PROOF OF CONCRETE QUALITY BY "LIMITING VALUES" AND/OR TESTS?

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Abstract

For the introduction of SN EN 206-1 in 2003 it was agreed in Switzerland that "designed concrete" with "limiting values for concrete composition" should be defined. At the same time it was agreed that a project should be carried out to examine whether it is necessary and possible to define "designed concrete" solely or additionally based on "performance-related design methods". In the "performance-related design methods" testing standards and limiting values have to be specified for the exposure classes. Within the project was shown that "designed concrete" is not sufficiently specified with "limiting values for concrete composition". Therefore concrete producers are obliged since 2008 to determine as function of the exposure class selected concrete properties according to the testing standard SIA 262/1 for "designed concrete". The reasons for these regulations as well as the experience with these regulations will be shown. Later on, a project was launched with the aim of setting up criteria for the control of the concrete quality on site on the construction itself and not on separately manufactured specimens. Up to now, this approach is optional. This approach will be explained, too.

1. INTRODUCTION

With the introduction of EN 206-1 in many countries "designed concrete" with "limiting values for concrete composition" was regarded as usual type of concrete. The regulations for „limiting values for concrete composition“ became in Switzerland more and more complex and have to be revised continuously. For instance in Switzerland, the first version of the SN EN 206-1 contained one national annex with regulations for the minimum cement content, the maximum w/c-ratio and the permitted type of cement as function of the exposure classes. Further regulations in this annex comprised the k-value concept for cement CEM I and the mineral additions fly ash and/or silica fume. Later, the national annex was enlarged with regulations for the k-value for fly ash when used with CEM II/A-LL (national annex C) and blast furnace slag in combination with cement CEM I (national annex D). Additionally rules were set up to evaluate if a cement can be used in a new exposure class (national annex B). In December 2010 the 6th version of table NA.3 was published (tab. 1). Today it is broadly accepted that this approach will become more and more complicated and never ending. One important reason for the continuous revision was and will be the aim to reduce the environmental impact (e.g. emission of greenhouse gases) of the concrete production. Therefore new cements were and will be developed and the use of mineral additions will increase. During the last 15 years the Swiss cement market changed for instance from a nearly pure CEM I to a nearly pure CEM II/A-LL market. In the future further changes will happen.

With the introduction of SN EN 206-1 in 2003 it was also clear that the „limiting values for concrete composition“ for "designed concrete" were a breach in the Swiss tradition. Before the introduction of SN EN 206-1 it was well accepted that relevant durability properties had to be determined on concrete in trial mixes (and nearly for every important construction site) and it was regarded as severe step backwards to omit the testing. For following durability properties tests were available: Water tightness (capillary suction), wear, freeze-thaw resistance, freeze-thaw and de-icing salt resistance.

Table 1: Newest (6th) version (December 2010) of table NA.3 with regulations for the composition of concrete for selected exposure classes having a Dmax32.

Anforderungen an	Expositionsklassen												
		Durch Karbonatisierung verursachte Korrosion				Durch nicht aus Meerwasser stammenden Chloride verursachte Korrosion				Frostangriff			
	XO	XC1	XC2	XC3	XC4	XD1	XD2a e)	XD2b e)	XD3	XF1	XF2	XF3	XF4
							Cl ≤0.5 g/l	Cl >0.5 g/l					
Maximaler w/z-Wert [-]		0,65	0,65	0,60	0,50	0,50	0,50	0,50	0,45	0,50	0,50	0,50	0,45
Mindestzementgehalt a) [kg/m³]		280	280	280	300	300	300	300	320	300	300	300	320 b)
Prüfungen (Grenzwerte und Kriterien gemäss Ziffer 8.2.3.2, Tabelle NA.5)					SIA 262/1, Anhang A: Wasserleitfähigkeit			SIA 262/1, Anhang B: Chloridwiderstand		wie XC4	SIA 262/1, Anhang C: Frost-Tausalzwiderstand		
Andere Anforderungen										SN EN 12620:2002 enthält Anforderungen an die Gesteinskörnungen			
Zulässige Zementarten c): CEM I	+	+	+	+	+	+	+	+	+	+	+	+	+
CEM II/A-LL	+	+	+	+	+	+	+	+	+	+	+	+	+
CEM II/A-M (D-LL)	+	+	+	+	+	+	+	+	+	+	+	+	+
CEM II/B-LL d)	+	+	+	+	-	-	-	-	-	-	-	-	-
CEM II/A-D	+	+	+	+	+	+	+	+	+	+	+	+	+
CEM II/A-S	+	+	+	+	+	+	+	+	+	+	+	+	+
CEM III/A	+	+	+	+	+	+	+	+	+	+	-	+	-
CEM III/B	+	+	+	+	+	+	+	+	+	+	+	+	+
CEM II/A-M (V-LL) 1)	+	+	+	+	+	+	+	+	+	+	+	+	+
CEM II/B-M (V-LL) 1)	+	+	+	+	+	+	+	+	+	+	+	+	+
CEM II/B-T 2)	+	+	+	+	+	+	+	+	+	+	+	+	+
CEM II/B-M (T-LL) 3)	+	+	+	+	+	+	+	+	+	+	+	+	+
CEM II/B-M (S-LL) 4)	+	+	+	+	+	+	+	+	+	+	+	+	+
CEM II/B-M (S-T) 5)	+	+	+	+	+	+	+	+	+	+	+	+	+

a) Ohne Anrechnung von Zusatzstoffen.
b) Bei der Kombination der Expositionsklassen XC4(CH), XD1(CH) und XF4(CH) beträgt der maximale w/z-Wert 0,50 und der minimale Zementgehalt 300 kg/m³. Diese Regelung gilt ausschliesslich für die genannte Kombination. Hinweis: Dieser Beton entspricht dem früheren Standardbeton für Tiefbauten.
c) „+“ bedeutet Verwendung zulässig, „-„ bedeutet Verwendung nicht zugelassen.
d) Die Mindestzementgehalte sind um 20 kg/m³ zu erhöhen.
e) Differenzierung bei der Expositionsklasse XD2(CH) gemäss Neufassung der Ziffer 8.2.3.2. XD2a(CH): Chloridgehalt ≤0.5 g/l („Süsswasser“); XD2b(CH): Chloridgehalt >0.5 g/l („Salzwasser“).
Hinweis: Es wird empfohlen, bei zeitweise oder dauernd hohen Chloridgehalten (z.B. bei Solebädern) einen Beton für die Expositionsklasse XD3(CH) zu wählen.

1) Hersteller: Holcim (Schweiz) AG, gemäss Entscheid der S-Cert AG, Schweizerische Zertifizierungsstelle für Bauprodukte, vom 7.10.2005.
2) Hersteller: Holcim (Baden-Württemberg) GmbH, gemäss Entscheid der S-Cert AG, Schweizerische Zertifizierungsstelle für Bauprodukte, vom 7.10.2005.
3) Hersteller: Holcim (Schweiz) AG, Holcim (Vorarlberg) GmbH, Holcim (Süddeutschland) GmbH und Holcim (France), gemäss Entscheid der S-Cert AG, Schweizerische Zertifizierungsstelle für Bauprodukte, vom 6.10.2010.
4) Hersteller: Jura-Cement-Fabriken AG und Juracime SA, gemäss Entscheid der S-Cert AG vom 6.3.2009.
5) Hersteller: Holcim (Schweiz) AG, Holcim (Vorarlberg) GmbH, Holcim (Süddeutschland) GmbH, gemäss Entscheid der S-Cert AG vom 10.12.2010.

A compromise was introduced in that way that in parallel to the SN EN 206-1 requirements on the concrete composition (limiting values for concrete composition), a research project had to be started to investigate, if the proof of durability by testing could be introduced in a future version of SN EN 206-1 as alternative or supplement to the concrete composition. This research was carried out by TFB and EMPA and financially supported by several industrial partners and the Swiss Road Authority (ASTRA). Subsequently results from this research [1] will be presented. In order to obtain results for the project, it was compulsory for the concrete plants to carry out durability tests for concrete for selected exposure classes:

- XC4, XD1-XD1: water tightness (Wasserleitfähigkeit) according to SIA 262/1, annex A

- XD2, XD3: chloride migration (Chloridwiderstand) according to SIA 262/1, annex B
- XF2-XF4: free-thaw and de-icing salt resistance (Frost-Tausalzwiderstand), according to SIA 262/1, annex C

In the water tightness test the capillary suction is determined and a "water conductivity" is calculated. The chloride migration test is similar to that developed by Tang [2]. The test to determine the "freeze-thaw and de-icing salt resistance" comprises 28 cycles of freezing and thawing with a 3 % NaCl solution and the scaling is measured.

Unfortunately it was not compulsory for the concrete plants to submit the results of the durability test and further information on the concrete.

2. RESULTS FROM THE RESEARCH PROJECT

From approximately 100 concrete plants from nearly all over Switzerland results of the durability tests were submitted to the researchers from 2004 to 2007 (tab. 2). Figure 1 demonstrates that for all concrete plants together, no relationship between the w/c-ratio and the compressive strength could be seen. Of course, for one concrete plant a close relationship exists. This can be regarded as one reason that SN EN 206-1 requires the permanent determination of the compressive strength.

Table 2: Results from durability tests evaluated in the project

Test	No. of Results
Compressive strength	1499
Water conductivity	1349
Chloride migration	605
free-thaw and de-icing salt resistance	459

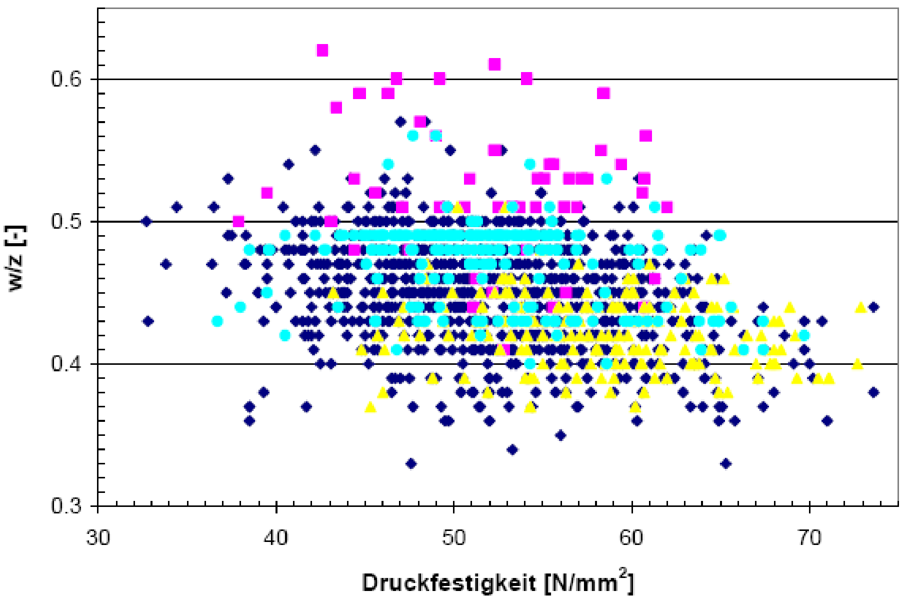

Figure 1: Compressive strength as function of the w/c-ratio, from [1]; rhombuses show results from concrete mixes complying with SN EN 206-1; squares show results from concrete mixes not complying with SN EN 206-1; triangles show results from concrete mixes comply-

ing with SN EN 206-1 and containing not more than 3 vol.-% air; circles show results with insufficient information of the concrete composition.

Up to 2003 it was well accepted that a water tight concrete should have a "water conductivity" of less than 10 g/m^2 h. The analysis showed that nearly all of the 1349 (except 13) test results complied with this limiting value (fig. 2). It might be concluded that the limiting value is not demanding enough, but its suitability is confirmed from practical experience during some decades.

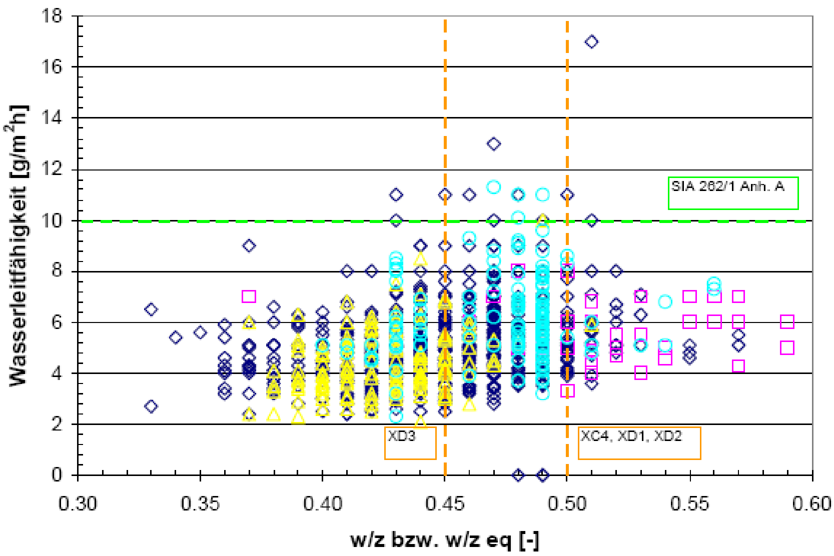

Figure 2: Water conductivity as function of the w/c-ratio, from [1]; for the explanation of the symbols, see fig. 1.

The results of the chloride migration tests showed a more difficult picture compared to the water conductivity (fig. 3). A minor influence of the w/c-ratio and a more pronounced of the type of binder on the chloride migration are visible. The chloride migration is in general not very low and does not differ very much for concrete for the exposure classes XD3 (w/c≤ 0.45) and XD1, XD2 (w/c≤ 0.45). From practice it is known that the ingress of chlorides differs significantly in the exposure classes XD3 and XD1 or XD2. Additionally it is known that a chloride migration coefficient of 10 x 10^{-12} m^2/s is not always sufficient for all exposures in XD3 and that many engineers prefer to have a high durability in combination with a not too high strength and modulus of elasticity to reduce the risk of cracking. Hence, the results demonstrate that the requirements for XD3, given solely by the concrete composition, are not sufficient in Switzerland.

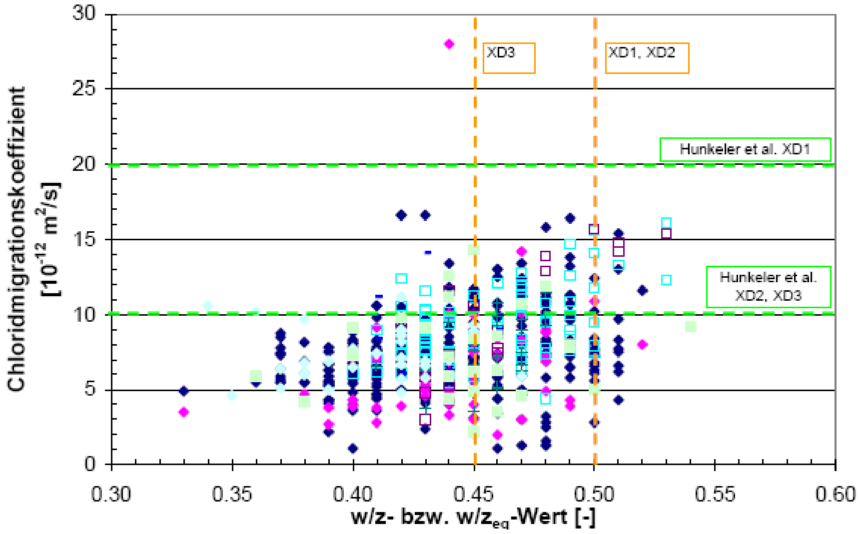

Figure 3: Chloride migration coefficient as function of the w/c-ratio and by symbols by the type of binder (explanation not given here), from [1].

As third durability parameter, the freeze-thaw and de-icing salt resistance was analysed (fig. 4 - 6). It was found no clear influence of the w/c-ratio (fig. 4) and that the minimum cement content for XF4 could be lowered for concrete with Dmax32 from 340 to at least 320 kg/m^3 (fig. 5) and that concrete with low air contents (< 3 vol.-%) could also yield a high freeze-thaw and de-icing salt resistance (fig. 6).

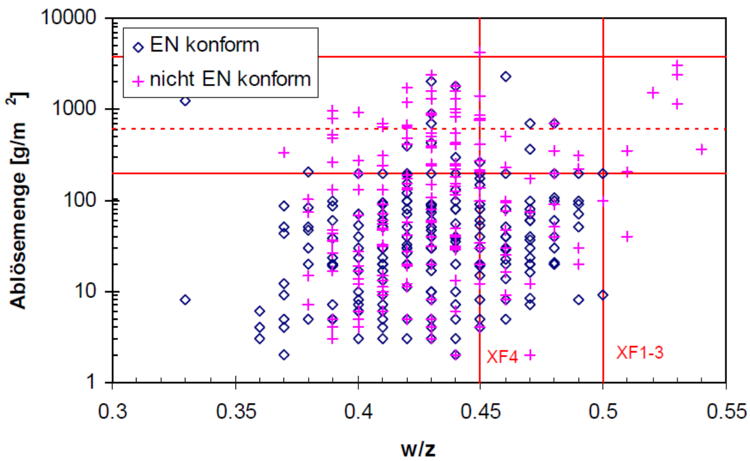

Figure 4: Amount of scaling during the freeze-thaw and de-icing salt as function of the w/c-ratio, from [1]; the horizontal lines denote the limiting values for scaling for a high and medium resistance.

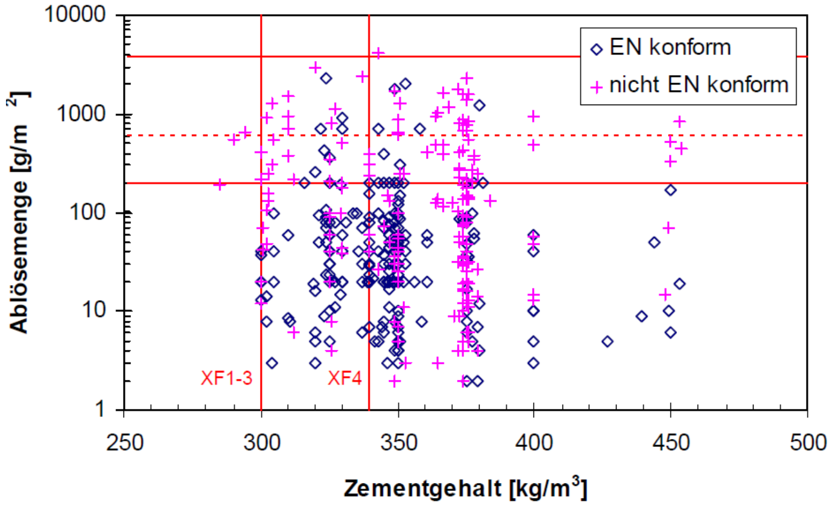

Figure 5: Amount of scaling during the freeze-thaw and de-icing salt as function of the cement content, from [1]; the horizontal lines denote the limiting values for scaling for a high and medium resistance.

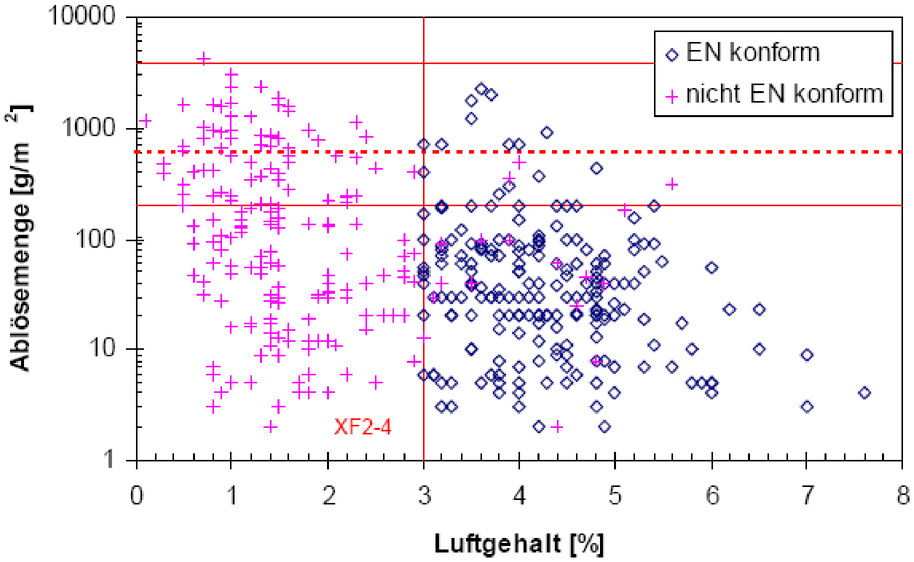

Figure 6: Amount of scaling during the freeze-thaw and de-icing salt as function of the air content of the fresh concrete, from [1]; the horizontal lines denote the limiting values for scaling for a high and medium resistance.

Based on the results of the research project and further considerations, it was decided to set up requirements on the concrete composition (tab. 1) as well as the durability tests (tab. 3). It was agreed that it was too early to omit the requirements on the concrete composition due to the lack of a suitable test (and limiting values) to determine the ability of concrete to prevent rebar corrosion. Since 2008 the concrete plants have to perform the durability tests and achieve the limiting values as part of the conformity control.

Table 3: Requirements on the durability properties as function of the exposure class, from SN EN 206-1; limiting values as well as limiting deviation (Grenzabweichung) and the testing frequency for concrete plants with and without experience are specified.

	Wasserleitfähigkeit	Chloridwiderstand	Frost-Tausalzwiderstand	
			mittel	hoch
Prüfung gemäss Norm SIA 262/1	Anhang A	Anhang B	Anhang C	
Prüfung ist durchzuführen bei Betonen für die Expositions-klassen	XC4 und XD1 sowie XD2 Fussnote a)	XD3	XF2 und XF3	XF4
Grenzwert für Serien-mittelwert	$q_w \leq 10$ g/m²h	$D_{Cl} \leq 10 \cdot 10^{-12}$ m²/s	$m \leq 1'200$ g/m²	$m \leq 200$ oder $m \leq 600$ g/m² und $\Delta m_{28} \leq (\Delta m_6 + \Delta m_{14})$
Grenzabweichung für Serienmittelwert	$q_w \leq 12$ g/m²h	$D_{Cl} \leq 13 \cdot 10^{-12}$ m²/s	$m \leq 1'800$ g/m²	$m \leq 250$ oder $m \leq 800$ g/m² und $\Delta m_{28} \leq (\Delta m_6 + \Delta m_{14})$
Prüfhäufigkeit für Betonhersteller ohne Erfahrung	Mind. 4 pro Jahr oder alle 500 m³, ab 4'000 m³ alle 1'000 m³, ab 30'000 m³ alle 1'500 m³	Mindestens 4 pro Jahr oder alle 125 m³, ab 1'000 m³ alle 250 m³, ab 5'000 m³ alle 500 m³		
Prüfhäufigkeit für Betonhersteller mit Erfahrung	Mind. 2 pro Jahr oder alle 1'000 m³, ab 4'000 m³ alle 2'000 m³, ab 30'000 m³ alle 3'000 m³	Mindestens 2 pro Jahr oder alle 250 m³, ab 1'000 m³ alle 500 m³, ab 5'000 m³ alle 1'000 m³		

During the last years was recognised that it could be in some cases difficult for the concrete plants to meet some of the specifications in table 3. This could be attributed to a not always sound concrete technology understanding and problems of unknown origin, too. Therefore discussions arose to change and/or discard some of the limiting values. Today the limiting values for XF2 and XF3 are mainly under discussion. The limiting value for these exposure classes was determined from the results of the research project. It might be speculated, that the submission of much more test results would have given a different picture. Probably a different (e.g. higher) limiting value would have been proposed. The limiting value for XF4 is not under discussion, because it is supported by experience of some decades. A research project will be hopefully started soon to check the necessary requirements for XF2 and XF3. Within this project it is, beside others, planned to compare laboratory results with the performance in practice. Minor discussions arose with the limiting value for chloride migration in XD3, but it could be shown (and it was accepted) that the limiting value of 10×10^{-12} m²/s are not always sufficient (too high) like e.g. tunnels and galleries along highways.

3. TESTING ON SITE

In chapter 2 requirements for the conformity control are explained. The tests have to be carried out on cores taken usually from concrete cubes of 150 mm edge length which are stored until testing in water. It is well known that the concrete properties of cubes might differ from that of the construction element. Reasons are for instance the different compaction, different curing and different temperature regime in the specimens and the construction element. In the Swiss testing standard 262/1, published in 2003, in annex E a non destructive air permeability test was specified in order to check the quality of a construction element. The test was developed by Torrent and demonstrated for instance in a round robin test its suitability [3]. In many studies a rather close relationship between the air permeability and durability parameters (e.g. water suction, chloride ingress, depths of carbonation) was shown [3, 4]. Due to a lack of details on how to perform the test and criteria for the compliance control, air permeability measurements were carried out only scarcely. To date, over 100 construction elements have been examined with the SIA 262/1 air permeability test method in Switzerland. Based on the accumulated knowledge, in 2009 recommendations for determining the air-permeability were published [4]. These recommendations cover proposals for the tendering, execution and evaluation of measurements of air-permeability. When conducting measurements of air-permeability, the required temperature and moisture conditions of the concrete elements must be observed and recorded.

The conformity control is based on at least six air permeability measurements per construction element at an age between 1 to 3 months. The age depends mainly on the length of the curing period. 5 of 6 measurements must meet the characteristic limiting value (tab. 4). If just two measurements exceed the characteristic limiting values, further six measurements can be made. 5 of the second set of six measurements must meet the characteristic limiting values. If the requirements of the characteristic limiting values are not fulfilled, further investigations (e.g. destructively by drilling cores and/or non destructively by e.g. measuring the rebar cover) can be performed. Afterwards can be decided how to proceed with the construction element(s): It might result in an application of a surface protecting system (e.g. hydrophobing agent, coating). Up to now, not sufficient experience is available to speak about the acceptance and suitability with this new approach.

Table 4: Characteristic limiting values for air permeability measurements according to SIA 262/1, annex F, as function of the concrete type (A – G), from [4]

Bezeichnung	A	B	C	D	E	F	G
Druckfestig-keitsklasse	C25/30	C25/30	C30/37	C25/30	C25/30	C30/37	C30/37
Expositions-klassen	XC1(CH) XC2(CH)	XC3(CH)	XC4(CH) XF1(CH)	XC4(CH) XD1(CH) XF2(CH)	XC4(CH) XD1(CH) XF4(CH)	XC4(CH) XD3(CH) XF2(CH)	XC4(CH) XD3(CH) XF4(CH)
Minimaler Zementgehalt [kg/m^3]	280	280	300	300	300	320	320
Maximaler w/z-Wert	0.65	0.60	0.50	0.50	0.50	0.45	0.45
Empfohlener Luftpermeabi-litätsgrenzwert kTs [10^{-16} m^2]	-	-	2.0	2.0	2.0	0.50	0.50

4. CONCLUSIONS

- The Swiss experience showed that for owners, engineers and concrete plants designed concrete according to SN EN 206-1 is well accepted. But due to the constant changes in the market for cement and mineral additions and limitations of the approach itself, the approach with limiting values for concrete composition reached its limits.
- Beside of requirements on concrete composition, further requirements on concrete properties must be introduced to guarantee a sufficient durability. An insufficient dura-

bility, which is the main reason for concrete damages worldwide, results in an unsound economic behaviour.

- The determination of the durability properties (type of test and limiting values) must be reliable for the performance in practice.
- To set up the appropriate tests and limiting values is a demanding challenge to satisfy all actors in the concrete market like producers of concrete constituents, concrete plants, constructors, engineers and owners.
- It is recommended to perform compliance tests on separately manufactured specimens and additionally on the construction element itself.

ACKNOWLEDGEMENTS

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