Relative Humidity Measured by Wooden Stick Method in Concrete Structures: Long Term Measurements and Reduction of Humidity by Surface Treatment.

By Viggo Jensen*

Synopsis: Measurements of relative humidity (RH) by means of wooden sticks of the species Ramin (*Gonystylus macrophyllum*) have been used in Norway since 1995. The method is especially applicable to concrete with high internal humidity as in structures damaged by Alkali Aggregate Reaction (AAR) or freezing and thawing. Results up to now show that the relative humidity is stable 5 cm from the surface and that ingress of rainwater is an important source of water in most of the outdoor exposed concrete structures. Correlation tests have shown that wooden sticks still are in good condition and reliable after 7 years continuous use. Measurements on surface treated columns and beams in two structures show that the relative humidity 5-cm from the surface decreased significantly during four years monitoring, which was not the case in untreated concrete. It is concluded that surface treatment is able to reduce the relative humidity in concrete structures exposed to rainwater.

Key words: concrete, Alkali Aggregate Reaction, relative humidity, surface treatment, silane, wooden stick method

*Managing director, NBTL, Norwegian Concrete and Aggregate Laboratory Ltd, 7018 Trondheim, Norway

Viggo Jensen is Master of Science in geology (1984) from University of Copenhagen, Denmark and doctor technicae (Dr. techn.) 1993 from the Technical University of Trondheim, Norway. Managing Director of the Norwegian Concrete and Aggregate Laboratory Ltd. (NBTL). Viggo Jensen has written 1 book, 40 papers and several technical reports.

INTRODUCTION

In 1995 an in-situ system for measurement of relative humidity (RH) in concrete was developed and pilot tested on a road bridge in Trondheim (Elgeseter bridge) and a dam structure in Southern Norway (Embretsfoss dam), both structures damaged by Alkali Aggregate Reaction AAR (1). The concept of the system was use of inexpensive equipment and simple and systematic procedures whereby the owners of structures carried out all the measurements themselves. Relative humidity is measured by use of wooden sticks (*Gonystylus macrophyllum*) in equilibrium with the relative humidity in the concrete. A similar method has been used in UK and Denmark (2, 3) but was improved and detailed documented in the Norwegian research project (1).

Measurements have been carried out for more than seven years and the reliability of the method has been documented. In 1998, the wooden stick method was used on The Norwegian Veritas office building in Oslo, which suffered from AAR. Here, six different surface treatment systems were tested for long term performance and ability to reduce the humidity in the concrete (4). In 1999 and 2000 new measurement locations were mounted in Elgeseter bridge and 3 columns were impregnated with 3 different types of silane.

The paper present information on the wooden stick method and results of humidity measurements in untreated and treated/impregnated concrete elements from Elgeseter Bridge in Trondheim and The Norwegian Veritas house in Oslo.

THE WOODEN STICK METHOD

Humidity measurement by electrical humidity probes is a standard method in the paint and wood industry. The electrical conductivity is measured between two “steel needles, which are pressed into the wood. The electrical conductivity that is recorded on the apparatus (e.g. Protiometer Timber Master) correlates well with the water content in the wood (water percent). The temperature has only minor influence on the electrical conductivity in wood, which is not the case in concrete (5, 6). The method has been used in few concrete structures in the UK and Denmark, but the reliability, uncertainty and limitation of the method have not been published to the author's knowledge.

Preparation and calibration of sticks

The wooden sticks of the species Ramin used in the Norwegian projects, have a diameter of 12 mm and are 45 mm long. Other types of wood might be used but documentation on accuracy and long term performance test should then be carried out. For each wooden stick, calibration curves of adsorption and desorption are made. Experience has shown that calibration curves vary between wooden sticks, sometimes significantly. Fig. 1 shows an example of adsorption and desorption curves for one wooden stick (no.360) and the 95% confidence interval calculated from 112 wooden sticks (1, 7, 8). It can be seen that the accuracy of measurements is improved by the use of individual calibration curves rather than by one standardized curve, which is the case in the UK and Denmark. The difference between relative humidity from the desorption curve and the adsorption curve can be used as a measure of the accuracy. Note the steeper inclination at higher relative humidity, which means, that the sensitivity is improved with higher relative humidity, see Fig. 1. This is opposite to all other commercial humidity apparatus where measurement of relative humidity higher than 98% often is uncertain.

Correlation with other methods

To assess the reliability of the wooden stick method, a correlation test between wooden sticks and a commercial type electrical humidity probe was carried out. Wooden sticks, mounted in Elgeseter bridge (Trondheim) were removed after a period of 3 years, then sealed in tight plastic bags, and taken into the laboratory. After the laboratory temperature was reached (20 ^{o}C), the measurements on the sticks were carried out (9). The sticks were then put into small tight plastic containers for measurements with the AHEAD hygrotemp II probes (Norwegian commercial equipment). Fig. 2 shows the correlation between the RH determined by the wooden sticks and AHEAD HygroTemp II sensors. Note the acceptable correlation between the two methods and that both methods more or less measure the same RH. Later correlation tests, carried out in 2000 and 2002 on wooden sticks and Humi Guard sensors (Swedish commercial equipment) but now “in situ” also showed acceptable correlation, see Fig. 3. However, Humi Guard sensors obtain lower RH relatively to wooden sticks in concretes with RH less than about 90%. This was not the case between wooden sticks and AHEAH HygroTemp II sensor. The results indicates that the wooden sticks were still reliable after 7 years use in structures.

<u>Structures</u>

It is very important that the wooden stick is not in contact with atmospheric air. In the Norwegian projects two wooden sticks (5 cm and 25 cm or 40 cm from the surface) were mounted in a specially fabricated plastic tube as shown in Fig.4 (1, 8). The plastic tube can be modified with only one wooden stick or several more, depending on the use and structural dimensions. The contact between concrete and plastic tube has been injected with epoxy. Measurements are simple to carry out. The wooden sticks are pulled out from the tube in the concrete and the electrical conductivity (water percent) and temperature are measured. The relative humidity is estimated from the calibration curve or by a spreadsheet.

CASE 1: ELGESETER BRIDGE, TRONDHEIM

Elgeseter bridge was built in 1949-1951 as a continuous 200 m long reinforced concrete bridge supported by 8 bents with 4 columns each having a diameter of 80 cm, see Fig 5. AAR was diagnosed by microstructural analysis in 1990 to be caused by the rock types mylonite, graywacke and argillite[1]. In columns, several vertical cracks up to 3-mm width can be followed from ground level to the underside of the supported beams. Some columns also contain map cracking. Inspection and measurement of cracks in columns show more cracking on the western faces compared with eastern faces due to rainwater (eastern faces of columns stay dry when it rains). Measurements have also shown that columns exposed more westerly and located in the middle of the river have more cracks. Cracks are still opening and increase from 0.04 mm to 0.15 mm yearly (9).

In 1995, an in-situ system for measurement of relative humidity by wooden sticks (and expansion of cracks not presented in this paper) was initiated as a pilot project. Eight measurement locations were mounted in one beam and 4 columns with diameter 80 cm. Results to date show that the relative humidity in the bridge varies from 100% to 87% and is not

[1] Jensen V. 1990. “Microstructural analysis on cores from Elgeseter bridge”. Sintef test report confidential (in Norwegian)

significantly influenced by temperature fluctuations[2] see Fig. 6 (9). Five cm from the surface the relative humidity is more or less stable. Rainwater is an important source of water because western faces obtain higher relative humidity than eastern faces (stays dry during rain), even the columns are located in the river.

With the aim of measuring the relative humidity in other columns, both on land and in the river, eleven new measurement locations were mounted in 1999. Three different types of silanes were also applied on 3 whole columns. Silane type A (*100% isobutyl-tri-ethoxysilan*) was applied by the road directory in July 2000. Silane type B (*40% organosilan ester in isopropanol*) and Silane type C (*80% not specified silane type, with creamy consistence*) were applied by the product dealers in September 1999. All the products were applied according to the producer's recommendations.

Results of impregnated columns to date (September 2002) are given in Table 1. Results suggest that treatment with silane apparently reduces the concrete's relative humidity even when columns are massive and AAR is in an advanced stage[3]. Moreover, one of the products apparently reduces the relative humidity more efficiently compared with the other two products; Fig. 7, 8 and 9.

CASE 2: THE NORWEGIAN VERITAS HOUSE, OSLO

The Norwegian Veritas house (DNV) was built during the period 1974 - 1976 using prefabricated columns and beams. The building covers a ground area about 1400 m^2 with several unit buildings of 3 to 5 storey heights. Today, cracking is observed on the exposed faces of the columns and beams, mostly on the upper faces of the building, see Fig. 10. It is uncertain when cracking first appeared but employees working in the building have indicated that the intensity of cracking has increased during the past few years. In 1996, AAR was diagnosed by microstructural analysis caused by impure limestone (metamarl), sandstone and mylonite[4]. In 1998, twenty measurement locations were mounted on beams and columns on the roof of one of the buildings.

[2] Jensen V. "Unpublished measurement results".
[3] Jensen V. 2002: NBTL report R02001, (in Norwegian), 78 pages, confidential
[4] Jensen V. 1996. "Microstructural analysis on cores from Veritas House in Høvik", Sintef test report confidential (in Norwegian)

Relative humidity was measured by wooden sticks 5 cm from outer surface and in the middle of the elements (19 cm). Eleven measurement locations to monitor expansion of cracks were mounted, but only minor expansions have been measured up to date[5]. With the aim to document the long term performance of surface protection systems, and the ability to reduce the concrete's relative humidity, several test areas were established.

Three types of surface treatments were applied, Acrylic type (*elastic acrylic dispersion*), Oligomer siloxane type (*oligomer siloxan/silane + lazur paint*) and Silane type A *(100% isobutyl-tri-ethoxysilan),* - same as in Elgeseter Bridge. The product dealers applied the products on the whole of the outdoor exposed faces of columns or beams and according to specification. In addition, the owner (DNV) mounted "ventilated" aluminum cladding on one column. In 1999 new measurement locations and products were applied on a beam (new sites). Two new products were applied, Silane type D *(100% isobutyl-tri-ethoxysilan with catalysator),* Silane type B *(40% organosilan ester in isopropanol*), - same as in Elgeseter Bridge and Oligomer siloxane type (*oligomer siloxan/silane + lazur paint*). The new test areas are about 1 square meter each. These products were applied according to the producer's recommendations.

Results to date show that the relative humidity is highest in outer surfaces and reduces in the middle of the elements[5] (4, 10). Results of relative humidity from surface treated and untreated columns/beams (new sites) is given in Table 2. Note that the initial relative humidity varies from 89% to 95% in places mounted in 1998 and from 79% to 82% in new sites from 1999, which suggest that the humidity varies between the different elements. In sites from 1998, significant reductions in the relative humidity for all the products have been measured. This is not the cases for references and new sites. The relative humidity in the middle of elements is reduced with time for both untreated and treated elements. Fig. 9 shows the distribution of relative humidity 5 cm and 19 cm from the surface. Left figure is a reference and right figure a column impregnated with Silane type A. Note that the relative humidity 5-cm from the surface in the surface treated element is reduced by time, which is not the case for the reference. The same trend has been measured for all treated elements except for new sites. Fig. 10 shows the distribution of the relative humidity for all locations to date (October 2002). Note that all treated locations from 1998 (encircled) have moved to lower relative humidity close to 80%. For new sites two locations (one reference and 1 surface treated) obtain higher relative humidity 5 cm from the surface. Two products in new sites have more or less the same "initial" relative humidity,

[5] Jensen V. 2002: NBTL report R02002, (in Norwegian), 54 pages, confidential

which suggest that the products were able to "hinder" further increase in the relative humidity as measured for the reference and one of the new product.

In June 2001 the whole building complex were impregnated with Silane type A. Unfortunately, some or all of the reference locations, and possible treated test locations, were also impregnated with silane type A. Therefore, several of the reference locations show more or less reduced RH today.

DISCUSSION

It is generally accepted that the relative humidity is a good measure for assessment of concrete's susceptability for AAR. A limit of around 80% relative humidity in the concrete has been suggested from experimental work in the laboratory and concrete structures (11, 12, 13). In case the relative humidity is higher than 80%, AAR might occur when the concrete mix is reactive and sufficient time have passed since construction period. Long term measurements in several Norwegian structures have shown that the relative humidity is higher than 80% in concrete structures damaged by AAR. Results also suggest that more extensive damage or cracking occurs when the relative humidity is around 100% compared with lower relative humidity around 80% - 85%, e.g. as in columns from Elgeseter bridge.

Results and correlation tests have shown that wooden sticks are reliable after 7 years continuous use. The wooden stick method has also given valuable information on the long term behavior of the relative humidity in several Norwegian concrete structures. About 5 cm from the surface, the relative humidity is stable over time, and not influenced by outer humidity fluctuations. Rainwater is probably the most important source of water in outdoor exposed concrete structures under Norwegian climatic conditions. This has been demonstrated by profiles through elements where higher relative humidity occurs near faces exposed to rainwater relative to more dry faces (indoor or dry during rain).

The current knowledge on surface treatment as a measure to reduce the concrete's humidity, is insufficient and little reported in the literature. This is despite the fact that humidity is the most important parameter for the durability and repair of damaged structures with AAR and other deterioration processes. The results on Norwegian structures damaged by AAR and presented in this paper suggest that surface treatment is an efficient measure to reduce the relative humidity in outdoor exposed concrete structures.

Impregnation with 3 types of silanes has lowered the relative humidity in Elgeseter Bridge's columns. These even columns are relatively massive and AAR is in an advanced stage. All silane products reduce the RH 5 cm from the surface. Several of the locations 5 cm from the surface are now below 80% RH. Result suggests that one of the Silane products with a creamy consistency is more efficient in reducing the relative humidity than the two other Silane products (liquids).

The surface treatment systems assessed in The Norwegian Veritas House all lower the relative humidity significantly to around 80%. This is the case when the initial relative humidity in the concrete is high (89%-95%). Apparently, no significant differences in the ability to lower the relative humidity occur between the products and the aluminium cladding.

When the relative humidity in the concrete is about 80% (similar as the average annual relative humidity in atmospheric air at the locations) surface treatment apparently does not have any effect, but may hinder further ingress of rainwater. Rainwater will increase the concrete's relative humidity with time.

CONCLUSIONS

It can be concluded that the wooden stick method is operative and reliable after 7 years use. All Norwegian concrete structures damaged by AAR obtain a relative humidity higher than 80%. More damage and cracking due to AAR occurs when the relative humidity is high (100%) in comparison to the lower relative humidity (80%-85%), e.g. as in the columns from Elgeseter Bridge. Assessment of several surface treatment systems and products has shown that the relative humidity can be reduced in rainwater exposed concrete structures. The present work is a contribution to our understanding of the complex humidity conditions in concrete structures.

REFERENCES

1. Jensen V. & M. Haugen, 1996. "Alkali Aggregate reaction in in Northern Norway, Report no. 3: In-situ measurement of humidity and expansion". SINTEF-report no. STF22 A96807 (in Norwegian)

2. Wood, J.G.M. 1985, "Methods of control of active corrosion in concrete", Proceeding Deterioration of Reinforced Concrete in the Arabian Gulf, October 1985, Bahrain

3. APM 106, 1989. "Humidity measurement", AEC-laboratoriets test method, November 1989 (in Danish)

4. Jensen V. 2000: ”The Norwegian Veritas house in Oslo: Assesment of surface treatment to reduce damages due to Alkali Aggregate Reaction” Postdoctor project 1998-1999, report dated the 5 september 2000, 12 pages and 9 appendices (in Norwegian)

5. Apneseth, T. & Hay, M., 1992. "Test of electrical humidity apparatus", Norsk Treteknisk Institutt, Report (in Norwegian)

6. NORDTEST-Metoden, 1983. "Relative Humidity: Measured by wooden probes", Nordtest-prosjekt 943-90, 23. april 1993

7. Jensen V. 2000: “Relative Humidity and Expansion of Cracks in Protected and Non protected Structures damaged by Alkali Reaction”. 2000 International Conference – Repair, Rehabilitation and Maintenance of Concrete Structures, and Innovation in Design and Construction, Seoul, Korea – September 19-22, 2000

8. Jensen V. 2000: “In-situ Measurement of Relative Humidity and Expansion of Cracks in Structures Damaged by AAR”. Proceeding of the 11th International Conference on Alkali-Aggregate Reaction in Concrete, Quebec, Canada, 11-16 june 2000, 10pp

9. Jensen, V. 1998. “Humidity and expansion measurements. Documentation of methods for long term measurement in a concrete bridge and a concrete dam”, SINTEF report no. STF22 A97873 (in Norwegian)

10. Jensen V. 2001. “Research project: Security of dam structures”, Norwegian concrete day 2001 – NTNU-SINTEF information day 2001, Sintef report STF 22 A01616, pp 70-78 (in Norwegian)

11. Nilsson, L. O., 1981. "Pop-outs Due to Alkali-Silika Reaction - A Moisture Problem”, Proceeding 5th Int. Conf. on AAR in Concrete, Cape Town - South Africa, S252/27

12. Nilsson, L. O., 1983. "Moisture Effects on the Alkali-Silica Reaction", Proceeding 6th Int. Conf. on AAR in Concrete, Copenhagen, Denmark, pp 201-208

13. Stark, D., 1991. "The moisture Condition of Field Concrete Exhibiting Alkali-Silica Reactivity". SP 126/52, pp 973-987, Second Int. Conf. on Durability of Concrete, Canada

Table 1. Average relative humidity in columns; before and after impregnation with silane. Parenthesis is days after impregnation

Elgeseter Bridge, Trondheim	Western face of column		Eastern face of column	
5-cm from the surface	before imp.	after imp.	before imp.	after imp.
Silane type A (800 days)	100	96	96	84
Silane type B (1100 days)	99	91	95	82
Silane type C (1100 days)	98	87	97	77

Table 2. Average relative humidity, 1493 days and 1326 days after treatment

The Norwegian Veritas House, Oslo		5 cm			19 cm		
Sites 1998: Surfrace system	Site no.	day 0	1493 days	diff.	day 0	1493 days	diff.
References*	7 sites	94	87	-7	85	81	-5
Aluminium cladding	1 + 2	94	83	-11	84	82	-2
Oligomer siloxane/silane	9 + 10	95	81	-14	86	80	-6
Acrylic type	15 - 17	89	78	-11	84	78	-6
Silane type A	18 + 19	93	80	-13	84	80	-4

		5 cm			19 cm		
New sites 1999: Surface system	Site no.	day 0	1326 days	diff.	day 0	1326 days	diff.
References*	31	80	84	4	74	79	5
Silane type D	28	79	80	1	77	81	4
Silane type B	29	82	87	5	74	80	6
Oligomer Siloxane/silane	30	79	80	1	78	80	2

* Some or all the references were “accidentally” impregnated with silane type A, June 2001.

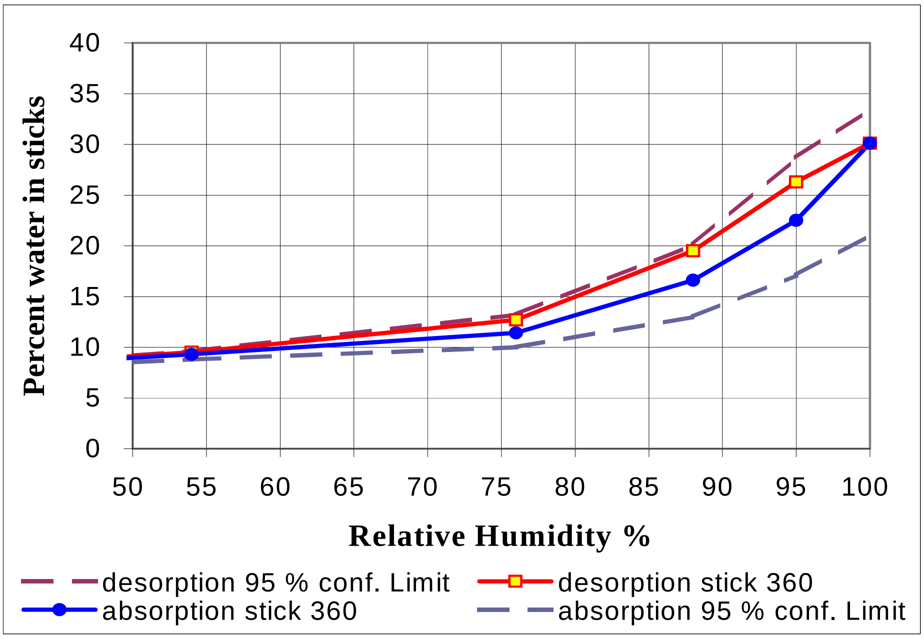

Fig. 1. Calibration curves for wooden stick no.360 and the 95% confidence interval for 112 wooden sticks shown with broken lines.

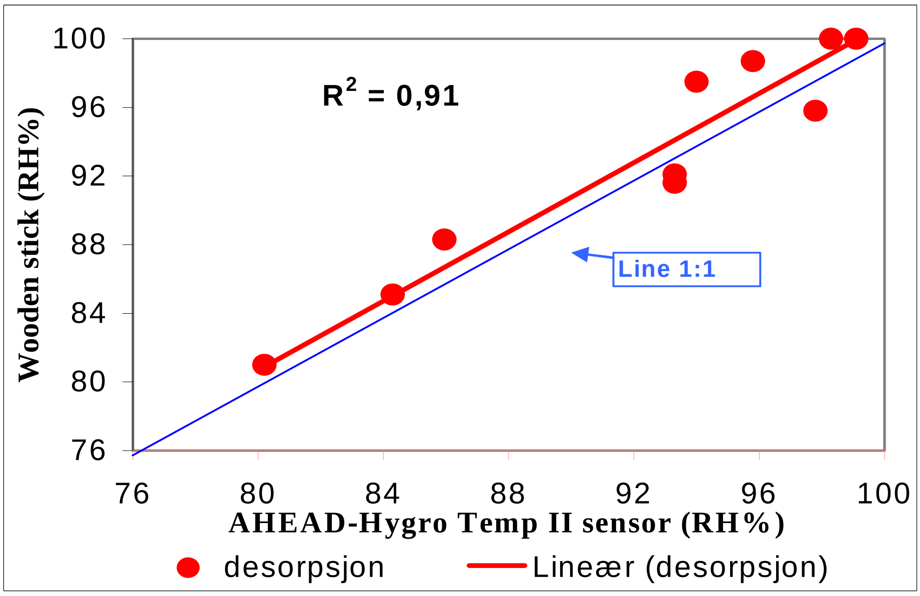

Fig.2. Correlation between wooden sticks by use of the desorption curve and AHEAD hygrotemp II sensors.

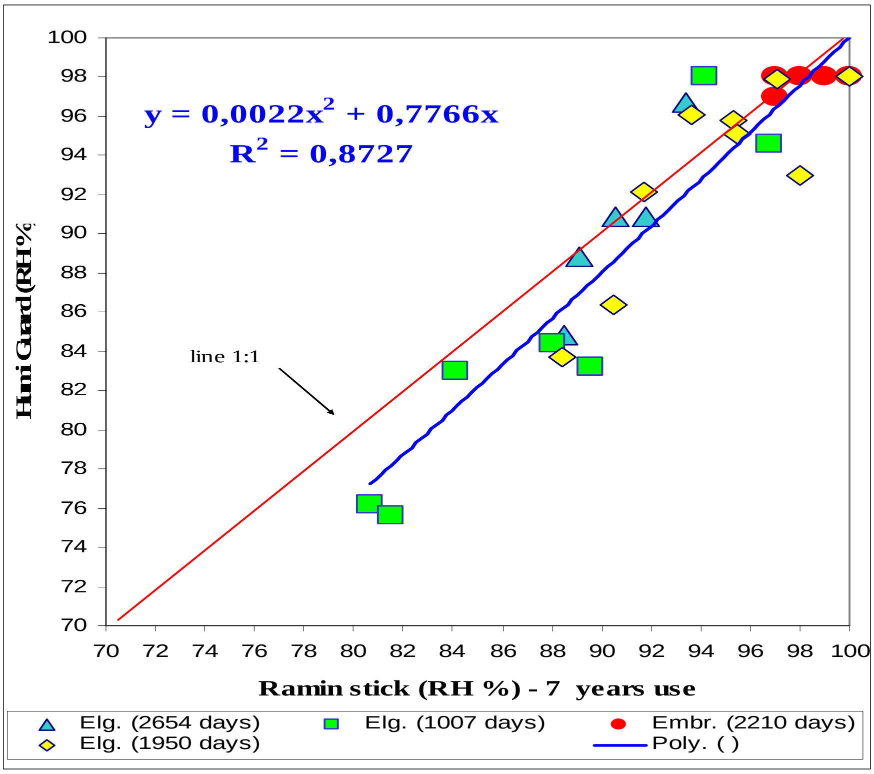

Fig. 3 Correlation between wooden sticks and Humi Guard sensors in-situ. Correlation measurements from Elgeseter bridge and Embretsfoss dam. Some wooden sticks continuous used 7 years.

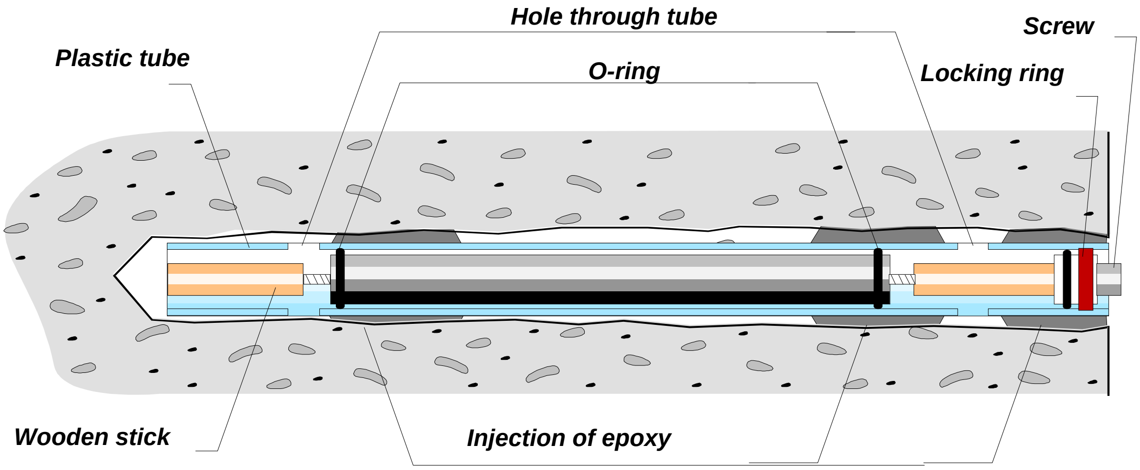

Fig. 4. Plastic tube (diameter 2 cm and length 25 cm) mounted with 2 wooden sticks and where the contact between the concrete and the plastic tube has been injected with epoxy.

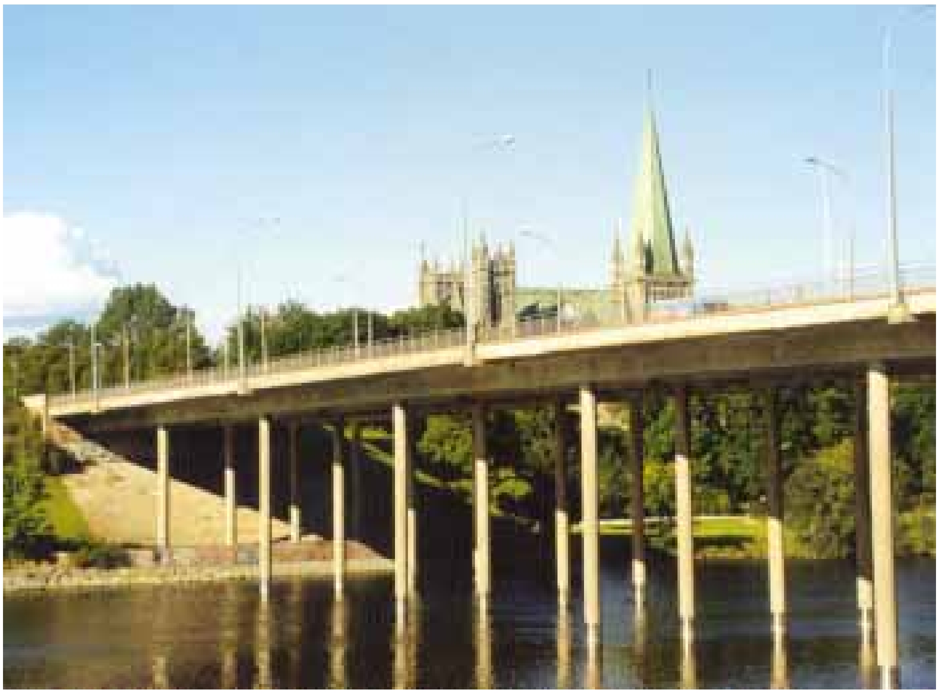

Fig 5. Northern part of Elgeseter Bridge, with the millennium old cathedral "Nidaros Dome" in the background.

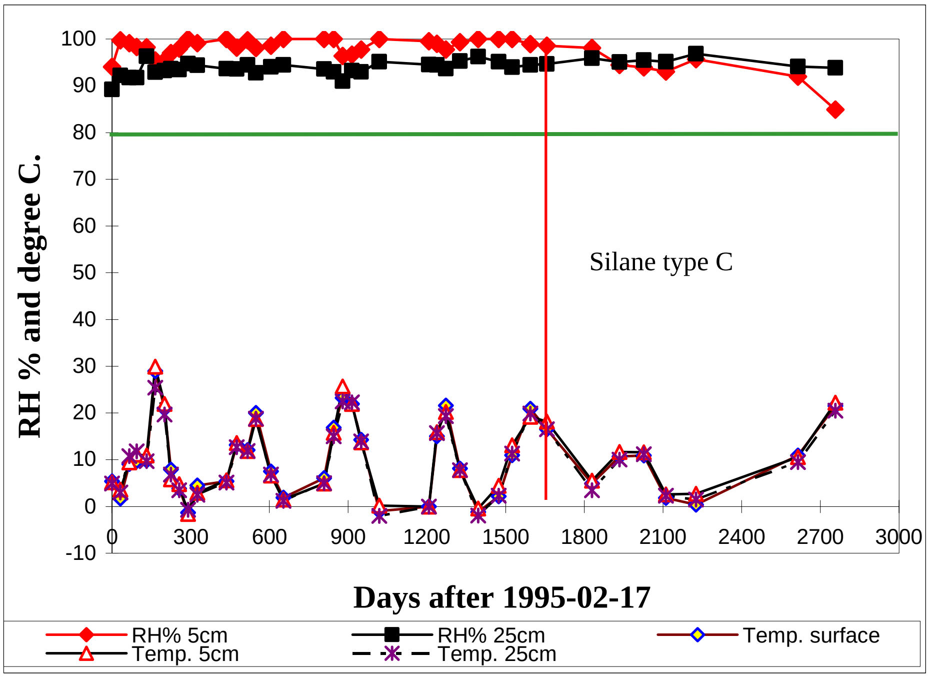

Fig. 6. Relative humidity and temperature during 7 years measurements. Silane type C was applied the column after about 1600 days. Note that 5 cm from the surface the relative humidity reduces after the impregnation with silane.

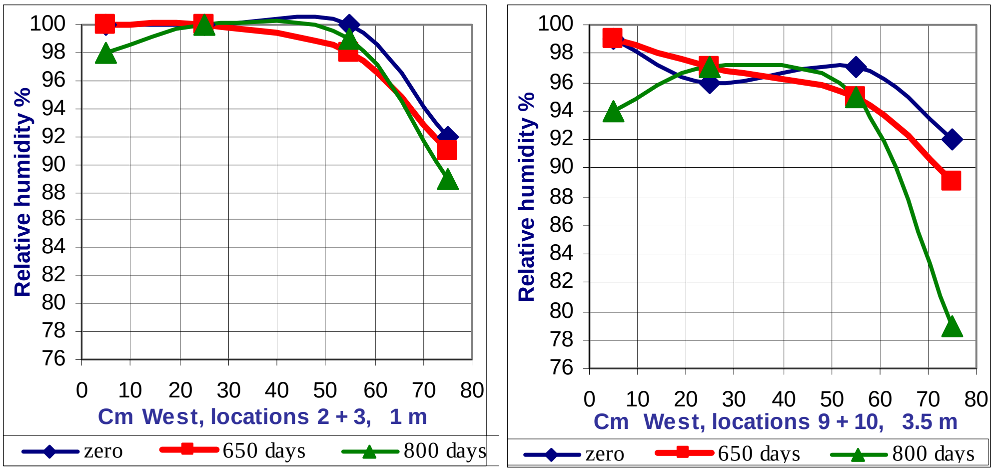

Fig. 7. Humidity profiles West – East, 1.2 meter (left figure) and 3.5 meter (right figure), over ground level. Measurement, before impregnation with silane type A (zero), and measurements 650 days and 800 days after type A was applied.

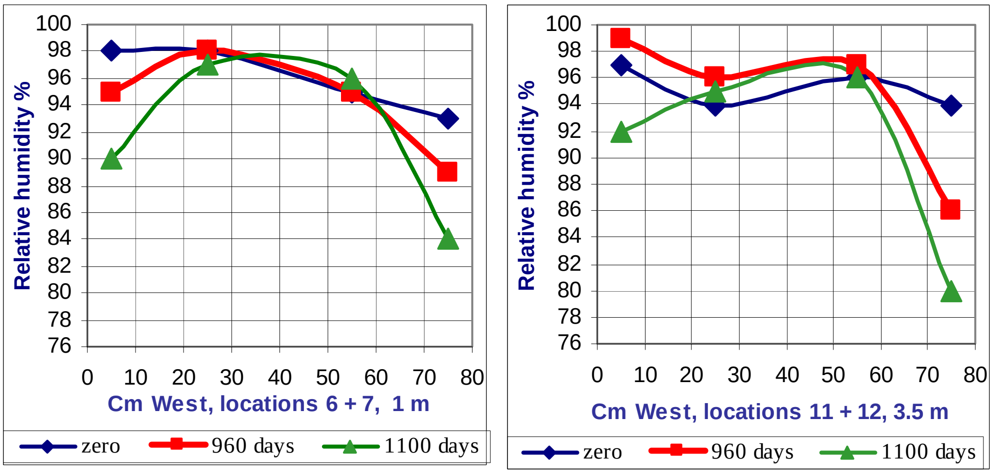

Fig. 8. Humidity profiles West – East, 1.2 meter (left figure) and 3.5 meter (right figure) over ground level. Measurement, before impregnation with silane type B (zero), and measurements 960 days and 1100 days after type B was applied.

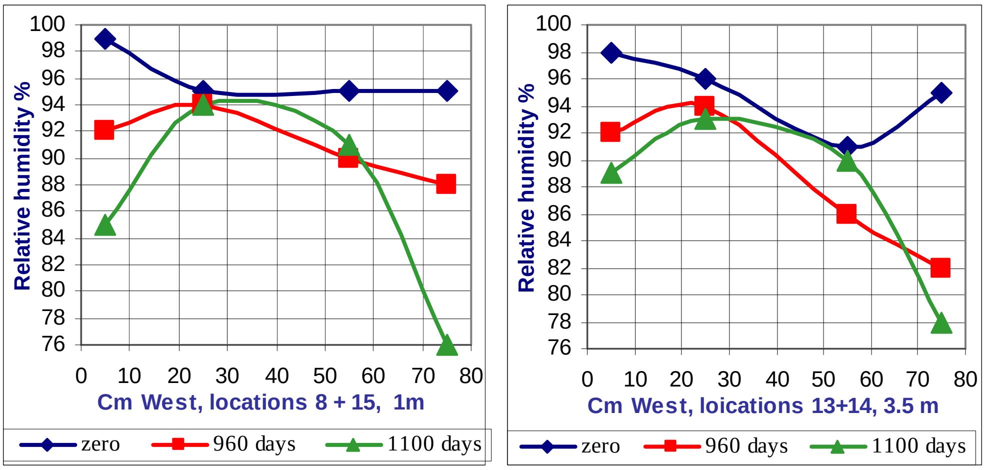

Fig. 9.. Humidity profiles West – East, 1.2 meter (left figure) and 3.5 meter (right figure) over ground level. Measurement, before impregnation with silane type C (zero), and measurements 960 days and 1100 days after type C was applied.

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Fig. 10 The Norvegian Veritas House with prefabricated beams and columns. Note the cracked beams in the front

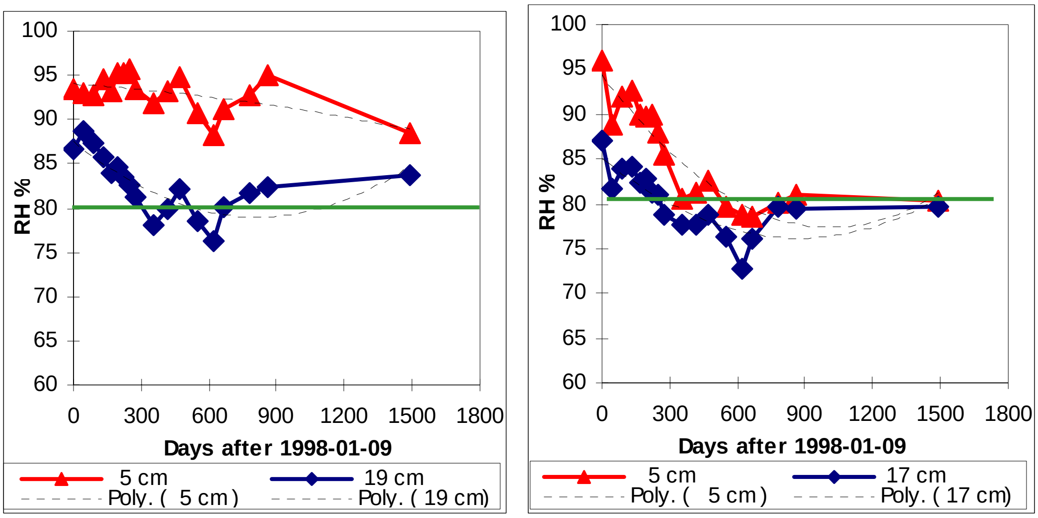

Fig. 11. Relative humidity 5 cm and 19 cm from outer surface in a reference (left figure) and a location treated with silane type A (right figure) after 1493 days, DNV

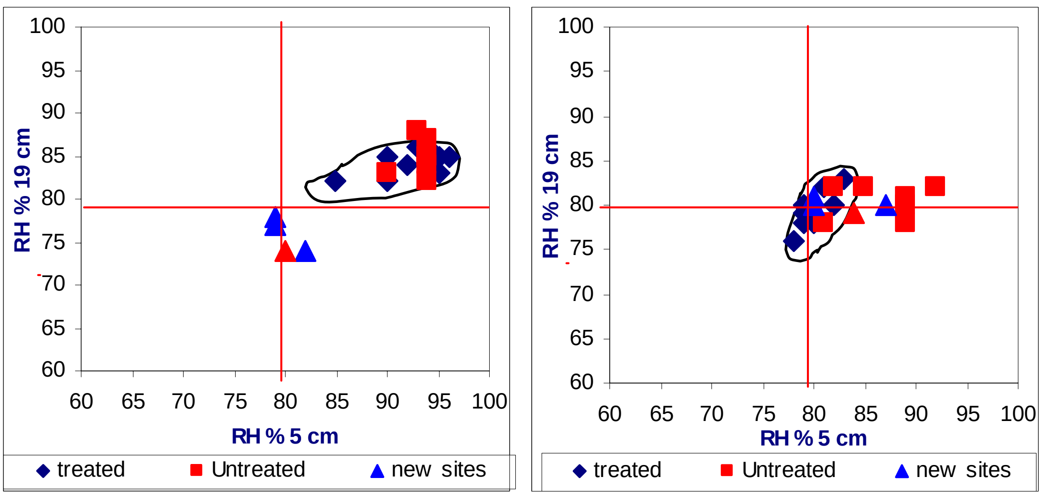

Fig. 12. Distribution of relative humidity, from the start (left figure) and after 1493/1263 days (right figure). Note that treated locations (enclosed by lines) obtain significant reduced RH% after 1493 days.