rain and ambient air temperature. The relative humidity in the surface layers to the depth of some cm varies during the seasons.

- When discussing the reliability of the results of out door measurements it was noted that
    - ♦ Temperature variation in concrete complicates considerably measurements of the relative humidity, because
        - ◊ it is more difficult to make measurements so that the temperature of the sensor and concrete will be the same at the time of measurement if the isolation of the measuring sensor is not proper.
        - ◊ there is a risk for condensation in the measuring sensor
    - ♦ Proper isolation of the sensors is needed to ensure practical and accurate measurements in demanding out door conditions e. g. on bridges.
- Different shrinkage and self-desiccation behaviour have been observed between different cement fabricates.
- In high performance concrete, under sealed conditions, a nearly uniform decrease of relative humidity due to self-desiccation has been observed.
- It is possible to measure the relative humidity in high performance concrete but it requires knowledge, special accuracy and more time than in the case of normal strength concrete.

LITTERATURE

1. Kukko, H., & Paroll, H. (Editors), Moisture measurement in concrete constructions exposed to temperature and moisture variations. Nordic Mini-seminar of the Nordic Concrete Federation, Espoo, Finland 22.8.1997. 118p.