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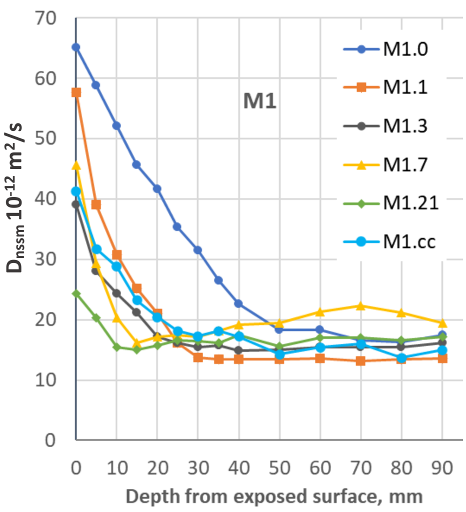
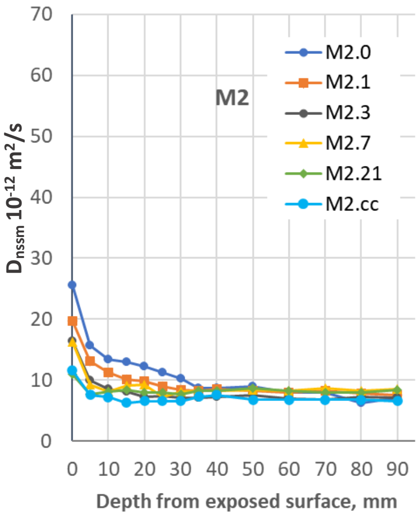
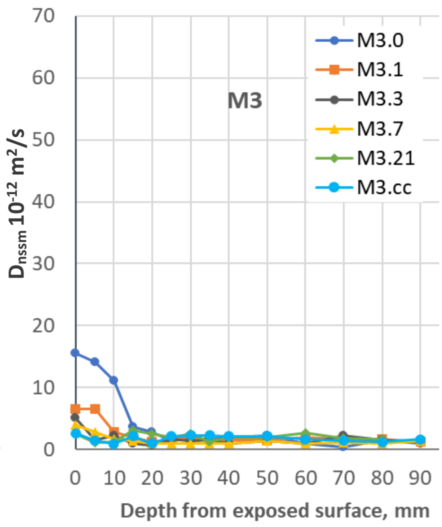
CASE 5.2 Pullout for rapid in-situ screening of bad curing and its implication on durability and cost of structures, Canada & USA







It is well known that bad curing conditions affects not only the potential strength of the concrete but also its durability in terms of penetration of deleterious ions such as chlorides that causes corrosion of the steel reinforcement in structures exposed to marine environment or deicing salts.

While durability evaluation of concrete mixes is a common practice in the concrete industry for important projects, the evaluation is very seldom done in-situ once the concrete has been cast. This would indicate what the effect of the real curing conditions is in the expected service life of the structure, in contrast with the well curing conditioning of lab specimens.

One example of the severe implications of bad curing in service life is the experiment presented by R. D. Hooton et al[(1)]. In this lab study, 3 mortar mixtures were subjected to 6 different curing regimes: 0, 1, 3, 7 and 21 days under moist curing (100% RH) and 1 case with no moist curing but treatment with a common curing compound. After their curing time, the specimens were exposed to low air flow at 20ºC and 65% RH.

Mortar	Cement	w/c	f'c (21 days, moist curing)
M1	Portland	0.5	45 MPa
M2	Portland	0.35	62 MPa
M3	73% Portland + 20% FA + 7% SF	0.35	67 MPa

At day 21, migration chloride diffusion coefficients, D_{nssm}, were then estimated as a function of depth using a modification to the rapid migration test (NT Build 492). The figures above show the variation of coefficients with depth from the exposed surface and the affected depths are presented in the next table (the range in millimeters where the diffusion coefficients are at least 15% higher than the average value in the interior part of the specimen).

Depth of curing-affected zone (mm)			
Type of Curing	**M1**	**M2**	**M3**
0 d	40 to 50	30 to 35	20 to 25
1 d	25 to 30	20 to 25	15 to 20
3 d	20 to 25	15 to 20	10 to 15
7 d	5 to 10	5 to 10	5 to 10
21 d	0 to 5	0 to 5	0 to 5
Compound	40 to 50	5 to 10	0 to 5

A model to simulate service life prediction, in terms of the time for initiation of corrosion of the steel reinforcement, was applied using the data and assuming, among other things, a chloride corrosion concentration threshold of 0.2% by weight of concrete. For a 50 mm thick cover layer, the reduction in service life between 21 days and 0 days of curing resulted to be about **30% for M2 and M3 and almost 50% for M1.** These high values might actually be conservative if we take into account that lower chloride corrosion threshold values have been commonly reported and that the real in-situ conditions can be easily worse than low air flow exposure with 65% RH and 20ºC.

Assuming that the effect on strength of poor curing was acceptable, the economic implication in maintenance, repairs or early replacement of a given structure along its actual life would be quite important with such reductions. If a proper evaluation is made in time, as an integral part of the construction plan, corrective actions can be taken both to improve curing procedures and to implement protective actions for the affected concrete (e.g. application of sealers, plasters or coatings).

Migration tests are however expensive and time-consuming procedures that make them impractical for this purpose. But because bad curing also negatively affects the

(1) R. D. Hooton, M. R. Geiker and E. C. Bentz. "Effects of Curing on Chloride Ingress and Implications on Service Life". ACI Materials Journal No. 99-M20, 2002

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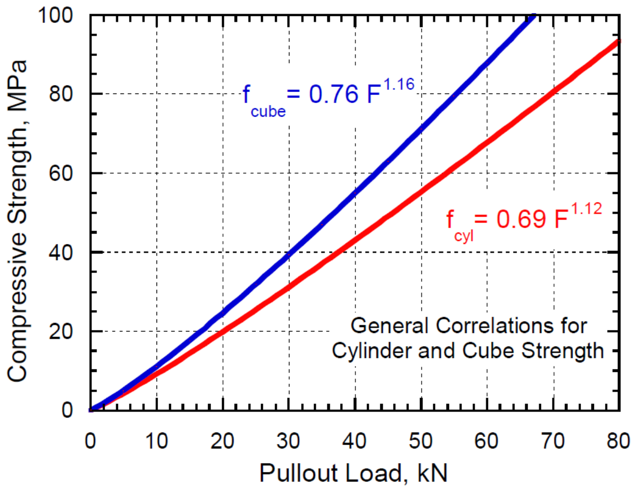
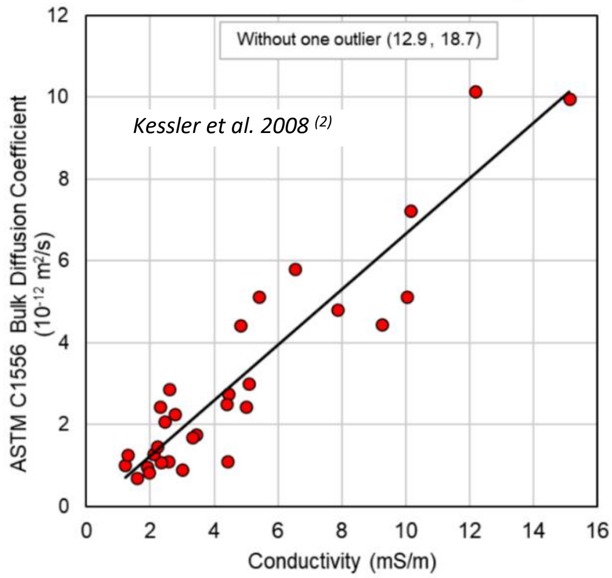
compressive strength of the concrete, testing this property is useful to do the job.

It is clear that coring is useless in this case because getting results from cores takes a couple of weeks and the interest is testing the cover layer only, but that is exactly what the **LOK-TEST and CAPO-TEST** do (pull-out tests): measuring the compressive strength of the outermost 25 mm of the cover layer within a few minutes at any accessible location. Unlike any other indirect test methods, the LOK-test (for inserts in fresh concrete) and CAPO-test (for inserts in hardened concrete) have been extensively proved to have a robust general correlation with compressive strength which can be used to estimate quickly the actual value of the strength of the cover layer. So, if this value is found to be significantly lower than the expected one, not only this is an alarm for investigating the inner strength of the concrete but it is also an immediate indicator of poor quality of the cover layer and of the potential risk of an important reduction in durability of the structure.



Even though there is no fixed correlation to infer the value of the increase of the chloride diffusion coefficient based on the reduction of strength, LOK and CAPO test will quickly indicate the affected areas for further evaluation.

For instance, one property that does have a fundamental relationship to chloride diffusion is the electrical conductivity (or its inverse, resistivity). In the literature, one can find published relationships between the chloride bulk diffusion coefficient determined by ASTM C1556 vs. conductivity, and this property can be easily measured in the cover layer if a core is extracted from the suspicious area and the top end is sliced away for testing with the **MERLIN** conductivity/resistivity meter. This conductivity value can be compared with the one obtained from the inner part of the core. The difference finally allows to estimate the increase of the diffusion coefficient caused by the affected cover layer as well as the inherent implication in service life and future maintenance costs.



One practical example of this approach was done over the concrete of four slabs produced by people of the CEE department at University of Illinois, within the project "Evaluation of PCC Pavement and Structure Coring and In-Situ Testing Alternatives (ICT R27-137)". All 4 slabs were designed with the same mix proportions of a typical road construction and delivered by the same mix-concrete company.

Compressive strengths were determined for each slab with the average of 8 cast in-place cylinders extracted and tested at day 16 after casting, and in parallel with the average of 3 CAPO-tests performed at the same day 16. The pull-out force was transformed to compressive strength of standard cylinders with the equation of the General Correlation $f_{cyl} = 0.69\ F^{1.12}$

Slab	f'c Cylinders (MPa)	f'c CAPO (MPa)	Difference
R1	34	22.6	-33.5 %
R2	38	26.6	-30.0 %
R3	43	29.8	-30.7 %
R4	39	25.7	-34.1 %
Avg.	38.5	26.2	-32.1 %

(2) Kessler, Powers, Vivas, Paredes, Virmani, 2008, "Surface Resistivity as an Indicator of Concrete Chloride Penetration Resistance," 2008 Concrete Bridge Conference, St. Louis MO, USA. Transportation Research Board.

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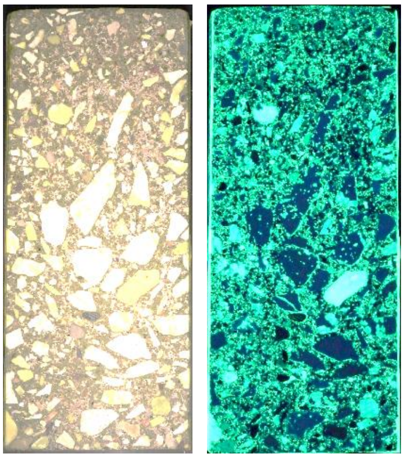
The comparison between cylinders and CAPO tests revealed an average reduction of strength of 30% between the top 25 mm thick layer and the bulk concrete, indicating the potential effect of bad curing or other defects in the cover layer. This was indeed corroborated by a microscope inspection of a 1 mm thin section of one of the cores that found high porosity, bleeding and lack of gravel in the cover layer, which in turn demonstrates that CAPO-tests results detected these anomalies accurately and are not product of a "different strength correlation" as one may erroneously inferred.

Cover layer

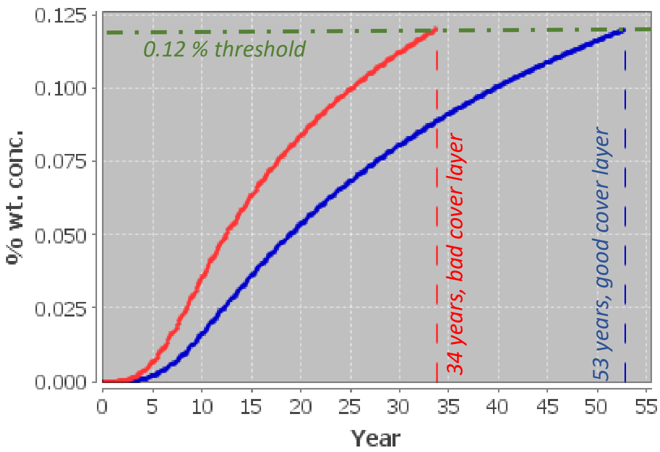


In order to evaluate the consequences in durability, two cores, 100 mm in diameter and 230 mm long, were drilled out. A 50 mm thick slice was cut from the top end of the cores (the cover layer) and conductivity measurements with MERLIN were performed on these slices and compared to measurements of the center part of the cores (bulk concrete).

Core:	C1	C2	Avg.	D_{cl} (10^{-12} m²/s)
Cond. cover layer (mS/m)	13.5	13.9	13.7	9.3
Cond. bulk concrete (mS/m)	9.8	10.2	10.0	6.0
Difference	-27.4 %	-26.6 %	-27.0 %	

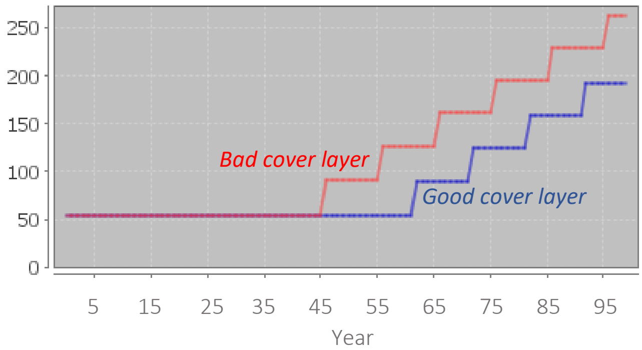
The average values of conductivity were converted to Chloride Diffusion Coefficients, D_{cl}, with the correlation published by Kesler et al., and with these coefficients, a simulation for predicting service life and life-cycle cost was made using the Life-365™ Software, free available at www.life-365.org, assuming a cover layer thickness of 60 mm, typical exposure conditions of chlorides coming from deicing salts used on bridges(3) and a chloride concentration threshold value of 0.12 %.

The simulation shows that the reduction of 27 % of conductivity might represent a reduction **of 36 % of service life**, 34 vs. 53 years (time for initiation of corrosion of the steel reinforcement).



If we assume that the Owner pretends that the structure lasts 100 years, the increase of costs at present value of construction and required repairs during that life **results to be of 37%**, **about $70 USD/m² more** than if corrective measures are taken.

Cumulative Present Value ($USD/m²)



The outcome of this example makes clear for Owners how important the effect of the cover layer is in relation to durability and future costs during the service of a reinforced concrete structure.

In practice, the easiest way to specify in a project a quality control of durability is leaving **LOK-test inserts** embedded in the fresh concrete while casting so they serve for a rapid screening of the strengths of the cover layer. If desired for a detailed evaluation, the suspicious areas detected can be later cored for further evaluation of chloride permeability with the MERLIN device.

Case prepared by **NDTitan Hugo Orozco**

(3) L. Nilsson, A. Andersen, T. Luping & P. Utgenannt, Chloride Ingress Data from Field Exposure, Chalmers University of Technology, REPORT P-00:5, Sweden.