THE SWISS P2P ROAD: FROM THEORECRETE TO LABCRETE TO REALCRETE

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ABSTRACT

In August 2013, the Swiss Standards for Concrete Construction (SIA 262 and 262/1) were updated. In terms of durability of concrete structures, the update was a large step further along the path from Prescriptive to Performance, making them the most advanced Performance Standards for Durability worldwide.

Although still keeping prescriptive requirements, inherited from EN 206-1, the Swiss standards have moved decisively towards performance requirements. Indeed, limiting values have been specified for the following laboratory tests: Water Absorption Rate, Chloride Migration Coefficient, Frost-thaw-salts Resistance, Carbonation Resistance. These tests have to be performed regularly on cast specimens to check that the mixes supplied comply with the requirements for the Exposure Class.

Finally, for structures exposed to severe carbonation (XC4), frost (XF1, XF2 and XF4) or chlorides (XD1, XD2 and XD3), the standard suggests limits for the coefficient of air-permeability measured on site. With this innovative approach, owners can order constructors to prove that the end-product (the structural elements) complies with those limits. The sampling plan and conformity criterion of the new standards are described in detail.

It is foreseen that the new standards will lead to more durable and sustainable structures. Moreover, the significant consequences derived for the Concrete Construction Industry and its players are also discussed.

1 INTRODUCTION

The Swiss Code for Concrete Construction is based primarily on 3 separate Standards, as listed below; in this paper we will focus exclusively on the aspects dealing with durability:

a. SIA 262:2013 [1] based on Eurocode 2. Defines Exposure Classes and cover depths

b. SIA 262/1:2013 [2]. Describes special tests and performance requirements associated to the Exposure Classes, to be fulfilled for laboratory and site tests (NDT and drilled cores).

c. SN EN 206-1 [3] based on EN 206-1. Prescriptive (w/C_{max}, C_{min}) and performance requirements (f'_{cmin}) for concrete production

The Swiss Standards are an outstanding example of progressing from a purely prescriptive to a performance based approach, in just 10 years. Currently, requirements for both approaches have to be fulfilled in parallel.

This paper summarizes the evolution of the Swiss Standards and presents its current status.

2 PRESCRIPTIVE APPROACH OF 2003 - "THEORECRETE"

In 2003, the original versions of Standards [1-3] were issued, in which prescriptive constraints of the mix composition were established for the different exposure classes, combined with some usage limitations of certain cement types (e.g. CEM II/B-LL, from unknown sources, for XC4, XD and XF classes and CEM III/A for XF2 and XF4). These constraints are indicated in Rows 1 and 2 of Table 1.

There was also a sort of performance requirement in the form of minimum strength grades for each exposure class (Row 3, Table 1). Usually, complying with the prescriptive mix constraints automatically ensures complying and often exceeding the strength requirements; hence, this requirement is no longer discussed here.

Table 1 - List of requirements of Swiss Standards for different Exposure Classes

Year	Row	Damage	Carbonation-induced Corrosion				Chloride-induced Corrosion				Frost with and without Deicing Salts			
		Exposure Class	XC1	XC2	XC3	XC4	XD1	XD2a	XD2b	XD3	XF1	XF2	XF3	XF4
2003		**"THEORECRETE"**												
	1	w/C_{max}	0.65	0.65	0.60	0.50	0.50	0.50	0.45	0.45	0.50	0.50	0.50	0.45
	2	C_{min} (kg/m³)	280	280	280	300	300	300	320	320	300	300	300	320
	3	$f'c_{min}$ (MPa)	C20/25	C20/25	C25/30	C30/37	C25/30	C25/30	C30/37	C30/37	C30/37	C30/37	C25/30	C30/37
2008		**"LABCRETE"**												
	4	qw_{max} (g/m²/h)	---	---	---	10	10	10	---	---	---	---	---	---
	5	DCl_{max} (10^{-12} m²/s)	---	---	---	---	---	---	10	10	---	---	---	---
	6	m_{max} (g/m²)	---	---	---	---	---	---	---	---	---	1200	1200	200/600
2013	7	K_{Nmax} (mm/y$^{1/2}$)	---	---	5.0/4.0	5.0/4.5	---	---	---	---	---	---	---	---
		"REALCRETE"												
	8	kT_s (10^{-16} m²)	---	---	---	2.0	2.0	2.0	0.5	0.5	2.0	2.0	0.5	0.5
	9	c_{nom} (mm)	20	35	35	40	40	40	55	55	*	#	*	#

w/C = water/cement ratio by mass.
C = cement content, including content of SCM corrected with corresponding "k" factors
f'c = strength class cylinder/cube
qw = water conductivity coefficient. Rather complex indicator, closely related to water absorbed in 24 hours w_{24} (g/m²): $w_{24} = 217 + 326 \bullet qw$
DCl = chloride migration coefficient, measured after Tang-Nilsson method [4]
m = scaling mass loss after 28 cycles of freezing (-15°C) and thawing (+15°C) in the presence of 3% NaCl solution
K_N = carbonation resistance = 2.6 K_S, with K_S (mm/d$^{1/2}$) measured in accelerated test after 7, 28 and 63 days exposure to CO_2 concentration of 4%-vol . The values indicated correspond to expected service lives of 50/100 years.
kT = coefficient of air-permeability, measured after Torrent method [5,6]; kT_s is a characteristic upper limit (see Section 5.3).
c_{nom} = nominal cover depth, values indicated are for reinforced concrete (values for prestressed concrete are 10 mm higher); tolerance ± 10 mm if $c_{nom} \geq 30$ mm
* = function of fire resistance required, at least equal to maximum size of aggregate and of steel bar diameter
# = for exposure to salts values of corresponding XD classes should be adopted
Note 1: Class XD2 was subdivided in 2008 into XD2a and XD2b, for chloride contents of the solution in contact with the concrete of up to or over 0.5 g/L, respectively. Requirements for XD2a are identical to those of XD1; similarly, requirements for XD2b are identical to those of XD3.
Note 2: The values indicated in rows 4 and 5 are for the average of 5 cores drilled from cast specimens and those in row 6 for the average of 3 to 5 cores drilled from cast specimens. There are also indicative limiting values (higher) for cores drilled from the structure, tested at 28 days of age.
Note 3: In Switzerland, 8 concrete types are defined for the most common exposure conditions which combine more than one Exposure class

2.1 "Theorecrete" Approach, its Limitations

We call this prescriptive approach "Theorecrete", because of the following associated drawbacks:

a) it assumes that concretes with the same composition will perform identically under the same aggressive environment

b) it assumes that the contribution of supplementary cementitious components (SCM) is the same, for a given type (e.g. fly-ash), for all relevant properties (k value concept)

c) the contents of cement, SCM and water of a mix are elusive, especially for the contractor who has to trust the accuracy of the producer's records

d) the water content of the mix actually placed in the forms may differ significantly from that reported by the producer due to: wash water in the trucks prior to loading, actual moisture of aggregates different to that reported, not recorded water added to the truck after leaving the batching point.

Regarding a), Fig. 1 shows the widely different performance of concretes made with same w/c ratios, but with different binder types. The w/c (according to SN EN 206-1) is therefore different from the w/b, if SCM are used. Within a research project funded by ASTRA (Swiss Federal Highway Administration) [7], it was clearly shown that due to the strong changes on the cement market and further influences, the w/c-ratio is of smaller importance than before.

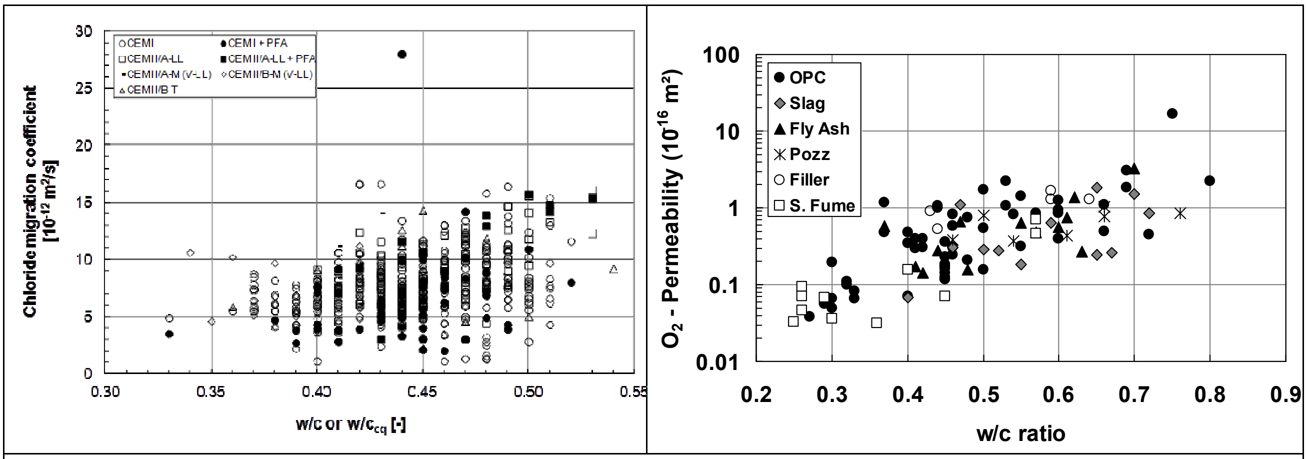

Fig. 1 - Relation of Chloride Migration (left) [7] and O_2 Permeability (right) [8] with w/c ratio

Regarding b), c) and, especially d), compliance with requirements for C_{min} and w/c_{max} is difficult to check, although in Annex H of [2] a method to determine the water content of the fresh concrete by drying is described.

These limitations called for the introduction of durability-related performance tests specifications. The background was that the cement industry was and is still forced to reduce the CO_2 emissions per kg of cement; therefore during the last 15 years very strong changes took place on the Swiss cement market. Since new cement types were introduced, where no experience exists for the usage in Switzerland, it was regarded as necessary to introduce performance requirements

3 PERFORMANCE APPROACH OF 2008 - "LABCRETE"

In 2008, some amendments were introduced to SN EN 206-1 [3], by which the concrete producer, besides complying with the preexisting prescriptive requirements, has to prove that the concrete supplied to jobs under certain exposure classes complied some minimum performance requirements. For that, he has to cast specimens with a minimum frequency (function of volume produced, but at least 4 times per year) and conduct laboratory tests (listed below) on these samples. The test results must comply with the minimum requirements indicated in Rows 4-6 of Table 1.

These tests can also be applied by the inspection to control the as-received concrete performance.

The tests required are:

- Water sorptivity test, according to Annex A of [2]

- Chloride Migration tests, according to Annex B of [2], based on [9]
- Resistance to Frost-Thaw-Salts cycles, according to Annex C of [2]

3.1 "Labcrete" Approach, its Limitations

The main drawback of the "Labcrete" tests is that the specimens used to conduct the tests are cast at the plant (eventually the jobsite) and moist cured for 28 days until the moment of test. Hence, they represent the quality of the as-produced concrete, but not that of the end-product, which is the one that is finally going to be subjected to the aggressive environment.

Fig. 2 illustrates the quality situation in the real structure ("Realcrete"). The cover concrete ("Covercrete"), which is the defense barrier against the aggressive actions of the environment, is typically of poorer quality than the core concrete, as it is most affected by frequent incorrect placement, compaction, curing and finishing practices. The cast specimens ("Labcrete") by no means are representative of the true quality of the "Covercrete".

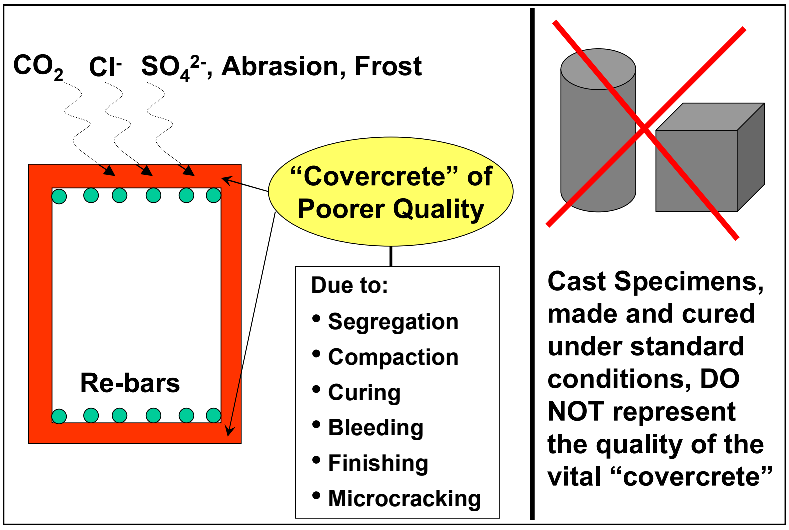

Fig. 2 - Concept of "Covercrete" vs. "Labcrete"

4 PERFORMANCE APPROACH OF 2013 - "COVERCRETE"

In the latest revision (2013) of the Standards, another "Labcrete" test was included:

- Carbonation Resistance, accelerated test according to Annex I of [2], based on [10]

The requirements are indicated in Row 7 of Table 1.

One of the most innovative aspects of the Swiss Standards is the recognition that the "Labcrete" is not representative of the "Realcrete", i.e. the quality of the end-product, the structure itself. In particular, within the "Realcrete", the vital role of the cover concrete ("Covercrete") for durability is explicitly addressed.

SIA 262 Code [1] describes the measures to be adopted in order to ensure durability and, acknowledging the importance of the "impermeability" of the cover concrete, specifically states:

- *"with regard to durability, the quality of the cover concrete is of particular importance"*
- "*the impermeability of the cover concrete shall be checked, by means of permeability tests (e.g. air permeability measurements), on the structure or on cores taken from the structure*".

However, despite the fact that already in 2003 a site test to measure the coefficient of permeability to air was standardized, based on [6], it is not until 2013 that limiting values were specified. Also, detailed sampling, testing (including suitable conditions in terms of age, temperature and moisture content of the concrete) and conformity compliance procedures were established. This was the result of a report produced by a group of experts for the Swiss Federal Highway Administration [11].

Therefore, since 2013, the air-permeability of the structural elements exposed to the most severe environments has to be checked on site, with the "Covercrete" test:

- Air-Permeability on the Structure, according to Annex E of [2]

The requirements are indicated in Row 8 of Table 1, the kT_s values being "characteristic" upper limits.

Since this is an innovative approach, it will be described in detail in the following chapter.

Another requirement for the "Covercrete" is the nominal cover depth c_{nom}, with requirements indicated in Row 9 of Table 1. There are ± tolerances, function of the type of surface and of the value of the nominal cover (e.g. ± 10 mm for formed or finished surfaces with $c_{nom} \geq 30$ mm). So far, no detailed method to check conformity with these values is specified: where and how (destructive or not) to measure, compliance rules, etc.

5 PRINCIPLES OF TESTING AIR-PERMEABILITY ON SITE

The method described in Annex E of Standard [2] serves to measure the coefficient of air-permeability of the cover concrete on site, in a non-destructive manner and operates as follows.

Vacuum is created inside the 2-chamber vacuum cell (Fig. 3), which is sealed onto the concrete surface by means of a pair of concentric soft rings, creating two separate chambers. At a time between 35 and 60 sec (with a vacuum of ca. 30 mbar, depending on the concrete, instrument, etc.) valve 2 is closed and the pneumatic system of the inner chamber is isolated from the pump. The air in the pores of the material flows through the cover concrete into the inner chamber, raising its pressure P_i. The rate of pressure rise ΔP_i with time (measurement starts at t_o = 60 s) is directly linked to the coefficient of air-permeability of the cover concrete.

A pressure regulator maintains the pressure of the external chamber permanently balanced with that of the inner chamber (P_e=P_i). Thus, a controlled unidirectional flow into the inner chamber is ensured (Fig. 4) and the coefficient of permeability to air kT (m^2) can be calculated for a semi-infinite body; derivation available in [12], with correction for finite bodies.

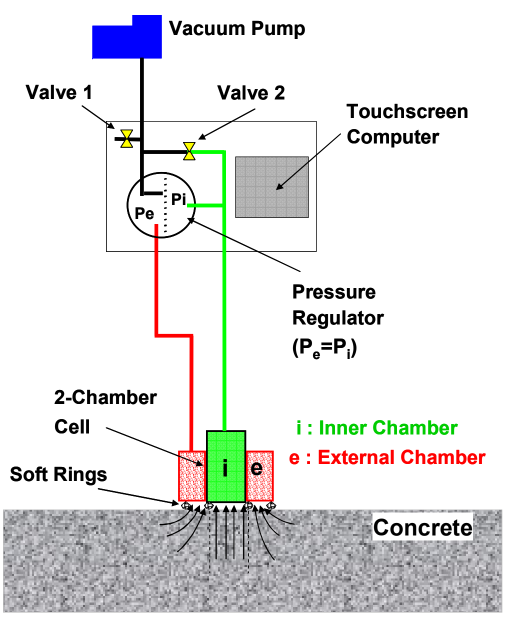

Fig. 3 – Sketch of air-permeability test.

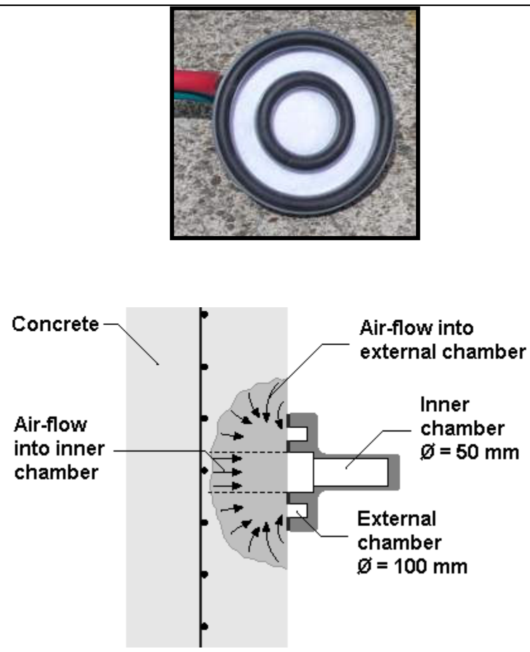

Fig. 4 –Vacuum cell and air-flow into both chambers.

5.1 Sampling

Grouping

The structure to be evaluated should be divided into Groups of elements that have the following features in common:

- same specified Air-Permeability value kT_s (see Row 8 in Table 1)

- were built with concrete belonging to the same concrete category (same strength, aggregate size and exposure class)
- were built applying similar concreting practices (placing, compaction, curing, etc.)

For compliance purposes, all the elements in the structure presenting the same features described above, constitute a Group. They should be listed chronologically, within each Group, by date of concreting; in the case of continuous elements (e.g. walls or deck slabs), segments concreted on the same day should be identified.

Test Areas

The elements within each Group are divided into Test Areas (Lots) according to the following criterion:

• 1 Test Area per each 500 m^2 of exposed surface area or extra fraction thereof, or

• 1 Test Area per three days of concreting of the elements of the Group

Measurement Points:

From each resulting Test Area, 6 Measurement Points will be sampled at random, avoiding excessive closeness to edges (especially top and bottom) and to each other.

5.2 Age, Temperature and Moisture Conditions of the Concrete

Age of Concrete:

The age of concrete when tested should be between 28 and 90 days. In particular, when slow-reacting cements (e.g. CEM III/B) or significant amount of slow-reacting mineral additions (such as fly-ash) are used, a minimum age of concrete of 60 days should be considered.

Temperature of Concrete:

The surface temperature of the construction element, measured for instance with an infrared thermometer, should be above 10°C.

Moisture Conditions of Concrete:

The moisture content should not exceed 5.5 % (by mass) when determined with an electrical impedance surface moisture meter (e.g. CMExpert manufactured by Tramex).

5.3 Conformity Rules

Each Test Area must satisfy the following conditions:

Condition 1: Out of the 6 air-permeability values kT_i, measured on a Test Area, not more than 1 can exceed the specified Air-permeability limit value kT_s.

In case that just 2 out of the 6 air-permeability values kT_i, measured on a Test Area, exceed the specified air-permeability limit value kT_s, another 6 further Air-permeability tests can be conducted on 6 new Measurement Points selected from the same Test Area.

Condition 2: Not more than 1 air-permeability value kT_i out of the 6 new determinations can exceed the specified air-permeability limit value kT_s.

If neither Condition 1 nor Condition 2 is satisfied, the Test Area is considered as not in conformity with the specifications and complementary/remedial measures have to be taken.

The Operating Characteristic (O-C) Curve of the compliance criterion is shown in Fig. 5, the construction of which is described in [11].

The graph in Fig. 5 means that a Test Area, composed by just 10% of non-compliant concrete (i.e. with $kT > kT_s$), has about 97% probability of being accepted (meaning that out of 100 times that the compliance criterion is applied in such Test Area, in just 3 cases it will fail). On the other hand a Test Area composed by 30-35% of non-compliant concrete has only about 50% of probability of being accepted. This gives a clearer statistical meaning of kT_s as 'characteristic' air-permeability upper limit.

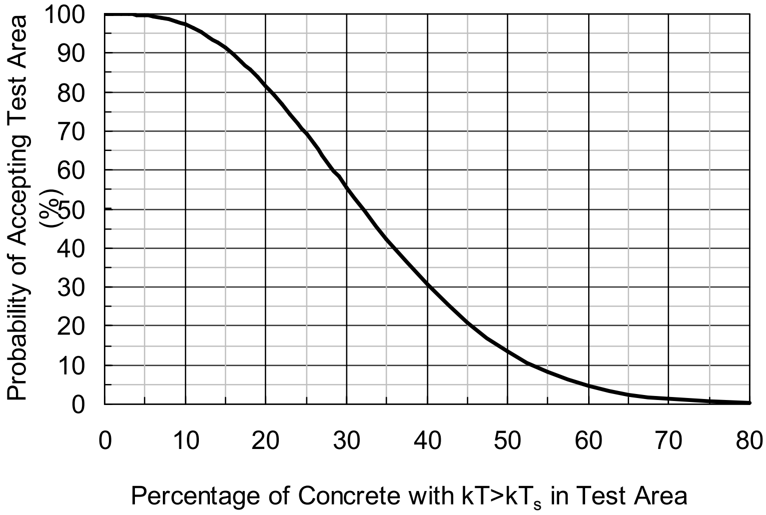

Fig. 5. O-C Curve of the Compliance Criterion [9]

5.4 Relation with other Durability Tests

Figs. 6-9 show correlations of the coefficient of air-permeability kT with other durability tests; more details and references on the data reported can be found in [13,14]. They show that kT is a good indicator of durability, closely linked to carbonation and chloride penetration rates and also to frost-thaw-salts damage.

Figs 6-8 show that as the air-permeability increases, so does the rate at which carbonation, chlorides and water under pressure penetrate the concrete; Fig. 9 indicates that concretes of low air-permeability have a high frost-thaw-salts (F-T-S) resistance, even without air-entrainment (low and fine porosity) and that air-entrained concrete, if too permeable, cannot achieve high F-T-S resistance.

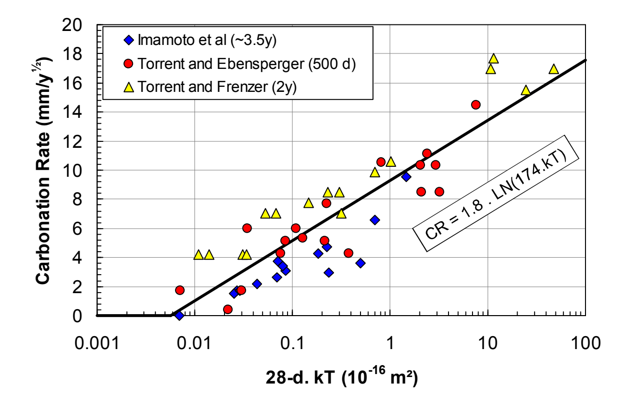

Fig. 6 - Natural carbonation rate vs kT

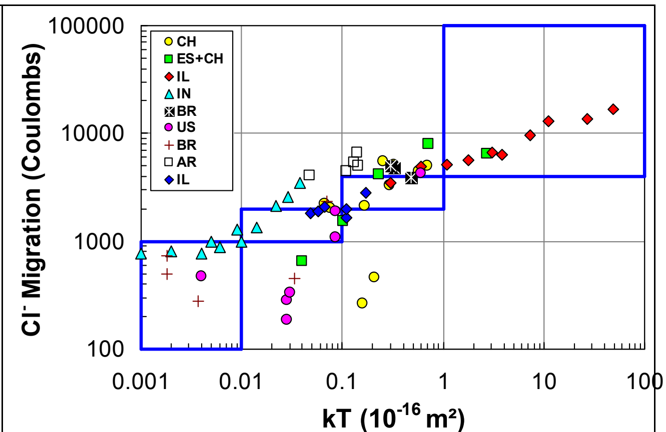

Fig. 7 - ASTM C1202 Coulombs vs kT

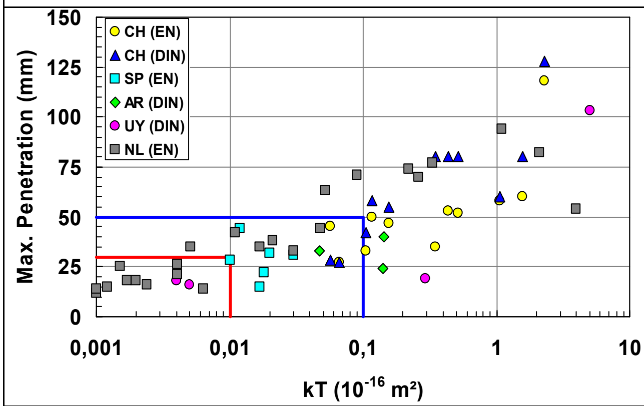

Fig. 8 - Water penetration EN12390-8 vs kT

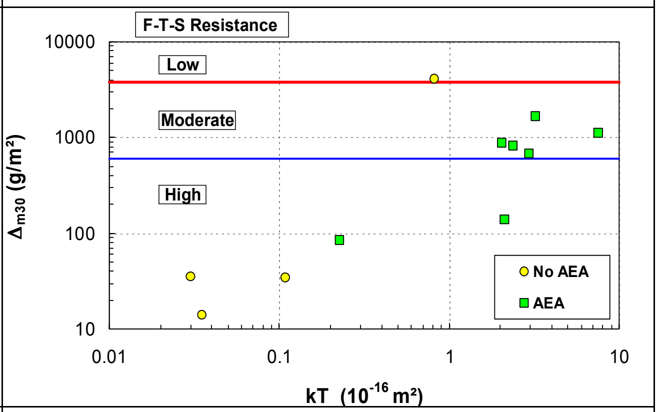

Fig. 9 - Scaling in Frost-Thaw-Salts test vs kT

6 CONCLUSIONS

In 2013, the Swiss Standards have moved decisively towards performance requirements, both for cast specimens and for site concrete. This will certainly have a positive effect on the durability of concrete structures, with the following expected benefits:

- By controlling the end-product, a performance-oriented mindset is consolidated in all the parties involved in the construction process (specifiers, contractors, material suppliers, inspectors, etc.)
- All too common bad practices (uncontrolled water addition to concrete trucks, poor compaction, lack of curing, improper slabs finishing, etc.) will be eradicated
- Contractors that fail to apply good concreting practices will have to use richer (and more expensive) mixes or face penalties for non-compliance, thus setting a fair competition scenario
- Owners will have more trust in the concrete, regardless of the type of cement and/or mineral addition used. This clearly opens the market for new and ecological more sound cementitious products.
- Finally, the use of innovative solutions that improve the quality of the "Covercrete" will be encouraged, such as permeable membranes for formwork, vacuum "dewatering" of slabs and the use of special concretes, such as self-compacting, high-strength, shrinkage-compensating, self-curing, etc. This will lead to more sustainable solutions too.

7 REFERENCES

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Annex B: Chloride Resistance
Annex C: Frost Resistance in Presence of Deicing Salts
Annex E: Air-Permeability on the Structure
Annex H: Water Content in Fresh Concrete
Annex I: Carbonation Resistance

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