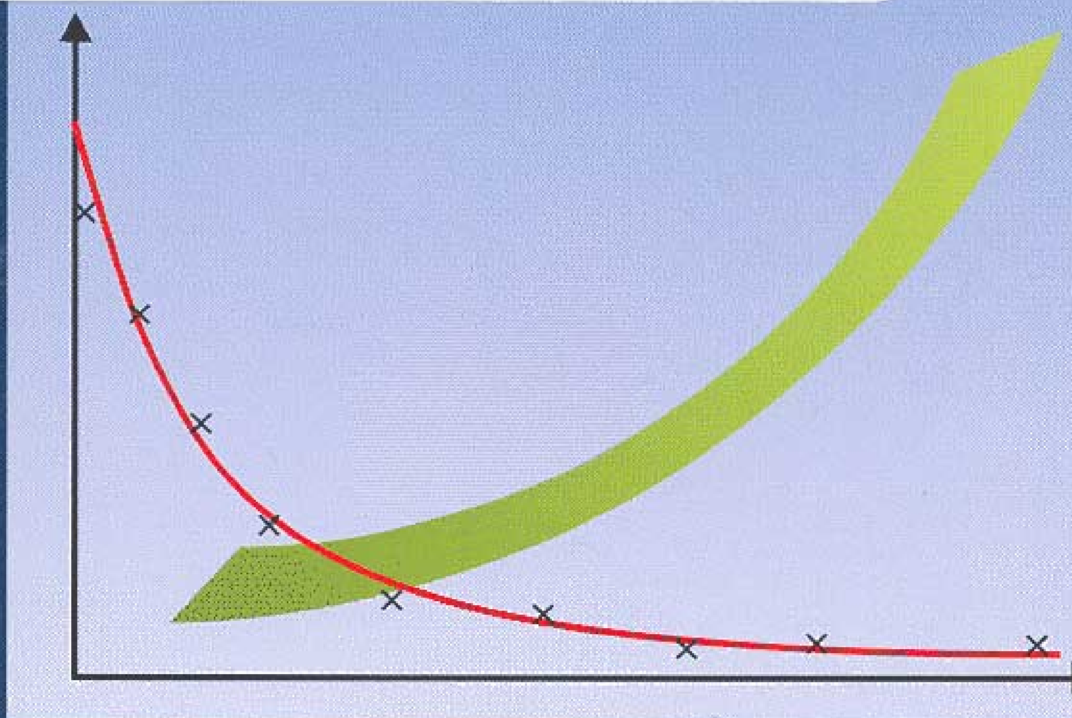
HETEK

The effect of the w/c ratio on chloride transport into concrete

Immersion, migration and resistivity tests



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Abstract:

This report is part of a series of reports generated in the research project HETEK headed by the Danish Road Directorate. The present sub task is concerning chloride transport into concrete and this report is about the effect of the *w/c* ratio on the diffusivity of chlorides in concrete measured by three different test principles.

Seven different *w/c* ratios covering the practical range of portland cement concretes were examined. The concretes were made of cement (ASTM type V), water, superplasticizer and aggregates (no puzzolanas and no air-entrainers were added). All concretes had as target the same paste volume, natural air content and workability (slump).

The effect of the *w/c* ratio on the following parameters were examined: 28-day compressive strength, the potential diffusivity as measured according to NT Build 443, the potential diffusivity as measured according to the CTH migration method, the electrical resistivity as measured according to APM 219.The *w/c* ratios of 0.30, 0.35, 0.40, 0.45, 0.50, 0.60 and 0.70 were used.

A monotonous relationship between *w/c* ratio and diffusivity measured according to NT Build 443 and the CTH-migration test method was found for the whole range examined. For the most interesting part of the examined range (below *w/c*=0.50) also the resistivity method showed a clear ability to distinguish different *w/c* ratios.

All test methods and data are presented in the report and in the appendices.

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1 Preface

1.1 Background

The Road Directorate in Denmark has launched a number of research projects in 1995 to be performed and completed during 1996. The package of projects has been given the name "HETEK", which is short, in Danish, for "*H*igh quality concrete, the *C*ontractors *TEC*hnology". The projects cover eight topics:

1. Test methods for chloride resistance of high quality concrete
2. Test methods for freeze/thaw durability of high quality concrete
3. Self-desiccation
4. Curing Technology
5. Casting and compaction
6. Curing treatment
7. Guidance in trial castings
8. Remedial measures during the execution phase

The projects are to give a state-of-the-art report, identify the need for further research, perform some of that research and finally give guidelines for the contractor.

The state-of-the-art report on Chloride penetration was first completed. This report describes the results of the first sub task of HETEK-1, the experimental study on the effect of *w/c* ratio on chloride penetration.

1.1.1 About HETEK-1

The research consortium ACCE was given the first project HETEK-1 on chloride resistance of high quality concrete. The task for this project is to re-evaluate existing methods, and develop new ones, for determining chloride penetration in high quality concrete. The methods must consider the differences in environmental actions on the concrete structure. Quantitative criteria for approval shall be laid down to ensure compliance with the durability requirements and the economy of the methods shall be estimated.

The research consortium ACCE consists of the three partners: AEC, Chalmers University of Technology and Cementa AB.

1.1.2 About the research consortium

AEC Consulting Engineers (Ltd.) A/S is a private consultant company in Denmark. AEC works mainly in the field of concrete structures and topics related to the repair, durability and maintenance of those. The typical clients of AEC are other consultants, contractors, building owners, insurance companies, cement producers and suppliers and also producers of materials for concrete repair and maintenance. The company has two departments: a *structural* department, which offers consultancy regarding specialized construction problems and conventional consultancy in civil engineering and a *materials* department. The materials department, the AEClaboratory, assesses deterioration of concrete structures, prescribes and develops repair methods and evaluates repair materials. Research and development regarding concrete durability tasks are solved for clients and/or financed by fundings.

Chalmers University of Technology educate civil engineers and researchers and do research in a number of basic and applied sciences and technologies. The department of Building Materials at the School of Civil Engineering, is participating in HETEK-1. The main research area is transport processes in porous building materials, mainly cement-based and wooden-based materials and surface materials on such materials. Examples of concrete research are: *Moisture* binding and flow properties of concrete, *self-desiccation and drying* of hardening high performance concrete, *plastic shrinkage* and early age cracking, *chloride* penetration into structures exposed to sea water and de-icing salts. The relationships between mix design, micro and pore structure and properties are experimentally studied and the behaviour in different environments are modelled and verified on concrete structures.

Cementa AB is a cement producer in Sweden. The activities of Cementa regarding concrete research are as follows: *High Performance Concrete*, i.e. high strength, low water content and low permeability. *Concrete and environment*, i.e. problems regarding moisture in concrete and emissions from concrete. *Durable Concrete*, i.e. long time experiments regarding chloride ingress, permeability, strength evolution and carbonation. *No Slump Concrete*, i.e. rheological aspects of making precast concrete products.

1.2 Scope

The scope of these investigations was to study the following:

- The relationship between the *w/c* ratio and the chloride ingress parameters measured according to NT Build 443 (formerly APM 302) and the CTH-method. Exposure started at 28 days maturity and for NT Build 443 exposure ended 35 days later at 63 days maturity.
- The relationship between the *w/c* ratio and the electrical resistance measured according to APM 219, at 7 days of age and at 28 days of age.
- The relationship between the electrical resistivity at 7 respectively 28 days of maturity and the chloride ingress parameters measured as mentioned above.

The investigations were made on seven concrete mixes having *w/c* ratios varying from 0.30 to 0.70.

1.3 Structure

The report gives in Section 2 an introduction where the background for the investigation is dealt with. In Section 3 the manufacture of the specimens is described in detail to an extent making it possible to re-make the concrete mixes for later investigations of this type. In Sections 4, 5 and 6 the results from the different chloride penetration tests are presented.

At the end, in Sections 7 and 8 the results are evaluated and conclusions are drawn.

Essential input to the report was given by H.E. Sørensen and J. Hansen (Section 4), A. Andersen (Section 5) and O. Klinghoffer (Section 6). The report was edited and written by J.M. Frederiksen and quality assurance was made by L.-O. Nilsson and H.E. Sørensen.

1.4 Limitations

The results presented in this report are valid for the specimens manufactured and tested for this investigation. Use of the results for concretes produced under different conditions or with different constituents is only valid if the compatibility and representability is proven.

2 Introduction

The potential chloride diffusivity of concrete is a decisive property, which is used in the models predicting service life and cover to reinforcement. Earlier work (e.g. the projects BMB and LIGHTCON[1]) has shown that the potential chloride diffusivity of young concrete is related to the equivalent *w/c* ratio. The relation is not fully revealed, because the maturity of the concrete has varied for the examined mix designs. As the chloride diffusivity changes with maturity, the results obtained so far gives quite a blurred picture. Furthermore, the relation is not determined with equal accuracy for the relevant interval of equivalent *w/c* ratios, specially not when considering all relevant binder types and combinations of these.

The relationship is needed for determination of accept criteria in the guidelines, and will be used to illustrate the influence of *w/c* ratio on the chloride penetration parameters.

Furthermore a quick and reliable method is needed to evaluate the chloride permeability of concrete in production. Such a method can be a resistivity method and/or a migration method.

Table 1. The test methods used and the extent of testing the concretes in the present investigations.

Property	Test method	Repetitions	No. of tests
Fresh concrete			
Slump	NT Build 192	2	14
Air content	NT Build 195	2	14
Hardened concrete			
Compressive strength	NT Build 203	3	21
Chloride penetration	NT Build 443	2	14
Chloride penetration	CTH-method	2	14
Resistivity	APM 219	2×2	28

[1] BMB: Beständighet Marina Betonkonstruktioner (Durability of Marine Concrete Structures), a Swedish research project from 1992-95. LIGHTCON a Norwegian research project from 1993-1996.

3 Manufacture of specimens

This section describes in detail how the specimens were manufactured.

3.1 Constituent Materials

The constituents for the concretes tested were ordinary materials used for concrete production in Denmark. Below some essential properties are presented.

3.1.1 Cement

The cement (DS 427 CEM I 42.5 (ASTM type V)) was purchased at an ordinary supplier of building materials. The cement was delivered in the original paper bags carrying the date of package: 1995-09-25. A sample of at least 5 kg was send to the Aalborg Portland Cement Factory for testing. The test results are shown in Tables 2 and 3.

3.1.2 Water

The water used was ordinary potable tap water.

Table 2. Selected test results from testing the chemical and physical properties of the cement used in this investigation.

Property		Value	Unit
Cl^-		0.006	%mass
Absolute density		3150	kg/m^3
Fineness (Blaine)		359	m^2/kg
le Chatelier		0.0	mm
Initial setting		2:10	h:min
Final setting		3:00	h:min
Compressive strength:	1 day	9.6	MPa
	2 days	18.6	MPa
	7 days	36.0	MPa
	28 days	54.9	MPa

Table 3. Test results from testing the cement composition. The cement type code is ***DS 427 CEM I 42.5****.*

Property		Value
		mass%
Oxides:	SiO_2	23.79
	Al_2O_3	3.07
	Fe_2O_3	2.49
	CaO	66.10
	MgO	0.68
	SO_3	2.14
Loss on ignition		0.78
Insoluble residue		0.06
Alkalies:	K_2O	0.17
	Na_2O	0.20
	Eqv. Na_2O	0.31
Clinkers:	C_3S	53.0
	C_2S	28.0
	C_3A	3.9
	C_4AF	7.6
$CaSO_4$		3.6
Free CaO		1.3

3.1.3 Superplasticizer

The superplasticizer used were Peramin F delivered by Fosroc A/S, who also supplied the characteristics from a chemical analysis of the actual batch. The results are presented in Table 4.

Table 4. Test results giving the characteristics of the superplasticizer (Peramin F) used in the concrete.

Property	Value	Unit
Density at 20°C	1209	kg/m³
Dry matter	33.6	mass%
Equivalent Na_2O	4.25	mass%
Chloride content	<0.001	mass%
pH-value	11.5	-

3.1.4 Fine Aggregates

The fine aggregates used were oven dried pure quartz delivered in 25 kg plastic bags. The origin of the fine aggregates is Sønder Vissing in Denmark.

Essential properties of the fine aggregates are shown in Table 5.

3.1.5 Coarse Aggregates

The coarse aggregates used were crushed granite rock delivered in big bags in the fractions 4-8 mm and 8-16 mm. The origin of the granite is Glensanda in Scotland.

Essential properties of the coarse aggregates are shown in Table 5.

Table 5. Essential properties of the aggregates used in the concretes.

Properties of Aggregates	Fine aggregate	1st Coarse aggregate	2nd Coarse aggregate	Unit
Trade name	Sønder Vissing	Glensanda Granite	Glensanda Granite	-
Mineralogical name	Quartz	Granite	Granite	-
Sieve size	Percentage passing			
32	100.0	100.0	100.0	mass%
16	100.0	100.0	92.0	mass%
8	100.0	91.0	4.0	mass%
4	100.0	11.0	0.0	mass%
2	95.0	0.0	0.0	mass%
1	82.0	0.0	0.0	mass%
0.5	57.0	0.0	0.0	mass%
0.25	15.0	0.0	0.0	mass%
0.125	1.0	0.0	0.0	mass%
0.075	0.1	0.0	0.0	mass%
Density, saturated surface dry	2623	2614	2626	kg/m³
Compaction ratio, dry	0.63	0.56	0.55	-
Absorption	0.28	1.00	0.80	mass%
Cl^--content	0.000	0.002	0.0015	mass%

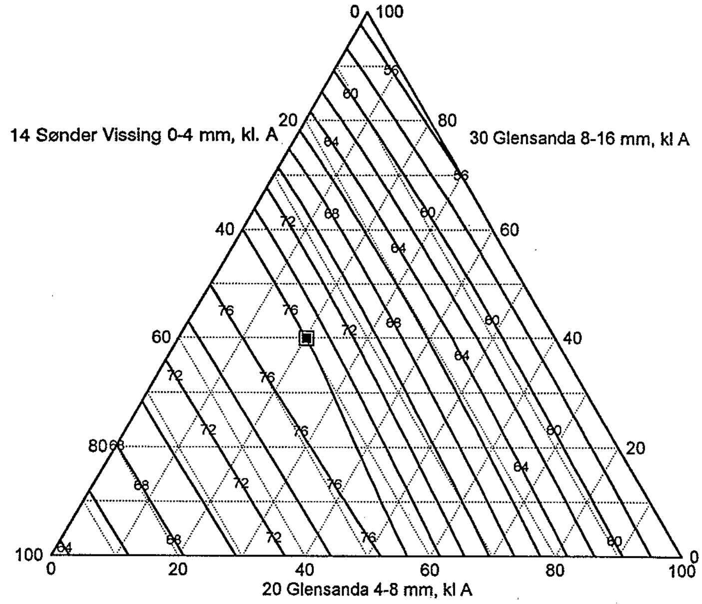


Figure 1. The result of a theoretical packing analysis. The curves in the triangle represents compositions having equal packing density. The chosen composition is marked on the figure.

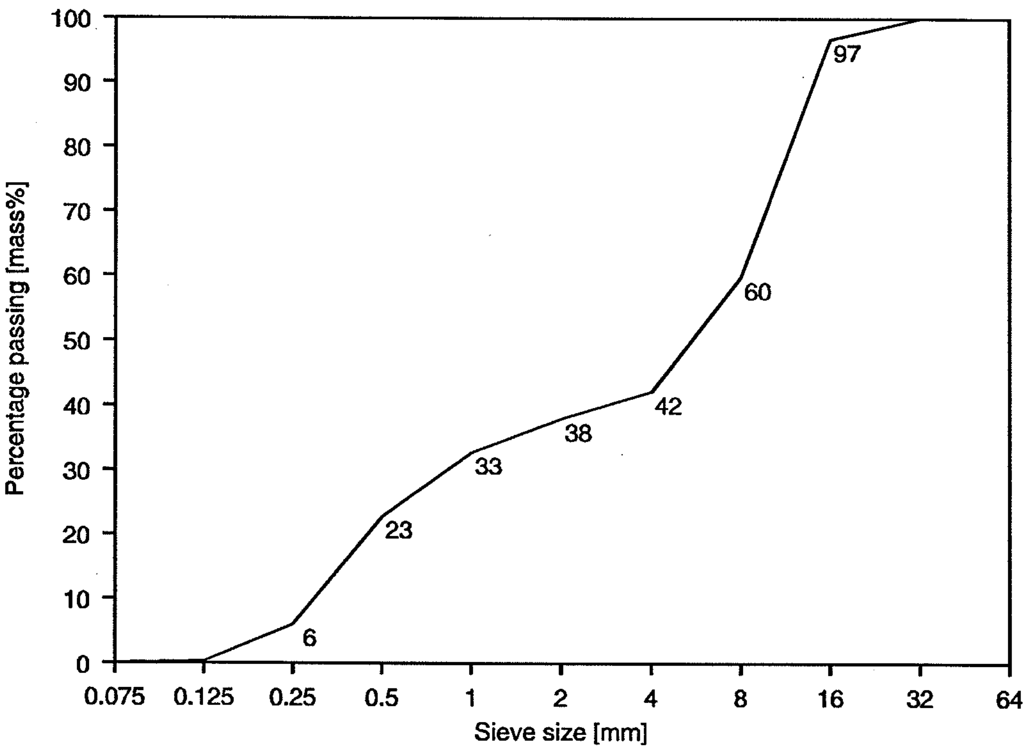


Figure 2. The grading of aggregate used in all mixes.

3.2 Concrete

3.2.1 Concrete mix designs

The concrete mix designs were made so that all concrete batches had the same paste volume. From practice it is known that the paste content in ordinary concrete is 26-28% by volume of the concrete. This is the reason for choosing 27% by volume as the target value for these investigations.

The concrete mixes were all made with the same aggregate grading. The grading was decided from theoretical packing calculations by using the commercial available program "DTI Pakning". The result of the packing analysis is shown in Figure 1. The grading curve resulting from composing the three aggregate fractions 40%/20%/40% is shown in Figure 2. The extent of testing the concretes is presented earlier in Table 1.

3.2.2 Mixing

The mixing was done by using a laboratory pan mixer made by Eirich. The constituents were all weighed on a 0-24.000 kg Mettler balance before adding them into the mixer pan. The constituents were added in the following order: fine aggregates, cement, water and superplasticizer while the mixer were rotating slowly. This mortar was then mixed to a uniform appearance whereafter the coarse aggregates were added. The total mixing time was approx. 5 minutes.

3.2.3 Casting

One batch of 60 litres was made from each mix design. This batch was used as follows:

- 10 litres for measuring the air content
- 25 litres for casting the prisms
- 15 litres for casting six Ø100×200mm cylinders

The moulds for casting the prisms were made from wood particle board covered by a smooth and non-absorbing melamine surface. The moulds had the following dimensions: l × d × h = 450 × 150 × 300 mm. Each mould was only used once.

The concrete was poured into a clean bucket and from there poured into the clean moulds. The moulds were vibrated on a vibrating table until a smooth surface was obtained.

3.2.4 Compositions and test results

Selected details regarding the concrete mixes are shown in Table 6.

3.2.5 Curing

Immediately after casting all specimens were carried to a room having a controlled standard laboratory climate of 23°C and 50% RH.

The six cylinders were demoulded at the age of 1 day. Three cylinders were put into plastic bags together with a wet tissue and kept at 23±2°C to be used for possible future investigations. The three other cylinders were put into a curing bath at 20±2°C until the age of 28 days and then used for testing the compressive strength.

The prisms were demoulded at the age of 3 days and kept at 23±2°C sealed in plastic.

Table 6. Final mix compositions and test results for the seven mixes tested.

Property		Mix Nº1	Mix Nº2	Mix Nº3	Mix Nº4	Mix Nº5	Mix Nº6	Mix Nº7	Unit
Date of casting		01-02	01-08	01-09	01-15	01-16	01-22	01-23	1996-mm-dd
Water added		11:17	13:52	11:45	11:25	9:40	14:45	13:50	hh:mm
Cement content		265	292	327	348	374	398	434	kg/m^3
Eff. water		185.5	175.1	163.7	156.8	150.5	140.5	130.2	kg/m^3
w/c ratio		**0.70**	**0.60**	**0.50**	**0.45**	**0.40**	**0.35**	**0.30**	-
SP-admixt.		0.00	0.10	0.75	1.12	1.83	2.66	3.00	%mass cement
Paste content		270	268	268	268	270	269	270	dm^3/m^3
Air content		1.6	2.2	2.1	2.1	1.6	2.6	2.5	vol%
Density		2360	2350	2370	2380	2410	2410	2440	kg/m^3
Initial slump		70	55	55	55	80	65	50	mm
Calculated maximum:	Cl^-	0.062	0.057	0.051	0.049	0.046	0.043	0.040	%mass cement
	Equiv. Na_2O	1.064	1.153	1.347	1.468	1.670	1.895	2.101	kg/m^3 mortar (≤4 mm)
Compressive	1	22.8	32.2	43.9	46.9	59.3	66.9	70.1	MPa
strength,	2	23.7	31.5	44.1	48.1	60.5	68.5	80.6	MPa
28 days	3	23.3	31.9	44.9	48.9	57.7	66.3	72.4	MPa
	average	**23.3**	**31.9**	**44.3**	**47.9**	**59.2**	**67.3**	**74.3**	MPa

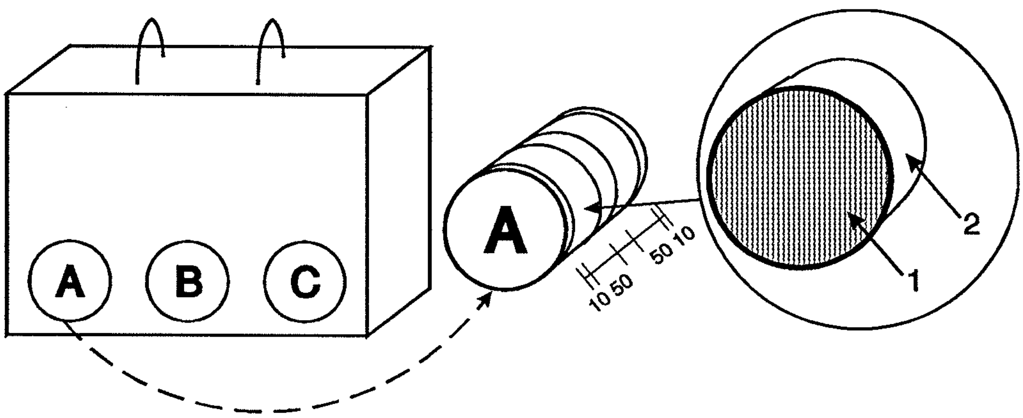


Figure 3. A sketch of the prisms from where cores were drilled and used for further analyses acc. to NT Build 443 (A), the resistivity method (B) and the CTH-method (C), cf. later sections of this report. From each core two 50 mm specimens were prepared. The outer cut surface was placed 10 mm below the as cast face. The exposed face was the one marked 1 while the face marked 2 was coated with a polyurethane or epoxy coating before exposure (only NT Build 443).

3.2.6 Preparation

The cast standard cylinders were not prepared after demoulding.

From the prisms three cores were taken from the lower part, cf. Figure 3. The cores were drilled at a concrete age of 3 days and then cured in plastic bags at 23±2°C. The dimensions of the cores were Ø100×150mm.

3.3 The effect of the *w/c* ratio on various properties

The measured dependence of strength on the *w/c* ratio is shown in Figure 4. In order to judge the measured relation comparison is made to formula (1):

$$f_c = \exp(a_1 + a_2 \times w/c) \tag{1}$$

where f_c is the compressive strength and $a_1 = 5.23$ and $a_2 = -2.96$.

Three parameters (the paste volume, the air content and the slump) were as target to be kept constant. In Figure 5 the obtained values are shown graphically for each of the mixes.

The dependence on the used proportion of superplasticizer on the *w/c* ratio in order to achieve the slump reported in Table 6 is shown in Figure 5.

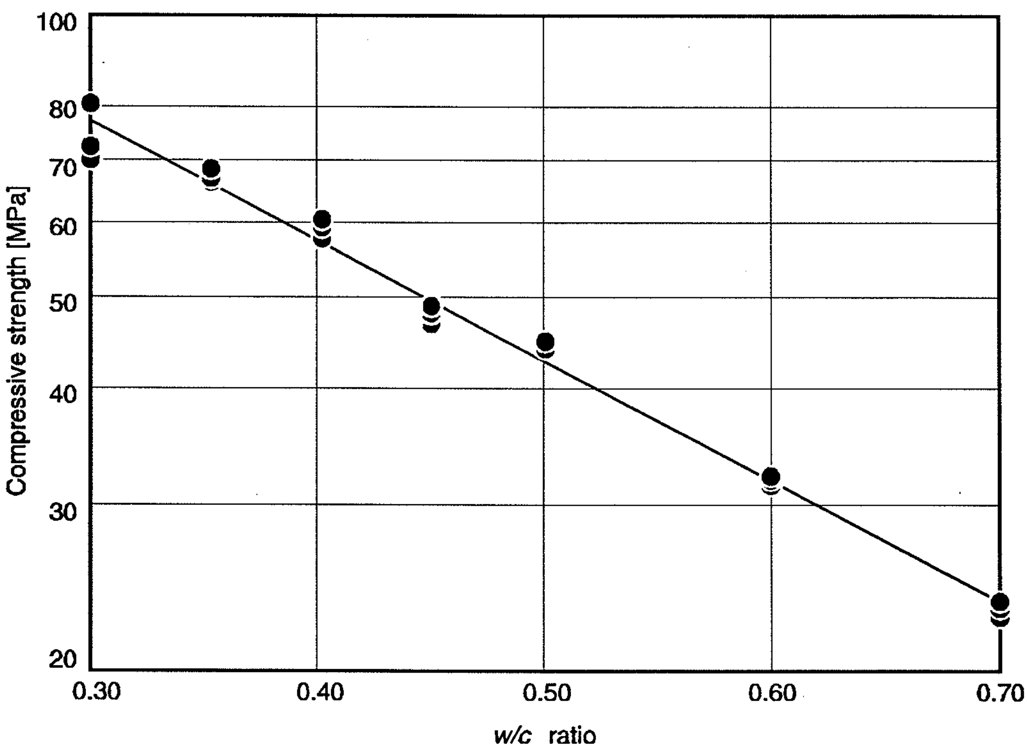


Figure 4. The effect of the w/c ratio on the strength. Comparison (the straight line) is made to formula (1). (log-normal diagram)

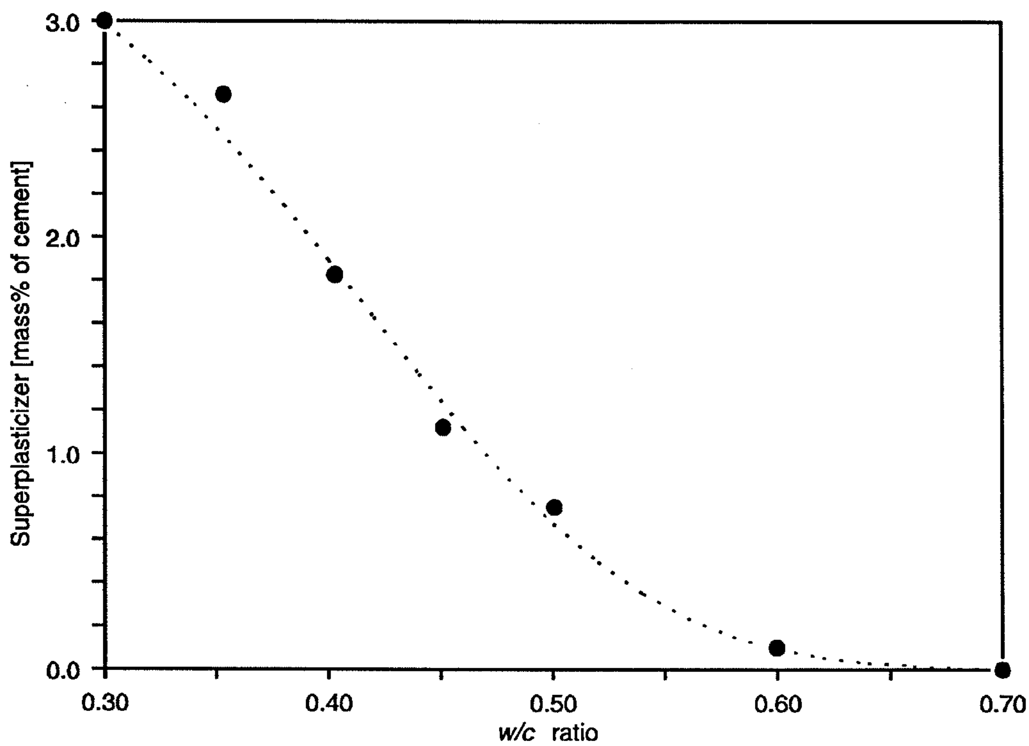


Figure 5. The effect of the w/c ratio on the used proportion of superplasticizer in order to achieve the slump reported in Table 6.

4 Immersion tests

This section describes in detail how the immersion tests were performed and what the test results were. In the appendix all sub-results can be found together with the chloride profiles etc.

4.1 Samples

The samples for the immersion tests were drilled cores taken from the cast concrete prisms as described in Chapter 3. From each core (marked A) two specimens were taken.

4.2 Test period

The tests were performed in the period 1996.01.23 - 1996.03.29.

4.3 Sample preparation

The samples were prepared according to NT Build 443 - "Accelerated chloride penetration". Figure 3 in the previous section shows the preparation of the samples in principle.

4.4 Test procedure

At an age of 28 days the prepared samples were tested according to NT Build 443. This procedure involved an exposure at 23°C in a NaCl solution having a concentration of 165 g $NaCl/dm^3$. The exposure lasted 35 days. Immediately after the exposure thin layers were ground of the exposed surface and collected for chloride analysis.

4.5 Results

The chloride contents were plotted against the corresponding depths. Using (2) as a model function, the test results (the transport parameters defined below) were calculated by using a non-linear optimisation procedure.

$$C_x = C_s - (C_s - C_i) \times \operatorname{erf}\left(\frac{x}{2\sqrt{D_{pex} t}}\right) \tag{2}$$

The test results for all specimens are given in Table 7 as the transport parameters:

C_s The calculated surface concentration arisen during the exposure to a sodium chloride solution of a chloride concentration as stated in Table 7.

C_i The **measured** initial chloride concentration in the concrete.

D_{pex} The calculated chloride transport coefficient for the measured chloride profile. The index *pex* means the "potential" parameter after a known "time of exposure".

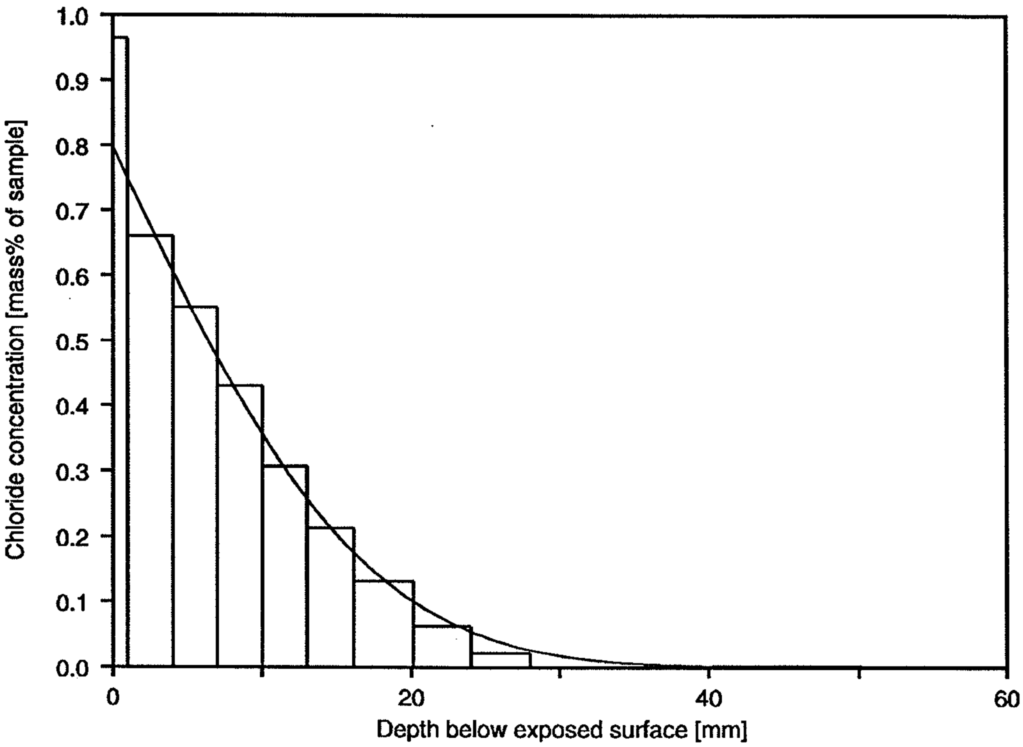


Figure 6. An example of a chloride profile measured by using the grinding technique. The curve represents the model (2) after optimization of the parameters D_{pex} and C_s.

The parameter $K_{0.05}$ is a penetration parameter that integrates the influence of the parameters C_i, C_s, D_{pex} and a reference concentration, C_r. The penetration parameter is calculated from (3):

$$K_{0.05}=\sqrt{4D_{pex}t} \times \mathrm{erf}^{-1}\left(\frac{C_r-C_i}{C_s-C_i}\right) \tag{3}$$

If the unit for D_{pex} is mm^2/year and the unit for t is years, $K_{0.05}$ is the estimated ingress in mm of the concentration 0.05 mass% after one year exposure with constant parameters.

Table 7. Test results from immersion tests according to NT Build 443.

Identification		Exposure		Test results				
Sample no	*w/c* ratio	NaCl [g/dm³]	Temp. [°C]	C_s [mass%]	C_i [mass%]	$D_{pex} \cdot 10^{12}$ [m²/s]	D_{pex} [mm²/year]	$K_{0.05}$ [mm/√year]
A1-1	0.70	166.69	22.0	0.913	0.000	32.7	1031	87
A1-2	0.70	167.13	22.0	0.788	0.000	38.3	1208	91
A2-1	0.60	166.92	22.5	0.798	0.000	28.6	902	79
A2-2	0.60	164.86	22.5	0.830	0.000	28.0	883	79
A3-1	0.50	165.27	22.6	0.836	0.000	15.8	498	59
A3-2	0.50	165.36	22.6	0.829	0.000	16.5	520	61
A4-1	0.45	165.84	22.8	0.721	0.000	13.6	429	53
A4-2	0.45	165.25	22.8	0.687	0.000	11.9	375	49
A5-1	0.40	164.96	22.8	0.730	0.000	10.6	334	47
A5-2	0.40	165.25	22.8	0.709	0.000	10.3	325	46
A6-1	0.35	165.15	22.9	0.646	0.000	7.3	230	38
A6-2	0.35	165.01	22.9	0.718	0.000	7.0	221	38
A7-1	0.30	165.48	23.0	0.565	0.000	5.6	177	32
A7-2	0.30	166.18	23.0	0.634	0.000	4.7	148	30

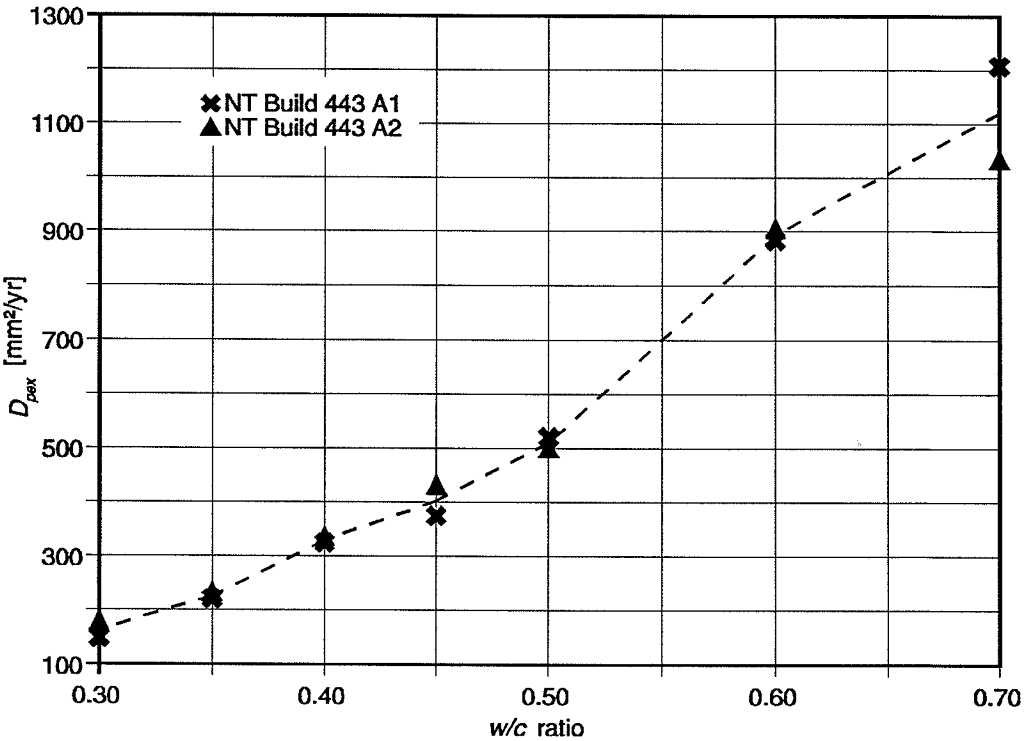


Figure 7. The effect of the w/c ratio on D_{pex}. The dotted curve represents the mean value.

5 Migration tests

This section describes in detail how the migration tests were performed and what the test results were. In the appendix all sub-results are presented.

5.1 Samples

The samples for the migration tests were drilled cores taken from the cast concrete prisms as described in Chapter 3. From each core (marked C) two specimens were taken.

5.2 Test period

The tests were performed in the period 1996.01.30 - 1996.02.18.

5.3 Sample preparation

The samples were prepared as shown in principle in Figure 3, Section 3, except that the cores were cut in two halves and the surface was cut off so that two nominally 50 mm thick specimens were obtained and the chloride diffusion proof membrane was not applied. The specimens were vacuum treated in water for 6 hours followed by 18 hours in water at atmospheric pressure.

5.4 Test procedure

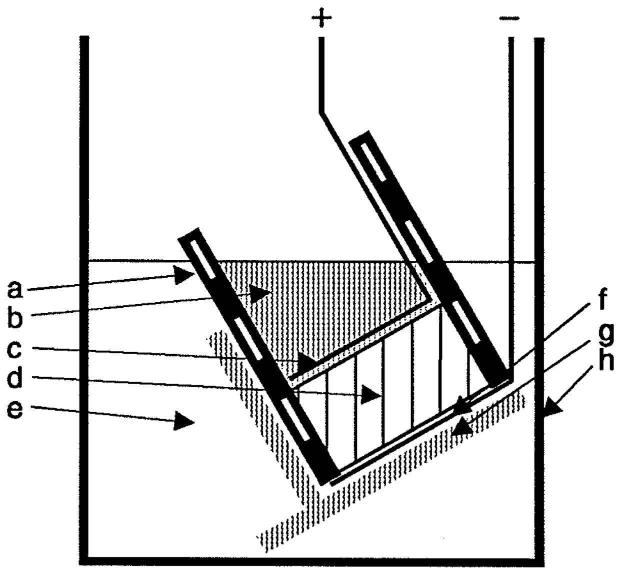
At an age of 28 days the prepared samples were placed in the CTH-test set-up. In Figure 8 the test set-up is shown in principle. The procedure involved an exposure to a NaCl solution (catholyte) having a molarity of 2 M Cl^- at 20°C while simultaneously applying an electrical field of 40 V. The exposure lasted up to 24 hours. From the measurements of the initial current the recommended test duration was decided.

Immediately after the exposure the specimens were splitted in two halves and sprayed with a 0.1 M $AgNO_3$ solution. The chloride contaminated area immediately becomes light grey (from the AgCl precipitate) and after light exposure the unaffected areas becomes brownish. The penetration depth was measured as the distance from the surface and down to the end of the light grey area. In all specimens a homogenous penetration depth was found.

5.5 Results

From previous investigations it is known that the concentration, c_d of chloride at the border line between the unchanged grey and the brownish areas is about $c_d \approx 0.07$ mass%. This together with the depth measurements, x_d and other specific parameters of the test were used to calculate the diffusion coefficients according to (4).

Figure 8. The principle of the test set-up for the CTH migration test method. The letters refer to: ***a.*** *rubber sleeve;* ***b.*** *anolyte;* ***c.*** *anode;* ***d.*** *specimen;* ***e.*** *catholyte;* ***f.*** *cathode;* ***g.*** *plastic support;* ***h.*** *plastic box. The applied voltage was 40V in this test series.*



$$D_{CTH}=\frac{RT\delta}{zFU}\times\frac{x_d-\alpha\sqrt{x_d}}{t} \qquad (4)$$

where

D_{CTH} is the diffusion coefficient [m²/s]
z is the absolute value of the ion valence for chloride ions, $z=1$
F is Faradays constant, $F = 9.648\cdot10^4$ [J/(V·mol)]
U is the absolute value of the potential difference [V]
R is the gas constant, $R = 8.314$ [J/(K·mol)]
T is the solution temperature [K]
δ is the thickness of the specimen [m]
x_d is the penetration depth [m]
t is the test duration [s]

and

$$\alpha=2\cdot\sqrt{\frac{RT\delta}{zFU}}\times \mathrm{erf}^{-1}\left(1-\frac{2c_d}{c_1}\right) \qquad (5)$$

where

c_d is the chloride concentration at the border line, $c_d \approx 0.07$ mass%
c_1 is the chloride concentration in the catholyte (the upstream cell), $c_1 = 2$ M.

The value of α can easily be calculated since (6) is constant for all specimens.

$$\mathrm{erf}^{-1}\left(1-\frac{2c_d}{c_1}\right)=1.281 \qquad (6)$$

The test results for all specimens are given i Table 8.

Table 8. Test results from migration tests according to the CTH-method. All tests were done using 40 V as potential difference and a concentration of 2 M Cl^- in the upstream cell.

Identification		**Exposure**		**Test results**		
Sample no	*w/c* ratio	Initial current [mA]	Duration [min]	Penetration depth [mm]	$D_{CTH} \cdot 10^{12}$ [m^2/s]	D_{CTH} [mm^2/year]
C1-1	0.70	169	200	17	39.0	1230
C1-2	0.70	172	200	18	41.5	1309
C2-1	0.60	148	360	26	34.1	1075
C2-2	0.60	148	360	25	32.7	1031
C3-1	0.50	119	660	27	19.3	609
C3-2	0.50	115	660	25	17.8	561
C4-1	0.45	117	735	28	18.0	568
C4-2	0.45	112	735	27	17.4	549
C5-1	0.40	110	960	30	14.9	470
C5-2	0.40	109	960	28	13.8	435
C6-1	0.35	87.2	1020	24	11.0	347
C6-2	0.35	84.9	1020	24	11.0	347
C7-1	0.30	68.4	1440	24	7.83	247
C7-2	0.30	70.0	1440	24	7.83	247

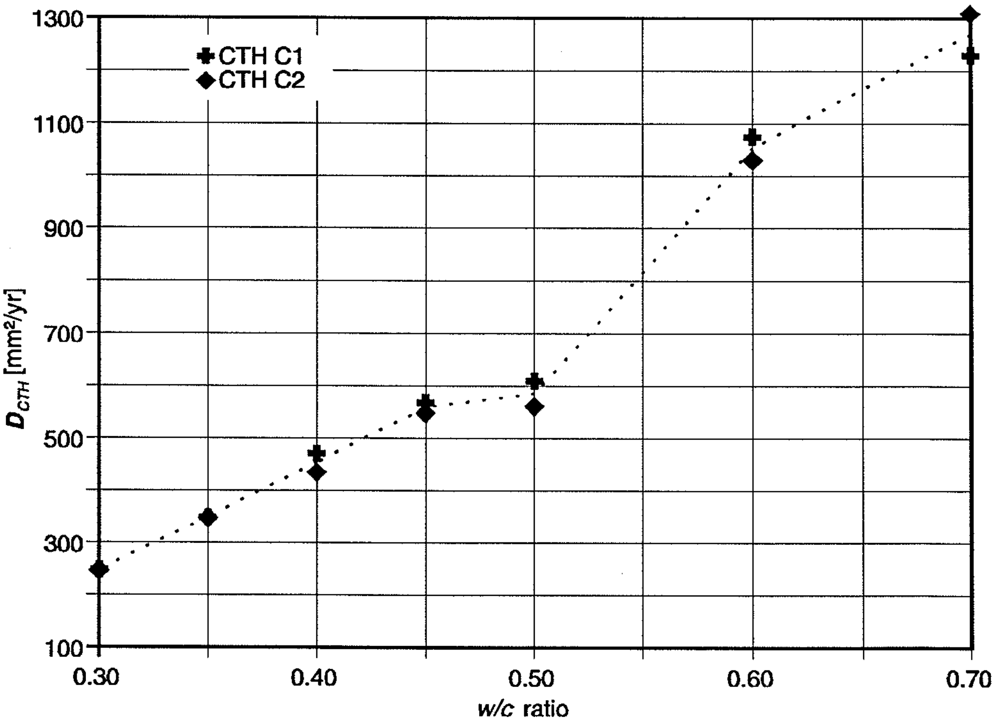


Figure 9. The effect of the w/c ratio on D_{CTH}. The dotted curve represents the mean value.

6 Resistivity tests

This section describes in detail how the resistivity tests were performed and what the test results were. In the appendix all sub-results can be found.

6.1 Samples

The samples for the migration tests were drilled cores taken from the cast concrete prisms as described in Chapter 3. From each core (marked B) two specimens were taken.

6.2 Test period

The tests were performed in the period 1996.01.09 - 1996.07.30.

6.3 Sample preparation

The samples were prepared as shown in principle in Figure 3, Section 3, however the chloride diffusion proof membrane was not applied. The specimens were stored in water at atmospheric pressure until constant weight (mass change less than 0.1 % per day) and an age of 7 days.

After the first measurement the specimens where stored sealed without moisture exchange with the surroundings. Approximately one week before the measurement at 28 days of maturity the specimens were again stored in water at atmospheric pressure until constant weight and the age of 28 days. This procedure was repeated at 80-104 days and at 160-210 days of age.

6.4 Test procedure

At the ages mentioned in the previous Section the prepared samples were placed in the test set-up. Figure 10 illustrates the test set-up in principle.

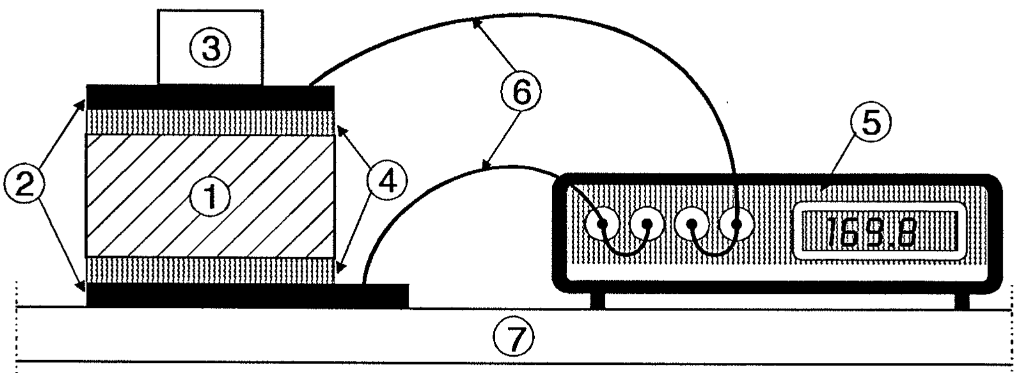


*Figure 10. Sketch of the test set-up for measuring the resistivity of concrete. The numbers refer to: **1.** Concrete sample; **2.** Stainless steel plate; **3.** 1.5 kg load; **4.** Sponge; **5.** Four point resistance meter; **6.** Connecting wires; **7.** Non-metallic table.*

6.5 Results

The dimensions of each specimen was measured using a slide calliper. At each age the resistivity was measured. The resistance of the systems sponge-specimen-sponge and sponge-sponge was measured. The difference is the resistance of the specimen. The resistivity was then calculated using (7)

$$\rho_s = AR/\delta \tag{7}$$

where

ρ_s is the resistivity of the specimen [kΩm]
A is the cross sectional area of the specimen [m^2]
R is the resistance of the specimen [kΩ]
δ is the thickness of the specimen [m]

The test results for all specimens are given i Table 9 and Table 10. The effect of the *w/c* ratio on the resistivity is shown in Figure 11. The resistivity is found to decrease with increasing *w/c* ratio is found.

Table 9. Test results from resistivity tests according to APM 219.

Identification		Dimension	Measurements			
Sample no	*w/c* ratio	Thickness [mm]	Resistance 7 days [kΩ]	Resistivity 7 days [kΩcm]	Resistance 28 days [kΩ]	Resistivity 28 days [kΩcm]
B1-1	0.70	50.42	0.248	3.85	0.285	4.06
B1-2	0.70	49.76	0.232	3.60	0.282	4.04
B2-1	0.60	50.35	0.290	4.51	0.283	4.40
B2-2	0.60	50.20	0.276	4.29	0.263	4.09
B3-1	0.50	51.06	0.309	4.74	0.312	4.79
B3-2	0.50	51.14	0.328	5.04	0.315	4.83
B4-1	0.45	50.29	0.336	5.24	0.332	5.17
B4-2	0.45	50.05	0.335	5.23	0.332	5.18
B5-1	0.40	50.09	0.317	4.96	0.364	5.70
B5-2	0.40	49.31	0.312	4.89	0.367	5.75
B6-1	0.35	49.93	0.372	5.90	0.453	7.13
B6-2	0.35	49.83	0.383	5.97	0.472	7.41
B7-1	0.30	50.15	0.437	6.90	0.582	9.09
B7-2	0.30	50.46	0.411	6.71	0.562	8.80

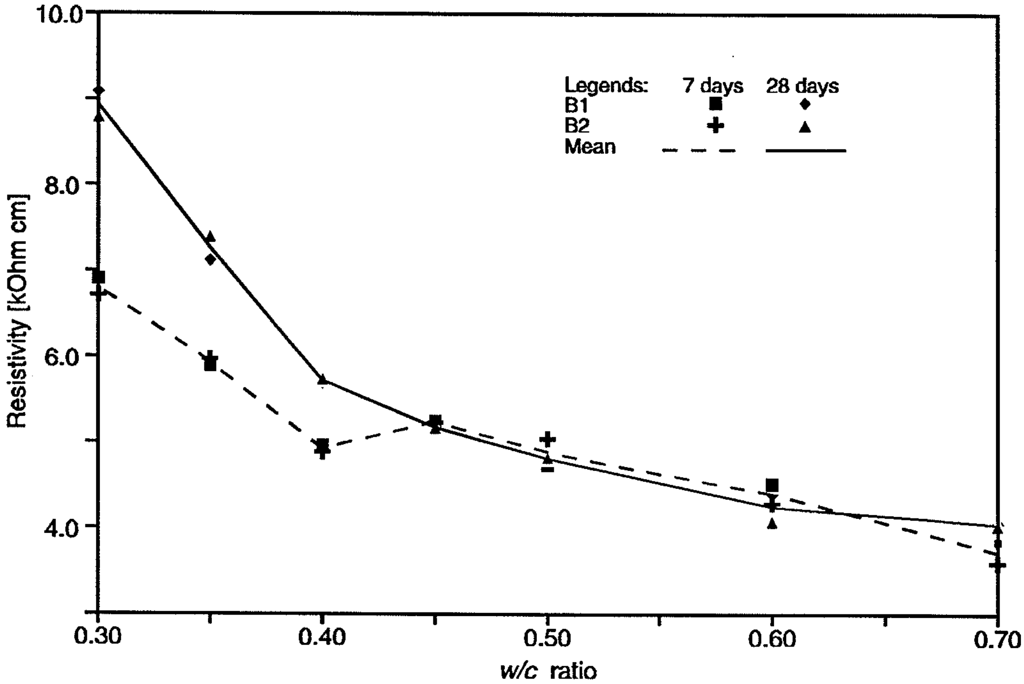


Figure 11. The effect of the w/c ratio on the resistivity. The shape of the curve representing the 7 days measurement is unexpected and cannot be explained at present.

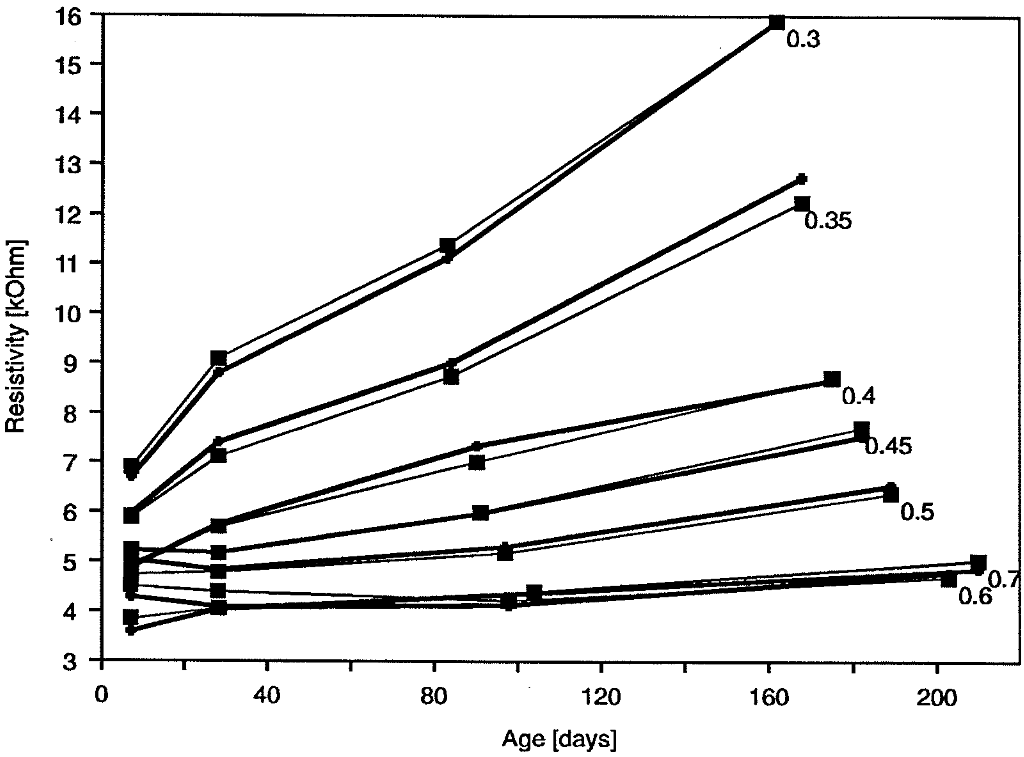


Figure 12. The effect of increasing age on the resistivity for different w/c ratios.

Table 10. Test results from resistivity tests according to APM 219 at different sample ages.

Identification	w/c ratio	Measurement	No. 1	No. 2	No. 3	No. 4
		Age [days]	7.0	28.2	103.9	209.9
B1-1	0.70	Resistivity [kΩcm]	3.85	4.06	4.40	5.03
B1-2	0.70	Resistivity [kΩcm]	3.60	4.04	4.37	4.86
		Age [days]	7.0	28.0	97.8	202.8
B2-1	0.60	Resistivity [kΩcm]	4.51	4.40	4.22	4.69
B2-2	0.60	Resistivity [kΩcm]	4.29	4.09	4.13	4.78
		Age [days]	7.1	28.1	96.9	188.9
B3-1	0.50	Resistivity [kΩcm]	4.74	4.79	5.18	6.38
B3-2	0.50	Resistivity [kΩcm]	5.04	4.83	5.31	6.54
		Age [days]	7.0	28.1	91.0	182.0
B4-1	0.45	Resistivity [kΩcm]	5.24	5.17	6.00	7.72
B4-2	0.45	Resistivity [kΩcm]	5.23	5.18	5.98	7.54
		Age [days]	7.0	28.1	90.0	175.0
B5-1	0.40	Resistivity [kΩcm]	4.96	5.70	7.02	8.72
B5-2	0.40	Resistivity [kΩcm]	4.89	5.75	7.35	8.67
		Age [days]	7.0	28.0	83.8	167.8
B6-1	0.35	Resistivity [kΩcm]	5.90	7.13	8.74	12.25
B6-2	0.35	Resistivity [kΩcm]	5.97	7.41	9.00	12.75
		Age [days]	7.0	28.0	82.9	161.8
B7-1	0.30	Resistivity [kΩcm]	6.90	9.09	11.39	15.90
B7-2	0.30	Resistivity [kΩcm]	6.71	8.80	11.13	15.90

7 Evaluation of results

In this section the results are evaluated and comparison and correlation between the three different methods for quantifying the diffusivity of chloride ions into concrete are discussed.

7.1 Immersion tests

In Figure 13 all the transport parameters determined by NT Build 443 is presented. By a curve fit the relationship between D_{pex} and the *w/c* ratio is found to match (7).

$$D_{pex}=50{,}000\times\exp\left(-\sqrt{\frac{10}{w/c}}\right) \qquad (7)$$

It is also seen in Figure 13 that the relationship between the penetration parameter $K_{0.05}$ and the *w/c* ratio can be approximated by a straight line.

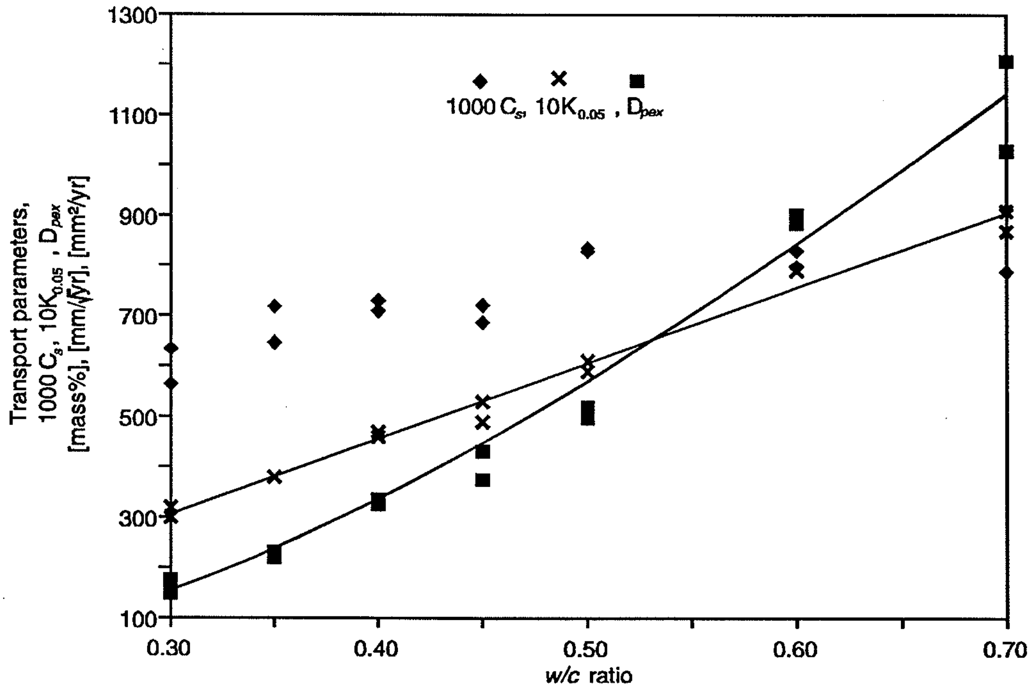


Figure 13. The effect of the w/c ratio on the transport parameters determined by NT Build 443.

7.2 Estimation of chloride binding using the immersion test

The boundary condition for the chloride profiles, C_s, measured after exposure acc. to NT Build 443 can physically be understood as a property depending on the binding capacity of the concrete material. Each specimen respond differently to the exposure conditions in NT Build 443 but a trend of a somewhat lower C_s-value the lower the *w/c* ratio is seen, cf. Figure 13.

The value of C_s in the testing acc. to NT Build 443 depends primarily on the concentration of the exposing liquid, on the porosity of the concrete and on the binding capacity of the cement gel. As the porosity of concrete is dependent on the volume and the porosity of the cement paste, these are important parameters. Almost the same volume of cement paste was obtained in all the concretes.

The binding capacity of the cement gel is proportional to the amount of gel, i.e. it is proportional to the cement content and the degree of hydration. The *w/c* ratio consequently should have an effect on the binding capacity and the value of C_s.

The found effect of *w/c* is predictable. A prediction was performed using the Freundlich binding isotherm by assuming no leaching. This is reasonable because the value of C_s is the response from the concrete interior to the external chloride source and because it is assumed that no significant leaching took place during the 5 weeks of exposure acc. to NT Build 443. The result of the prediction is presented in Table 11 and in Figure 13.

Table 11. Calculated and measured values of the surface chloride content of concrete. The calculated values were calculated using the Freundlich binding isotherm included in the ClinConc model for chloride ingress into concrete. The calculations were performed assuming no leaching of alkalies. In order to get no leaching the pH values given in the table were used. The densities of dry concrete were estimated on basis of the estimated degrees of hydration and the measured densities of fresh concrete. The results are shown graphically in Figure 13.

w/c ratio	ρ_w [kg/m³]	α	ρ_d [kg/m³]	Cement [kg/m³]	Ph	ClinConc estimates [% mass cement]	ClinConc estimates [% mass concrete]	NT Build 443 results [% mass concrete]	
0.30	2440	0.50	2375	434	13.90	2.8	0.512	0.565	0.634
0.35	2410	0.55	2347	398	13.80	3.5	0.593	0.646	0.718
0.40	2410	0.60	2350	374	13.70	4.2	0.668	0.709	0.730
0.45	2380	0.65	2325	348	13.70	4.5	0.673	0.721	0.687
0.50	2370	0.70	2321	327	13.60	5.0	0.704	0.836	0.829
0.60	2350	0.75	2306	292	13.55	5.8	0.734	0.798	0.830
0.70	2360	0.80	2323	265	13.45	6.9	0.787	0.913	0.788

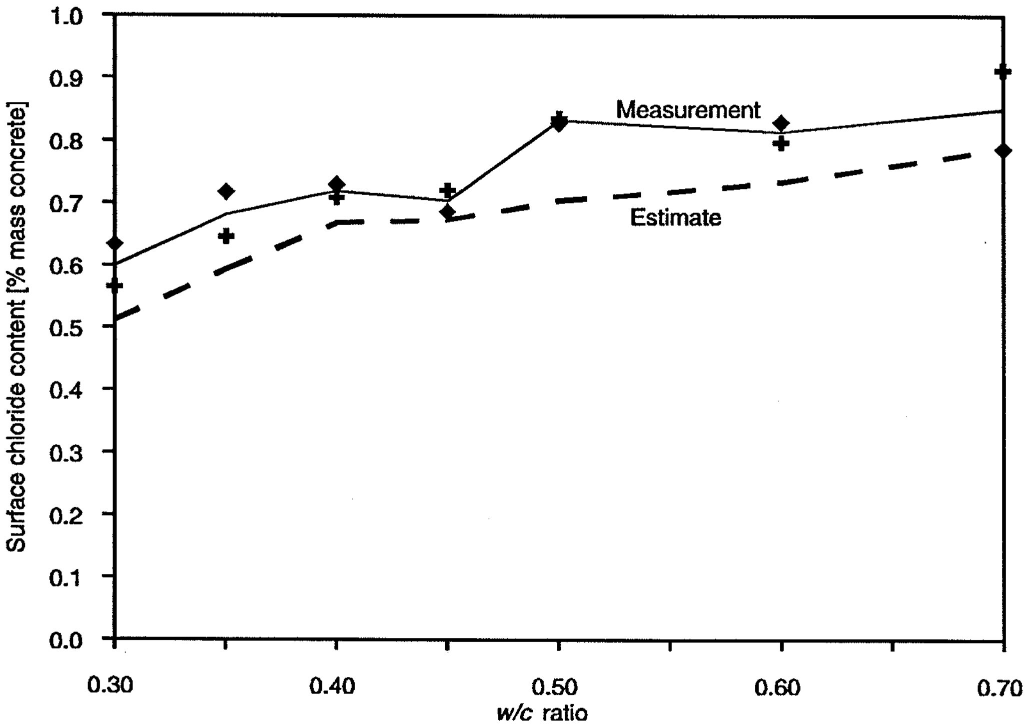


Figure 13. The effect of the w/c ratio on the surface chloride concentration measured according to NT Build 443 and calculated by use of the mathematical model for chloride ingress into concrete ClinConc.

As it is the case that the boundary condition can be calculated with a convincing precision the value of C_s also can be used to estimate a point on the binding isotherm when no better information is available. This is valuable for the prediction of chloride ingress.

7.3 An alternative to the immersion test

The CTH-method force the transport of chloride into concrete by using an electrical field. Because the results from the method is not electrical terms but a mass transport coefficient like the one obtained with NT Build 443 it is a strong alternative to the more slow immersion test.

In Figure 14 the correlation between results of the CTH-method and the results of NT Build 443 is shown. An almost straight line correlation is found in the *w/c* range from 0.30 to 0.70.

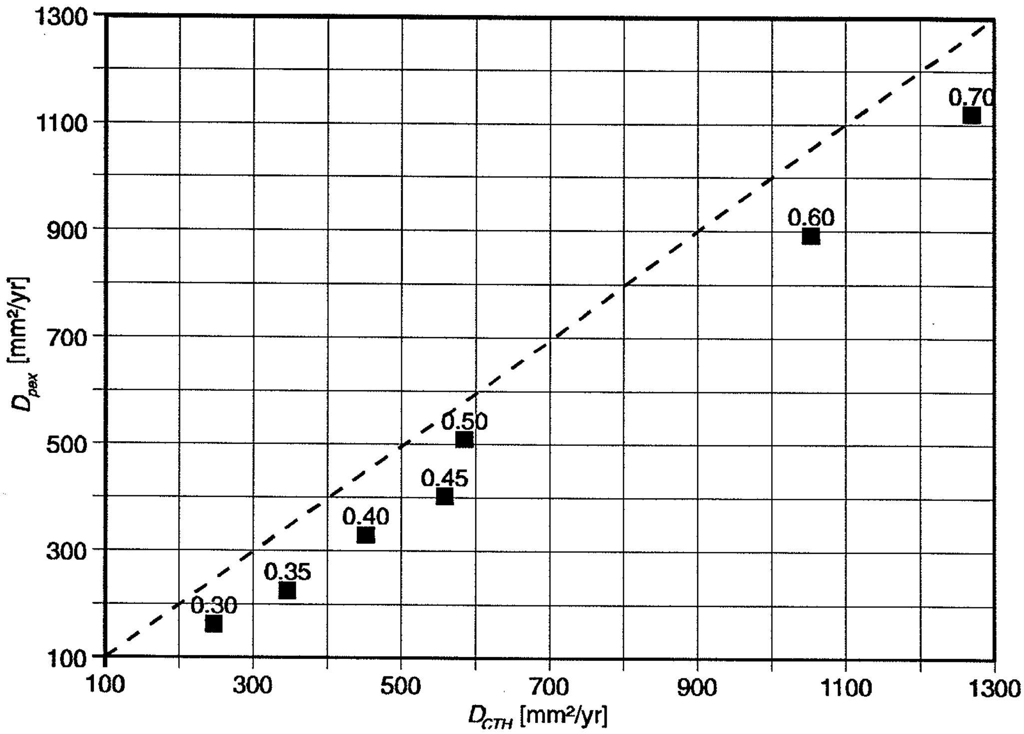


Figure 14. The correlation between D_{CTH} determined acc. to the CTH-method and D_{pex} determined acc. to NT Build 443 for different w/c ratios.

The D_{pex} and the D_{CTH} are not identical and should not be expected to be, since they are by definition two different diffusion coefficients. The difference is because:

- Different portions of the chloride binding capacity are active in the two tests.
- The chloride concentration in the test solutions are quite different.
- The age during the test is somewhat different: 28-63 days for NT Build 443 and 28-29 days in the CTH-method.

In spite of these differences, the close correlation may be utilized for using either method to obtain a diffusion coefficient.

7.4 Early measurements

In production control fast and early response to the quality is preferable. For this reason the correlation between the resistivity at 7 days and 28 days of hardening was measured. The correlation between the results at these two ages is shown in Figure 15.

The correlation is good in the *w/c* range from 0.30 to 0.40 where some effect of increasing age is found too. However, some scatter in predicting the 28 days value on basis of the 7 days value must be expected.

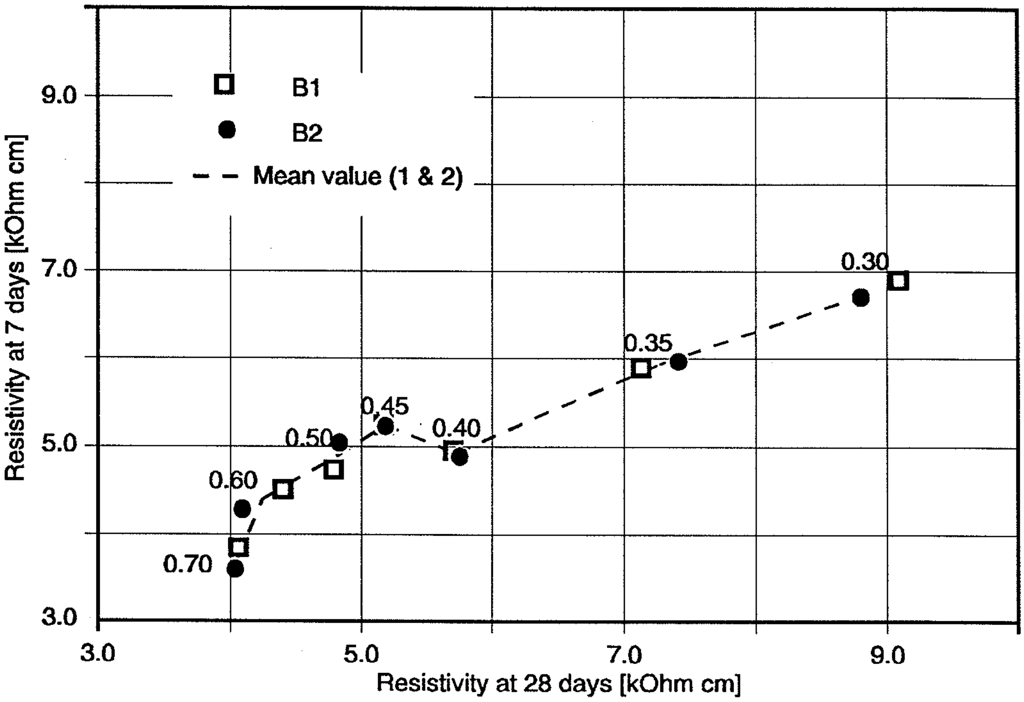


Figure 15. The correlation of the resistivity at 7 days and 28 days for different w/c ratios.

7.5 A substitute for the diffusivity measure

Due to the costs and the time consumption of the diffusivity test acc. to NT Build 443 it is preferable to find a substitute and reliable method to use for quality control (uniformity control). In this investigation two alternative methods have been tested, i.e. the CTH-method and APM 219. The latter is regarded as the most simple and the most inexpensive to perform.

Results from both NT Build 443 and the CTH-method showed an increasing diffusivity with increasing *w/c* ratio while the results of APM 219 showed a decreasing resistivity with increasing *w/c* ratio. This could be overcomed simply by presenting the results of APM 219 as the reciprocal of the resistivity, i.e. the conductivity.

$$\sigma_s = 1/\rho_s \tag{8}$$

In Figure 16 the dependence upon the D_{pex} and D_{CTH} of the conductivity acc. to APM 219 and (8) is shown.

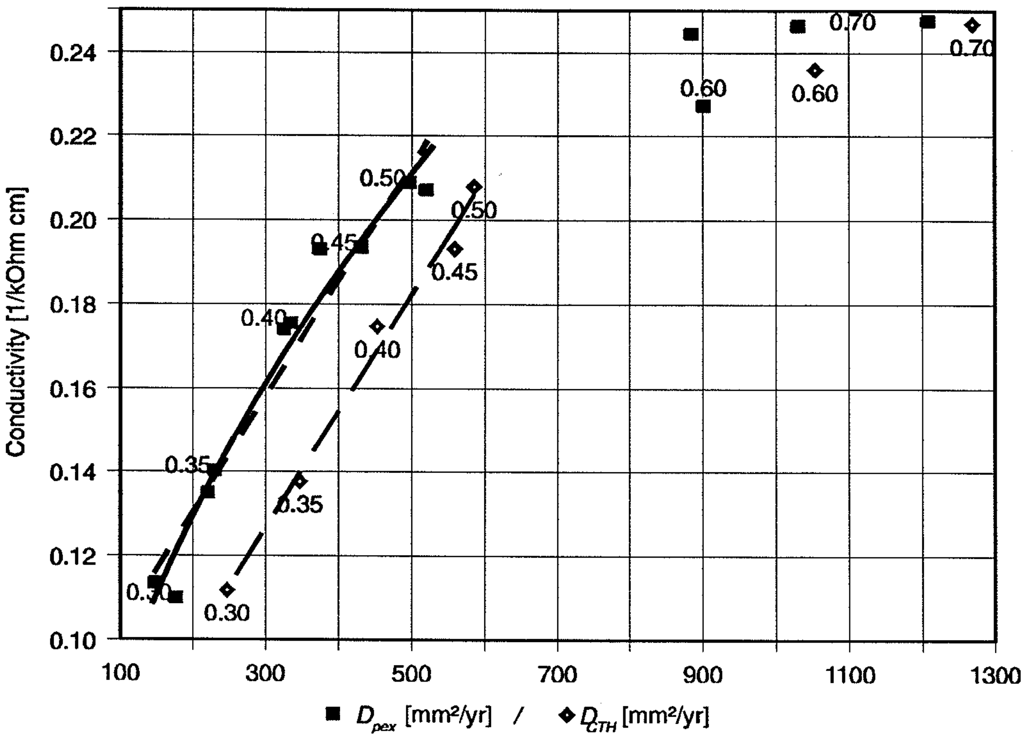


Figure 16. The relationship between the conductivity acc. to APM 219 and the diffusivity acc. to NT Build 443 and the CTH migration test.

In Figure 16 an approximately straight lined relation between both APM 219/-NT Build 443 and APM 219/CTH migration test. The straight lines are almost parallel (the deviation between the x-coefficients is 0.25%), but the relation between APM 219 and NT Build 443 seems to be more like a √-dependency of the type given by (9):

$$\sigma_s = a \times \sqrt{D_{pex}} - b \tag{9}$$

where a = 0.099 and b = -0.108.

7.6 The compressive strength as a quality measure

The *w/c* ratio is the most important quality parameter of concrete. There is no doubt that some relation exists between the *w/c* ratio and the compressive strength, cf. Figure 4, Section 3. For non air-entrained concretes as in this investigation the relationship between the *w/c* and the compressive strength is fairly simple.

As shown in Figure 17 the diffusivity D_{pex} acc. to NT Build 443 consistently decrease with increasing compressive strength. An interesting question is how air entrainment will affect the diffusivity. Air-entrainment will reduce strength if all other parameters are unchanged. If the concretes in this investigation were air entrained the strength would decrease, but would the diffusivity change?

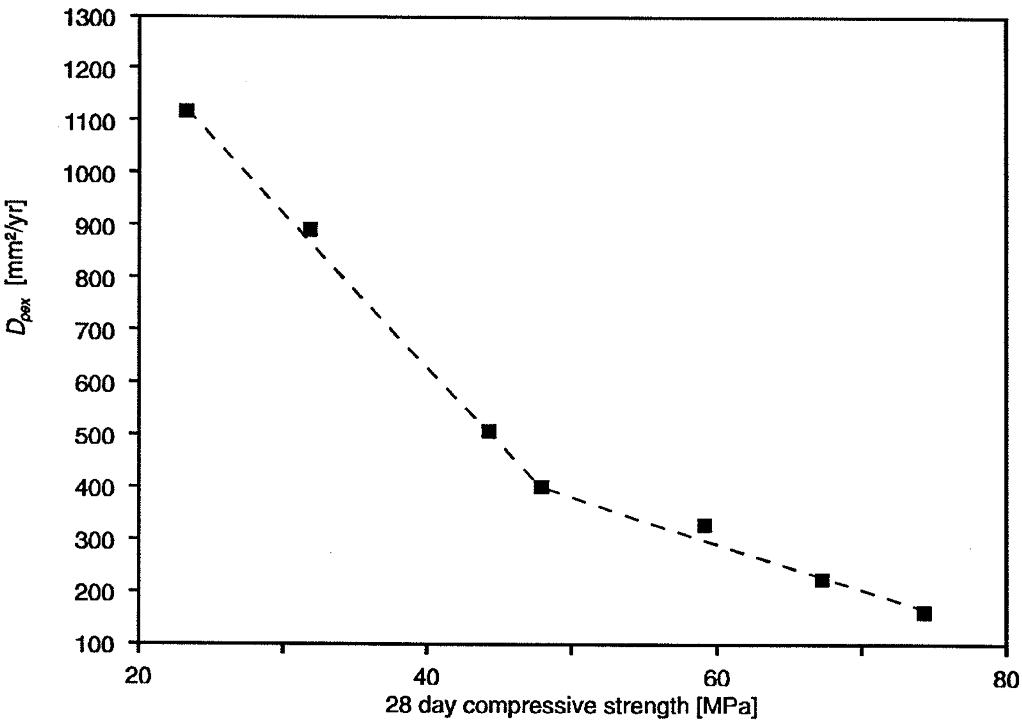


Figure 17. The relationship between the 28 day compressive strength and the diffusivity acc. to NT Build 443. It should be noted that the concrete is not air entrained.

8 Conclusions

Based on the investigations presented in this report the following conclusions are drawn:

8.1 NT Build 443 and the CTH-method

- A monotonous relationship between the transport parameters, D_{pex} and $K_{0.05}$ determined from NT Build 443 and the *w/c* ratio exists, cf. Figure 17, Section 7.
- A monotonous relationship between the transport parameters, D_{CTH} determined by the CTH-method and the *w/c* ratio exists, cf. Figure 9 in Section 5.
- An almost proportional relation exists between the NT Build 443 and the CTH-method, cf. Figure 14, Section 7.
- The results from the NT Build 443 and the CTH-method seems to reliably distinguish potential diffusivity of non air-entrained concrete without puzzolanas no matter what the *w/c* ratio is in the range from 0.30 to 0.70.
- Because of no air-entrainment in all of the mixes a simple relation exists between the *w/c* ratio and the compressive strength (cf. Figure 4 in Section 3) and thus also between the D_{pex} (or D_{CTH}) and the 28 day compressive strength, cf. Figure 17 in Section 7. For air entrained concretes this relation may become less clear, but this is still to be investigated.

8.2 APM 219

- A relationship exists between the electrical resistivity and the *w/c* ratio. As expected the electrical resistivity of water saturated concrete tends to decrease with increasing *w/c* ratio both for resistivities measured at 7 and 28 days of age.
- For low water/cement ratios between 0.30 and 0.40 it is possible (but with some uncertainty) to distinguish the difference in sample age based on resistivity values.
- The possibility of using the resistivity measure in production control as a substitute for the diffusivity measure is obvious.

HETEK

The effect of the *w/c* ratio on chloride transport into concrete

Appendices

Report No. 54
1996

AALBORG PORTLAND, Cement- og Betonlaboratoriet Den, 960320

Prøvenr. 0113856 Arkiv nr. K109 Udt.sted HUADIV

Prøvemærkning cement: (PC(A/HS/EA/G)) - 5 kg.

Kommentarer

Prøvetilstand [X] Prøve som modtaget [ ] Tørret prøve [ ] Glødet prøve

H_2O, 105 °C	%		Moduler og mineraler				TiO_2	%	0,15
SiO_2	%	23,79	KM		%	89,9	P_2O_5	%	
Al_2O_3	%	3,07	SiM			4,28	MnO	%	
Fe_2O_3	%	2,49	AlM			1,23	Cl^-	%	0,006
CaO	%	66,10		ASTM		ASTM,korr.	CO_2	%	
MgO	%	0,68	C_3S		%	53	Korr.glødetab	%	
SO_3	%	2,14	C_2S		%	28	Vandopl. chromat		
Glødetab	%	0,78	C_3A	3,9	%	3,9	Egenfarve	mg/kg	0,6
Sum	%		C_4AF	7,6	%	7,6	DS 1020	mg/kg	
Uopl. rest	%	0,06	$CaSO_4$	3,6	%	3,6	Red.kap.	mg Cr^{+6}/kg	
Flyveaske	%		Fri Kalk		%	1,29	Abs.densitet	kg/m³	3150
Syreopløselig alkali							Kornkurve		
K_2O	%	0,17	K_2O		%		Elrepho		
Na_2O	%	0,20	Na_2O		%		Refleksion	%	
Na_2O ækv.	%	0,31	Na_2O ækv.		%		Dom. bølgel.	Å	
							Mætningsgrad	%	

Blaine	m²/kg	359	Vand til NK	%	23,4
Sigterest			Beg. bindetid	min.	130
0,20 mm	%		Slut bindetid	timer,min.	3,00
0,09 mm	%		le Chatelier	mm	0,0
0,063 mm	%		Autoklavekspansion	%	
0,045 mm	%		Pack set indeks		
0,045 mm våd	%		Tusschenbroeck / /	mm efter 5/10/15 min.	
False set ASTM C 359, 180 mL			/ / / /	mm efter init/5/8/11 min./remix	
False set ASTM C 359, 192 mL			/ / / /	mm efter init/5/8/11 min./remix	

Trykstyrke		1 døgn	2 døgn	7 døgn	28 døgn		
EN 196	MPa	9,6	18,6	36,0	54,9		
ASTM	MPa						

Kopifordeling: DB

Peramin F

ANALYSECERTIFIKAT

KUNDE	A.E.C. Rådgivende Ingeniører A/S
LEV. DATO	1995 12 19
LEV. MÆNGDE	30 kg
KONTROLAFSNIT	95472100
PRODUKTIONSDATO	1995 11 21
ANVENDES INDEN	1996 11 21

ANALYSEVÆRDIER

Densitet ved 20°C	1.209 kg/l
Tørstofindhold	33.6 %
Ækvivalent Na_2O	4.25 %
Chloridindhold	<0.001
pH-værdi	11.5

DEKLAREREDE EGENSKABER

EGENSKAB	VÆRDI	METODE
Densitet ved 20°C	1.210 ± 0.020 kg/l	DS/ISO 758
Tørstofindhold	34.0 ± 1.5 %	ASTM C 494/86
Ækvivalent Na_2O	< 5.00 %	DS 258
Chloridindhold	< 0.050 %	DS 239
pH-værdi	10.5 ± 1.0	DS 287

18/12-95
Dato

Lis N. Pedersen
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nordtest method

NT BUILD 443
Approved 1995–11

CONCRETE, HARDENED:
ACCELERATED CHLORIDE PENETRATION

UDC 622.43

Key words: Test method, hardened concrete, chloride penetration, non-steady state diffusion

1 SCOPE

This Nordtest method specifies a procedure for the determination of penetration parameters for estimating the resistance against chloride penetration into hardened concrete or other cement-based materials.

The resistance against chloride penetration is determined by accelerated testing.

2 FIELD OF APPLICATION

The method is applicable to test specimens from existing structures and to new samples older than 28 maturity-days. The concrete test specimens must be free from construction faults such as cavities and visible cracks.

It is important to keep in mind that the values for the chloride penetration parameters are dependent on concrete maturity. Especially concretes containing pozzolans will not have reached optimum maturity after a period of 28 maturity-days, which is the specified minimum curing time before exposure.

Deviations from the requirements of the method concerning exposure temperature, exposure time, together with the composition and the chloride concentration of the exposure liquid, can be made where required by the purpose of the test. In case of any deviations, it must be stated in the test report that the results are obtained from a modified test and the deviations must be specified.

Parameters of importance for the resistance against chloride penetration are e.g. composition, workmanship, surfacing, curing, age.

3 REFERENCES

NT BUILD 202, 2nd ed. Approved 1984-05. Concrete, hardened: Sampling and treatment of cores for strength tests.

NT BUILD 208, 2nd ed. Approved 1984-05. Concrete, hardened: Chloride content.

4 DEFINITIONS

Chloride penetration: The ingress of chlorides into concrete due to exposure to external chloride sources.

Exposure temperature: The temperature of the exposure liquid while the test specimen is submerged in it.

Exposure time: The time from immersion of the test specimen in the exposure liquid to profile grinding.

Profile grinding: Grinding off concrete powder in thin successive layers from a test specimen using a dry process.

Maturity-day: A concrete of 28 maturity-days has developed a maturity corresponding to curing for 28 days at 20 °C.

Surface-dry condition: Is achieved by drying the water-saturated test specimen with a clean cloth or similar leaving the test specimen damp but not wet. This is achieved by wetting the cloth with the liquid in which the test specimen has been immersed and then wringing it out sufficiently to absorb any liquid adhering to the surface of the specimen.

5 SAMPLING

This method requires drilled cores or cast cylinders as test specimens. They must be representative of the concrete and/or structure in question. The concrete must be hardened to minimum 28 maturity-days. At least three test specimens should be used in the test. The diameter should be at least ∅75 mm, but not less than 3 lines the maximum aggregate size. The length should be minimum 100 mm.

6 METHOD OF TEST

6.1 Principle

A water-saturated concrete specimen is on one plane surface exposed to water containing sodium chloride. After a specified exposure time thin layers are ground off parallel to the exposed face of the specimen and the chloride contant of the layers, C_x, is measured. The original (initial) chloride content of the concrete, C_i, is measured at a suitable depth below the exposed surface. The effective chloride transport coefficient, D_e, and the boundary condition of the chloride profile at the

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exposed surface, C_s, are calculated. This is done by using the related values of measured depth below the exposed surface, x, and measured chloride content, C_x.

The penetration parameter, K_{C_r}, is calculated for a selected chloride concentration, C_r. The influence of D_e, C_s, C_i, and C_r is combined in the calculation of K_{C_r}, which facilitates comparison of the results.

6.2 Reagents and apparatus

6.2.1 Reagents

- Redistilled or demineralised water.
- Calcium hydroxide ($Ca(OH)_2$), technical quality.
- Sodium chloride (NaCl), technical quality.
- 2-component (chloride-ion diffusion-proof) polyurethane or epoxy-based paint (membrane).
- Chemicals for chloride analysis according to applied test method.

6.2.2 Apparatus

- Water-cooled diamond saw.
- Balance, accuracy better than ±0.01 g.
- Thermometer, accuracy better than ±1 °C.
- Temperature controlled cupboard.
- Plastic container with tight-fitting lid.
- Equipment for grinding off and collecting concrete powder from thin concrete layers (less than 2 mm).
- Equipment for crushing concrete.
- Standard sieve, mesh width 1.0 mm.
- Equipment for chloride analysis according to applied test method.
- Slide caliper, accuracy better than ±0.1 mm.

6.3 Preparation of test samples

From each of the concrete cones or concrete cylinders, the parts 6.3.1 and 6.3.2 specified below are cut off by means of a water-cooled diamond saw.

6.3.1 Test specimen for exposure in NaCl solution

If a drilled core is used, the test specimen is prepared by cutting off the outermost approx. 70 mm of the core. A test specimen is thus obtained, of which one end face is the original surface and the other is a sawn face. The outermost approx. 10 mm is then cut off the original concrete surface (note 1), and the resulting sawn surface is exposed in the NaCl solution.

Note 1: It is very important that the test is made on the concrete between the surface and the layer of reinforcement because it is here that the protection against chloride penetration is needed. Furthermore, the quality of the concrete in this particular area can deviate from the rest of the concrete. The outermost approx. 10 mm of concrete is removed to ensure that the measurement is made in an area with an approximately constant cement matrix content.

If a cast cylinder is used, the test specimen is prepared by dividing the cylinder into halves by a cut perpendicular to the axis of the cylinder. One half is used as test specimen, with the sawn surface exposed in the NaCl solution.

The test specimen is immersed in a saturated $Ca(OH)_2$ solution at about 23 °C in a tightly closed plastic container. The container must be filled to the top to minimize carbonation of the liquid. The next day the mass in surface-dry condition (m_{sd}) is determined by weighing the test specimen.

The storage in the saturated $Ca(OH)_2$ solution continues until m_{sd} does not change by more than 0.1 mass % per 24 hours.

All faces of the test specimen except the one to be exposed are then dried at room temperature to a stable white-dry condition and given an approx. 1 mm thick epoxy or polyurethane coating. Precautions must be taken to ensure that no coating material gets onto the surface to be exposed. It must be ensured that the method of application and hardening prescribed by the supplier of the coating material is observed.

When the coating has hardened, the test specimen is immersed in the $Ca(OH)_2$ solution until m_{sd} stabilizes as described above.

6.3.2 Slice of at least 20 mm thickness

From the remainder of the drilled core or cast cylinder a slice of at least 20 mm thickness is cut in extension of test specimen 6.3.1.

6.4 Procedure

6.4.1 Exposure liquid

An aqueous NaCl solution is prepared with a concentration of 165 g ± 1 g NaCl per dm^3 solution. This exposure liquid is used for 5 weeks and then replaced by a new pure NaCl solution. The NaCl concentration of the solution must be checked at least before and after use.

6.4.2 Exposure temperature

The temperature of the water bath must be 21–25 °C with a target average temperature of 23 °C. The temperature must be measured at least once a day.

6.4.3 Exposure

The $Ca(OH)_2$ solution in the container used for water saturation is replaced with the exposure liquid and the test specimen 6.3.1 is immersed in surface-dry condition in the saline solution. It is important that the container is completely filled with the exposure liquid and closed tightly. The ratio between the exposed area in cm^2 and the volume of exposure liquid in dm^3 shall be minimum 20 and maximum 80. The container is placed in the temperature controlled cupboard during exposure. The exposure shall last for at least 35 days, and the container is shaked once every week. The date and time of exposure start and exposure stop is recorded.

6.4.4 Profile grinding

The chloride profile is measured immediately after the exposure by grinding off material in layers parallel to the exposed surface. The grinding is performed within a diameter approx. 10 mm less than the full diameter of the core. This obviates the risk of edge effects and disturbances from the coating.

At least eight layers must be ground off. The thickness of the layers must be adjusted according to the expected chloride profile, so that minimum 6 points covers the part of the profile between the exposed surface and the depth with a chloride content of C_i + 0.03 mass %. However, the outermost layer must always have a thickness of minimum 1.0 mm.

It must be ensured that a sample of at least 5 g of dry concrete dust is obtained from each layer. For each sample of concrete dust collected, the depth below the exposed surface is calculated as the average of five uniformly distributed measurements using a slide caliper.

6.4.5 Chloride analysis

The acid-soluble chloride content of the samples is determined to three decimals in accordance with NT BUILD 208 or by a similar method with the same or better accuracy. The accuracy must be documented.

6.4.6 Initial chloride content

From the concrete slice 6.3.2, a representative subsample of approx. 20 g is prepared, e.g. by crushing until the material passes a 1 mm standard sieve, followed by splitting. The acid-soluble chloride content of the subsample is determined to three decimals by using the method described in 6.4.5. The measured chloride content is the initial chloride content of the specimen, C_i.

6.5 Expression of results

6.5.1 Test results

The values of C_s and D_e are determined by fitting the equation (1) to the measured chloride contents by means of a non-linear regression analysis in accordance with the method of least squares fit. The first point of the profile determined from the sawn face is omitted in the regression analysis. The other points are weighted equally.

$$C(x,t) = C_s - (C_s - C_i) \cdot \operatorname{erf}\left(x/\sqrt{4 \cdot D_e \cdot t}\right) \qquad (1)$$

where

$C(x,t)$ [mass %] is the chloride concentration, measured at the depth x at the exposure time t

C_s [mass %] is the boundary condition at the exposed surface

C_i [mass %] is the initial chloride concentration measured on the concrete slice 6.3.2

x [m] is the depth below the exposed surface (to the middle of a layer)

D_e [m²/s] is the effective chloride transport coefficient

t [s] is the exposure time (with an accuracy better than 5 hours)

erf is the error function defined in (2)

$$\operatorname{erf} z = 2/\sqrt{\pi} \cdot \int_0^z \exp(-u^2)\,du \qquad (2)$$

Tables with values of the error function are given in standard mathematical reference books.

The penetration parameter, K_{C_r}, is calculated using the values of C_i [mass % of concrete], C_s [mass % of concrete], D_e [m²/s], and C_r [mass % of concrete] (note 2) according to (3). The C_r-value is set to 0.05 mass % unless another value is required.

$$K_{C_r} = 2\sqrt{D_e} \cdot \operatorname{erf}^{-1}\left(\frac{C_s - C_r}{C_s - C_i}\right) \qquad (3)$$

Note 2: In (3) C_r is a selected reference chloride concentration. Note that K_{C_r} only is defined when $C_s > C_r > C_i$.

The test results are:

- The initial chloride concentration, C_i, stated to three decimals in mass % of dry concrete.
- The boundary condition at the exposed surface, C_s, stated to three decimals in mass % of dry concrete.
- The effective chloride transport coefficient, D_e, stated to two significant digits in m²/s.
- The penetration parameter, K_{C_r}, stated to two significant digits in mm/√year. The C_r-value used to calculate K_{C_r} must be clearly stated in the test report.

Please note that the values of C_s and D_e should not be directly used for prediction of chloride penetration under conditions other than those used in the test. (If K_{C_r} is calculated in the unit mm/√s it is multiplied by $5.6157 \cdot 10^6$ to translate the unit to mm/√year.)

6.5.2 Other information of importance

- The measured chloride contents at all points are plotted versus the depths below the exposed surface. The curve for the optimized mathematical model (1) is plotted on the same graph (See Figure 1).
- The correlation between the measured chloride contents and the corresponding chloride contents calculated according to (1) is determined by means of a linear regression analysis.
- The average exposure temperature is calculated. The variation must be illustrated, e.g. by giving the measured temperature curve.
- The average chloride concentration of the exposure liquid is calculated.

6.6 Accuracy

The following variation coefficients (the standard deviation divided by the mean value) can be expected:

C_s = 20 %, D_e = 15 % and $K_{0.05}$ = 10 %

6.7 Test report

The test report shall include the following information, if relevant:

a) Name and address of the test laboratory, and the place at which the tests were performed if different from the laboratory address.

b) Date and identification number of the test report.

c) Name and address of the organisation or person who ordered the test.

d) Purpose of the test.

e) Method of sampling and other circumstances (date and person responsible for the sampling).

f) Name and address of the manufacturer or supplier of the tested object.

g) Name or other identification marks of the tested object.

h) Description of the tested object including the age of the test specimen.

i) Date of supply of the tested object.

j) Date of the test.

k) Test method.

l) Conditioning of the test specimens, environmental data during the test (temperature, chloride concentration in exposure liquid, etc.)

m) Identification of the test equipment and instruments used.

n) Any deviations from the test method together with other information of importance for judging the result.

o) Test results.

p) Inaccuracy or uncertainty of the test result.

q) Date and signature.

A.1 NON-LINEAR REGRESSION ANALYSIS

The regression analysis is performed by minimising the sum given in (A.1)

$$S = \sum_{n=2}^{N} \Delta C^2(n) = \sum_{n=2}^{N} (C_m(n) - C_c(n))^2 \qquad \text{(A.1)}$$

where

S	[(mass %)^2]	is the sum of squares to be minimized
N	[-]	is the number of concrete layers ground off
$\Delta C(n)$	[mass %]	is the difference between the measured and the calculated chloride concentration of the n'th concrete layer
$C_m(n)$	[mass %]	is the measured chloride concentration of the n'th concrete layer
$C_c(n)$	[mass %]	is the calculated chloride concentration in the middle of the n'th concrete layer

Refer to Figure 1 for clarification.

A.2 BACKGROUND INFORMATION

Frederiksen, J. M.: "APM 302 - dansk målemetode for chloridindtrængning i beton" (APM 302 - Danish test method for chloride penetration into concrete). Dansk Beton, No. 2, p. 22-27, 1992. (In Danish.)

Sørensen, H. E.: "Determination of chloride penetration parameters for concrete". Nordtest project 1154-94, Nordtest, SF-02151 ESPOO.

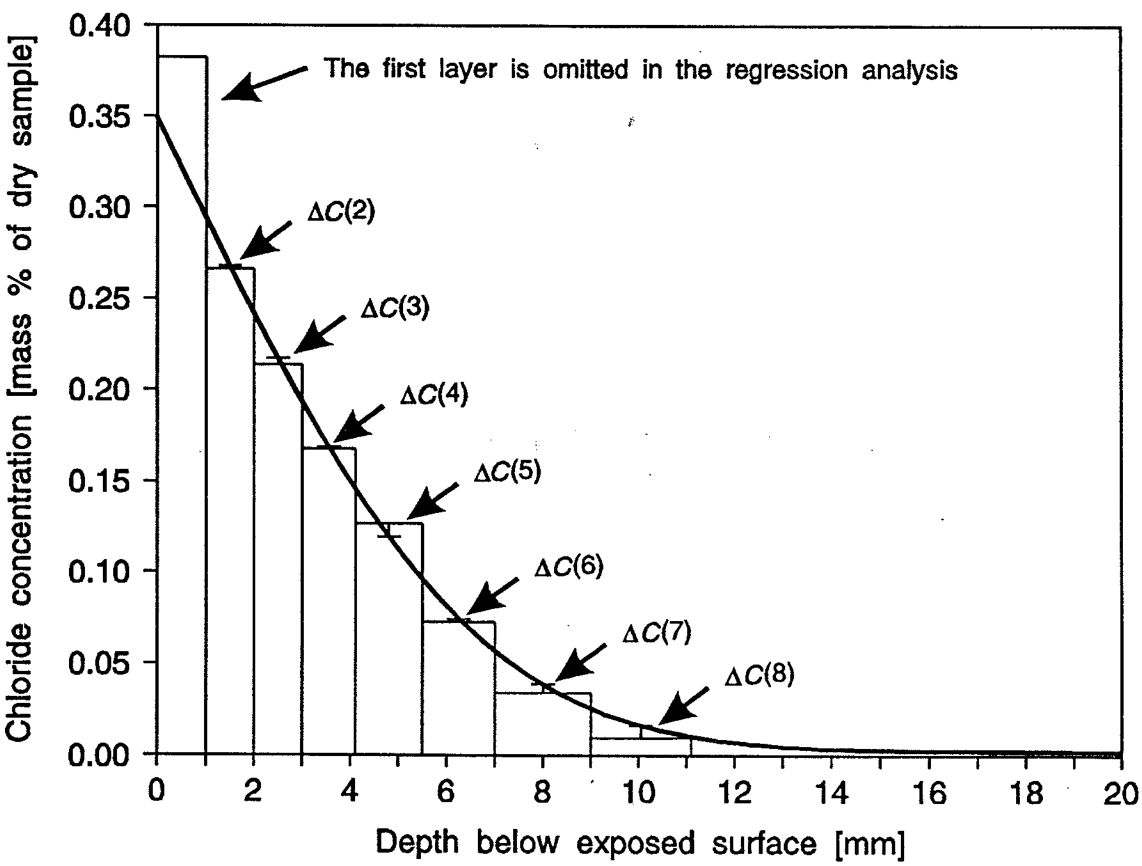

Figure 1. The regression analysis. The bars represent the measured chloride contents. The curve represents the optimized mathematical model.

Recommended Procedure for Determination of Chloride Diffusion Coefficient by Using CTH Rapid Method

(April 1996, 2 nd draft)

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1. SCOPE

1.1 This procedure is for the determination of chloride diffusion coefficient in aged ordinary concrete specimens.

2. APPARATUS

2.1 Vacuum Saturation Apparatus

2.1.1 Vacuum container: capable of containing at least one piece of rubber sleeve assembled with specimen and clampers (Ref. 2.2.1, 2.2.2 and 4.1.1).
2.1.2 Vacuum pump: capable of maintaining a pressure of less than 10 mmHg (1.33 kPa) in container.

2.2 Potential Supply Apparatus

2.2.1 Rubber sleeve: 150 mm long, cut from a ∅115/100 mm (outer/inner) multi-layer silicon rubber pipe.
2.2.2 Clamper: ∅115×20 mm stainless steel (see Fig. 1).
2.2.3 Catholyte reservoir: 370×270×280 mm (L×W×H) plastic box.
2.2.4 Plastic support: (see Fig. 2).
2.2.5 Cathode: 0.5 mm thick stainless steel plate (see Fig. 2).
2.2.6 Anode: 0.5 mm thick stainless steel plate (see Fig. 3).
2.2.7 Power supply: capable of supplying a voltage of 60 VDC and a current of 1 A.

2.3 Specimen Splitting Equipment

2.3.1 Any hydraulic splitting device with a capacity of 10 tons.

3. REAGENTS

3.1 Catholyte

3.1.1 10% NaCl in 0.1 M Na/K(OH) solution (NaOH/KOH = 1).

3.2 Anolyte

3.2.1 0.3 M Na/K(OH) solution (NaOH/KOH = 1).

3.3 Silver nitrate solution

3.3.1 0.1 N $AgNO_3$ solution, stored in a spray bottle.

4. SPECIMENS AND PRECONDITIONING

4.1 Specimens

4.1.1 Shape and size: cylinder samples with a diameter of 100 mm and thickness of 50 mm, drilled from the structure or cast in a special mould.

4.2 Conditioning

4.2.1 Assemble specimen in rubber sleeve and tight it with two clampers to prevent the leakage through the curved surface (see Fig. 3).
4.2.2 Place specimen in vacuum container and fill both container and the top side of specimen with anolyte up to a certain level.
4.2.3 Seal container and start vacuum pump. Pressure should decrease to less than 10 mmHg (1.33 kPa) within a few minutes.
4.2.4 Maintain vacuum for 6 hours and then allow air to reenter container.
4.2.5 Keep both sides of specimen suck anolyte for about 18 hours more.

5. TEST PROCEDURE

5.1 Potential applying

5.1.1 Empty the solution from the top side of specimen, transfer specimen to catholyte reservoir and set it on plastic support (see Fig. 5).
5.1.2 Put anode and fill 500 ml anolyte in the top side of specimen.
5.1.3 Connect cathode to negative pole and anode to positive pole of power supply. Turn on the power, set to 30 ±0.2 V, and record initial current with a 3½-digit multimeter.
5.1.4 Chose a proper test duration according to initial current (see Table 1).
5.1.5 Record final current before terminate test.

5.2 Penetration depth measuring

5.2.1 Take away anode and empty the solution from the top side of specimen.
5.2.2 Take off specimen from rubber sleeve by means of wooden rod, and wipe away solution on the surfaces of specimen.
5.2.3 Axially split specimen into two pieces with a hydraulic splitting device.

5.2.4 Spray silver nitrate solution on the splitt surfaces, store specimen pieces in a dark place for one hour, and then expose them under a fluorescent light for a few hours.

5.2.6 Measure the average front of white zone in the central part of specimen and take a mean value of two pieces of specimen. This mean value with a precision of 0.5 mm stands for penetration depth of chlorides.

6. CALCULATION

6.1 Calculate the diffusion coefficient by using the following equation

$$D = \frac{RTL}{zFU} \cdot \frac{x_d - \alpha\sqrt{x_d}}{t}$$

where:

$$\alpha = 2\sqrt{\frac{RTL}{zFU}} \cdot \mathrm{erf}^{-1}\left(1 - \frac{2c_d}{c_0}\right)$$

D: diffusion coefficient, m^2/s;
z: absolute value of ion valence, for chloride ions, $z = 1$;
F: Faraday constant, $F = 9.648 \times 10^4$ J/(V·mol);
U: absolute value of potential difference, V;
R: gas constant, $R = 8.314$ J/(K·mol);
T: solution temperature, K;
L: thickness of the specimen, m;
x_d: penetration depth, m;
t: test duration, second, $t = t_{CTH} \times 3600$;
erf^{-1}: inverse of error function;
c_d: chloride concentration at which the colour changes, $c_d \approx 0.07$ N;
c_0: chloride concentration in the upstream cell, $c_0 \approx 2$ N;

Let $\xi = \mathrm{erf}^{-1}\left(1 - \frac{2 \times 0.07}{c_0}\right)$, the values of ξ are given in *Table 2*.

Table 1—Test Duration for ∅100×50 mm specimen

Initial Current I_0 (mA)	Test Duration t_{CTH} (hour)
$I_0 < 5$	$t_{CTH} = 168$
$5 \leq I_0 < 10$	$t_{CTH} = 96$
$10 \leq I_0 < 30$	$t_{CTH} = 48$
$30 \leq I_0 < 60$	$t_{CTH} = 24$
$60 \leq I_0 < 120$	$t_{CTH} = 8$
$I_0 > 120$	$t_{CTH} = 4$

Table 2—The values of ξ

c_0	0.5 N	1.0 N	1.5 N	2.0 N	2.5 N	3.0 N	3.5 N	4.0 N	5.0N
ξ	0.764	1.044	1.187	1.281	1.351	1.407	1.452	1.491	1.554

EXPLANATORY NOTES

1) For very dense concrete, a voltage of 40 V may be applied instead of 30 V (Ref. 5.1.3).

2) The experimental set-up can be used for a steady-state procedure. In this case, the curved surface of specimen may be coated with epoxy, a platinum anode may be used and a lid for the top end of rubber cleeve should be added to prevent anolyte from evaporation.

3) The experimental set-up can also be used for AASHTO test, if its procedure is followed (Ref. AASHTO T 277-83, "Standard Method of test for determination of the chloride permeability of concrete").

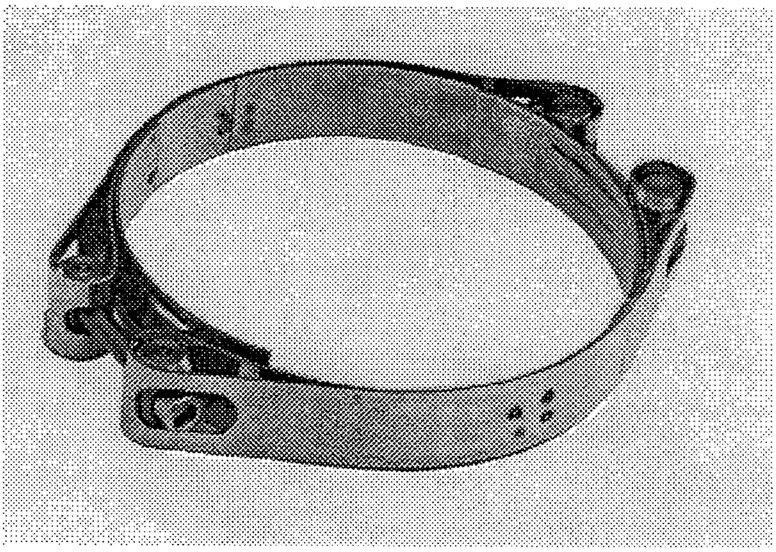

Fig. 1—Stainless steel clamper.

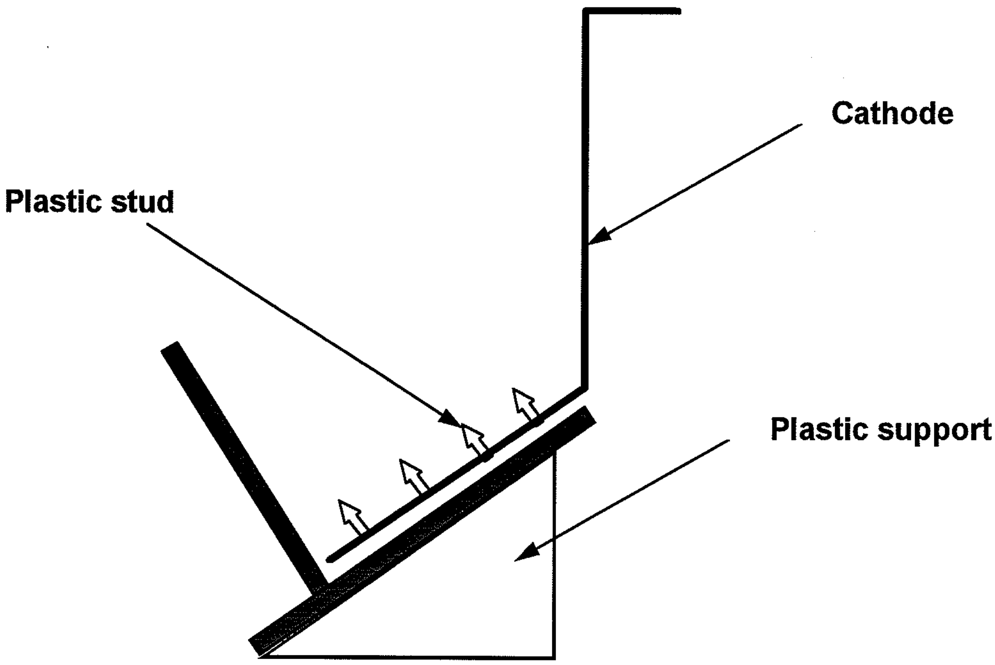

Fig. 2—Plastic support and cathode.

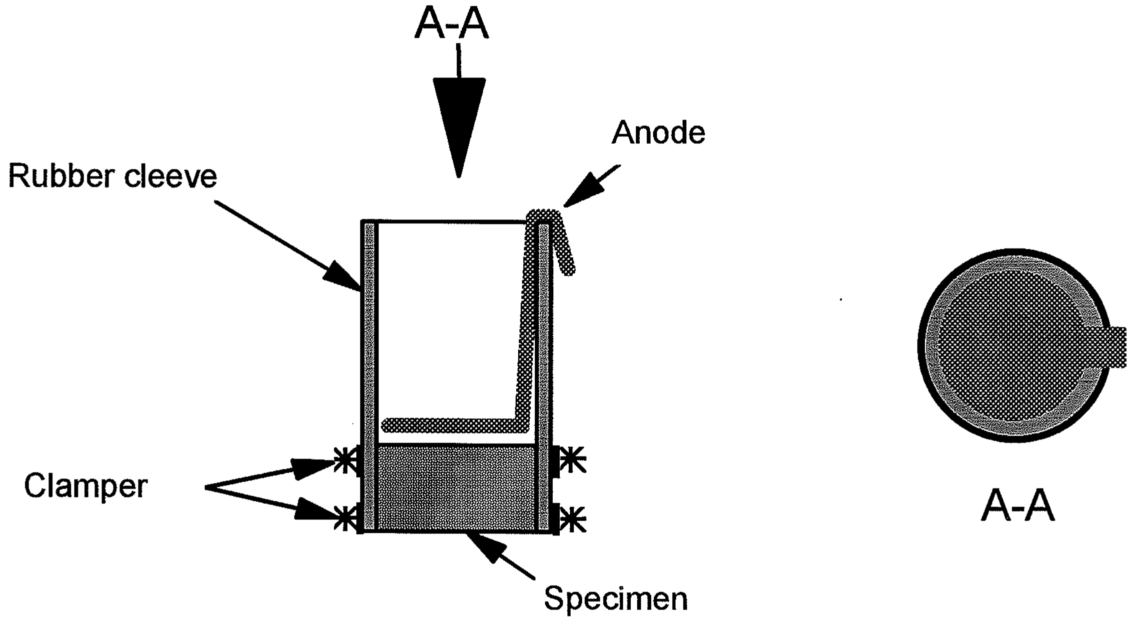

Fig. 3—Rubber sleeve assembled with specimen, clampers and anode.

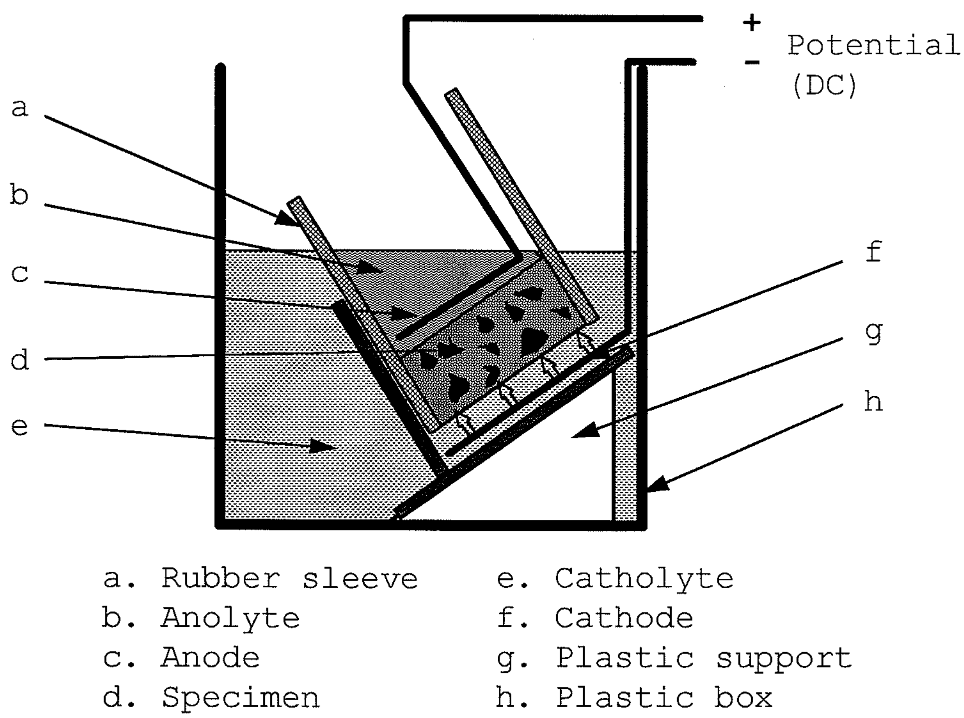

Fig. 5—Experimental arrangement for potential applying.

AEClaboratory	Concrete testing	APM 219
Staktoften 20 DK-2950 Vedbæk	Hardened concrete **Electrical resistivity**	1. edition May 1996
tlf +45 45 66 12 66		Init: JMF

1. Field of application

The method presupposes the existence of a relationship between quality of concrete and electrical resistivity. The electrical resistivity is mainly depending on the water/cement ratio, the moisture content, the temperature, the concrete maturity and the composition. Due to this electrical resistivity of hardened concrete can be used as a uniformity parameter. The scope of this test method is to provide a detailed description of how to measure the resistivity of concrete.

It is assumed that the concrete test specimens are free of construction faults such as cavities and visible cracks and no reinforcement are present.

2. References

NT BUILD 201, 2. ed., Concrete: Making and curing of moulded test specimens for strength test.

NT BUILD 202, 2. ed., Concrete, hardened: Sampling and treatment of cores for strength tests.

3. Test specimens

This method requires drilled cores or cast cylinders as test specimens. They must be representative for the concrete and/or structure in question. At least three test specimens should be used in the test.

4. Short description of the test

A water saturated concrete specimen of well-defined thickness is subjected to an alternating current field over a well-defined area. The test result is provided as directly readings of the electrical resistance (in kΩ) of the concrete specimen. Knowing the dimensions of the test specimen, the electrical resistivity (in kΩcm) is calculated from the electrical resistance.

5. Chemicals

5.1 A calcium hydroxide solution is prepared by adding $Ca(OH)_2$ to distilled or demineralized water in the ratio of 2 g per dm^3. This solution is referred to as the "wetting solution".

6. Apparatus

6.1 Stone saw

6.2 Balance, capacity/accuracy better than 1000±1 g

6.3 Four point resistance meter, e.g. the commercial product: "Norma", Erdungsmesser D3950, which is able to supply a stable alternating current of approx. 40 mA at the frequency of 108 Hz, quartz-stabilized. This apparatus is provided with a 4 digit digital display for readings of ohmic resistance. The electrical resistance is given in Ω or in kΩ (maximum reading is 199.9 kΩ).

Alternatively a programmed datalogger can be used if many measurements shall be performed at the same time.

6.4 Two stainless steel plates with the minimum dimensions corresponding to the exposed surface of the concrete specimen. The stainless steel plates shall be connected through insulated wires to the resistance meter.

6.5 Two sponges to be placed between the stainless steel plates and the test specimen.

6.6 Pressure spray can containing the wetting solution for prewetting of sponges before the measurements.

6.7 Weight with a mass of 1.5 kg.

7. Specimen preparation

Three test specimens are made from three drilled cores or cast cylinders (Ø100 ± 1 mm). Preparing specimens from drilled cores: After cutting of the outer 10 mm from the original end face test specimens with a thickness of 50 ± 1 mm shall be cut. Preparing specimens from cast cylinders: The specimens can be three 50 mm slices cut around the middle of the core.

The test specimens are kept under water in order to saturate the specimens and to prevent any drying. In order to avoid leaching as little water as possible should be used. The specimens are kept under water until the change in mass per day is less than 0.1% and the time for performing the measurements is due.

8. Test procedure

The electrical resistivity measurements shall be performed according to the following procedure:

8.1 The test setup shall follow the principles shown in Figure 1.

8.2 The sponges are wetted using the pressure spray can containing the "wetting solution", cf. Section 5.1 and wringed a little to remove excess water on the sponges. The sponges are placed in the test setup and the total resistance of both sponges, R_{sp} is recorded when stability is achieved (normally after 5 to 10 seconds). The electrical resistance of the sponges shall not exceed 100 Ω.

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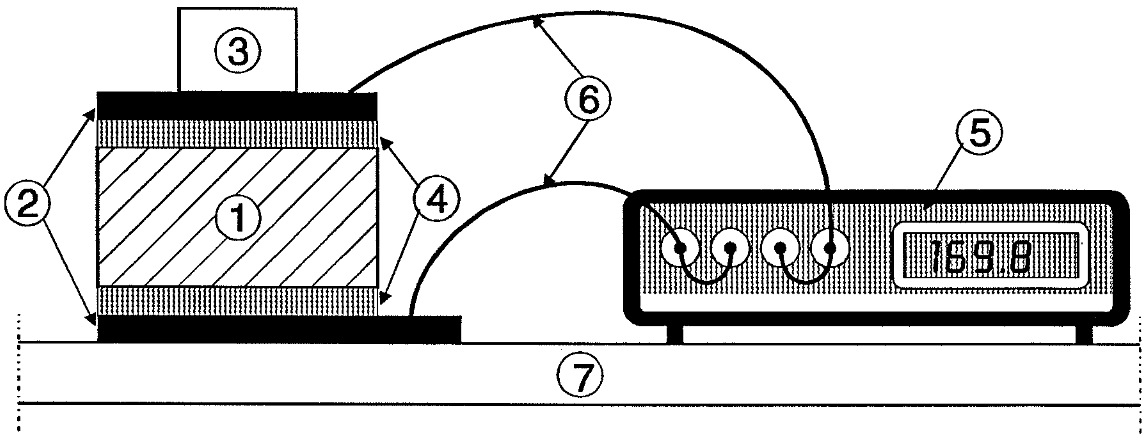


*Figure 1. Sketch of the test set-up for measuring the resistivity of concrete. The numbers refer to: **1.** Test specimen; **2.** Stainless steel plate; **3.** 1.5 kg weight; **4.** Sponge; **5.** Four point resistance meter; **6.** Connecting wires; **7.** Non-metallic table.*

8.3 Each test specimen shall carefully be wiped dry with a tissue especially on the curved surface on which the sponges are not attached. The temperature of the test specimens shall be maintained close to the room temperature, 23±2°C.

Each test specimen is then placed between the sponges in the test setup. The total resistance of both sponges and the test specimen, R_{s+sp} is recorded when stability is achieved.

The measurement on each test specimen is repeated after 2 to 3 minutes. If the difference between the obtained resistance values in two measurements on the same test specimen is less than 5% the test is concluded. If the difference between two measurements is bigger than 5%, the procedure is repeated until the obtained results are within the acceptable scatterband.

9. Calculation of results

The electrical resistance of each of the specimens is appearing from (1):

$$R_s = R_{s+sp} - R_{sp} \qquad (1)$$

where

R_s is the electrical resistance of each test specimen

R_{s+sp} is the measured mean electrical resistance of each test specimen and the sponges

R_{sp} is the measured electrical resistance of the sponges

★

The electrical resistance of the test specimens will normally be given in kΩ. The electrical resistivity, ρ, is calculated from (2):

$$\rho = A \times R_s / \delta \qquad (2)$$

where

ρ is the electrical resistivity of each test specimen	[kΩcm]
A is the cross sectional area of each test specimen	[cm^2]
δ is the thickness of each test specimen	[cm]

10. Presentation of the test result

The test result is given as the resistivity value for each test specimen and their mean value. The latter is taken as the resistivity of the particular concrete. The resistivity values are all given with three significant digits in kΩcm.

11. Test report

A test report must at least contain the following information:

11.1 Name and address of the test laboratory, and the place at which the tests were performed if different from the laboratory address.
11.2 Date and clear identification of the report.
11.3 Name and address of the client.
11.4 Description and marking of the sample.
11.5 Date of receipt of the sample and performance of the test.
11.6 Specification of the test method.
11.7 Description of the sampling, if relevant.
11.8 All deviations from or additions to the test method, and any omissions, together with other information of importance for judging the result.
11.9 Test result.
11.10 Signature and title or other identification of person(s) responsible for the technical content of the report.
11.11 Date of release of the report.

This annex contains additional data concerning the exposure conditions during the immersion test according to NT BUILD 443.

Sample no.	Mass before exposure [g]	Weight gain during exposure [g]	Area/volume-artio [cm²/l]
680-1-1	1132.1	5.8	34
680-1-2	1552.3	5.8	33
680-2-1	1238.8	5.4	34
680-2-2	1266.6	4.6	34
680-3-1	1194.4	2.1	35
680-3-2	1335.0	3.0	36
680-4-1	1283.8	1.5	33
680-4-2	1402.4	1.6	33
680-5-1	1349.8	1.2	33
680-5-2	1323.6	1.1	33
680-6-1	1328.5	0.9	35
680-6-2	1304.6	0.9	33
680-7-1	1336.4	0.5	33
680-7-2	1318.2	0.3	33

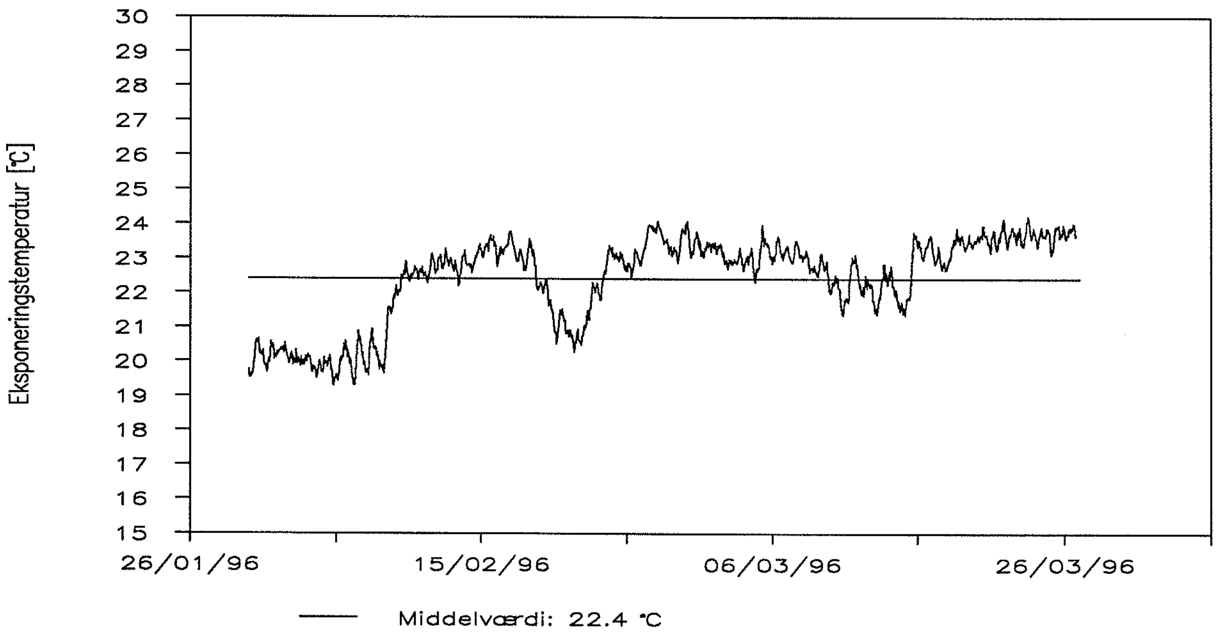
Table A: Weight gain of samples during exposure and area/volume ratios.

	NaCl concentration		
Sample no.	Before exposure [g/l]	After exposure [g/l]	Mean value [g/l]
680-1-1	165.15	168.22	166.69
680-1-2	165.15	169.11	167.13
680-2-1	165.15	168.69	166.92
680-2-2	165.15	164.56	164.86
680-3-1	165.15	165.39	165.27
680-3-2	165.15	165.57	165.36
680-4-1	165.94	165.74	165.84
680-4-2	165.94	164.56	165.25
680-5-1	165.94	163.97	164.96
680-5-2	165.94	164.56	165.25
680-6-1	165.94	164.36	165.15
680-6-2	165.94	164.07	165.01
680-7-1	165.94	165.02	165.48
680-7-2	165.94	166.44	166.19

Table B. Sodium chloride concentrations for the immersion tests.

L680 NT BUILD 443 - HETEK sub-task 1
Exposure temperature

Sample No.	Temp mean	Temp Deviation	Start Date	Time	End Date	Time
1-1	22.04	1.46	30/01/96	09:15	05/03/96	10:20
1-2	22.06	1.46	30/01/96	12:00	05/03/96	14:00
2-1	22.51	1.17	05/02/96	09:00	11/03/96	09:40
2-2	22.52	1.16	05/02/96	10:30	11/03/96	13:30
3-1	22.59	1.09	06/02/96	09:00	12/03/96	10:00
3-2	22.60	1.07	06/02/96	12:00	12/03/96	14:00
4-1	22.75	0.91	12/02/96	14:30	18/03/96	09:30
4-2	22.76	0.91	12/02/96	14:35	18/03/96	13:30
5-1	22.77	0.92	13/02/96	15:00	19/03/96	10:30
5-2	22.78	0.92	13/02/96	15:00	19/03/96	14:00
6-1	22.87	0.96	19/02/96	11:00	25/03/96	09:30
6-2	22.88	0.97	19/02/96	13:00	25/03/96	14:00
7-1	23.06	0.80	20/02/96	09:30	26/03/96	10:30
7-2	22.95	0.93	20/02/96	13:00	26/03/96	14:30



Accelerated Chloride Penetration

acc. to NT BUILD 443

AEClaboratory
Staktoften 20
DK-2950 Vedbæk
Tel +45 45 66 12 66

Lab no: *680*
Sample no: *01-1*
Init: *jh/HS*
Printed: *14/06/96*

Exposure conditions

Exposure start:		Date:	30/01/96	Time:	09:15	
Exposure stop:		Date:	05/03/96	Time:	10:20	
Exposure time:	841.1	hours =	35.0	days =	0.1	yr
NaCl conc. in solution	166.7	g/l solution		Liquid temperature:	22	°C
Casting:		Date:	02/01/96	Time:	11:17	
Sample age at start:	670.0	hours =	27.9	days =	0.1	yr

Profile geometry

No of points: *12*

Layer no.	1	2	3	4	5	6
Layer start [mm]	0.0	1.0	4.0	7.0	10.1	13.1
Layer stop [mm]	1.0	4.0	7.0	10.1	13.1	16.1
Layer no.	**7**	**8**	**9**	**10**	**11**	**12**
Layer start [mm]	16.1	19.2	22.1	25.2	28.1	31.0
Layer stop [mm]	19.2	22.1	25.2	28.1	31.0	34.7

Chloride content according to DS 423.28

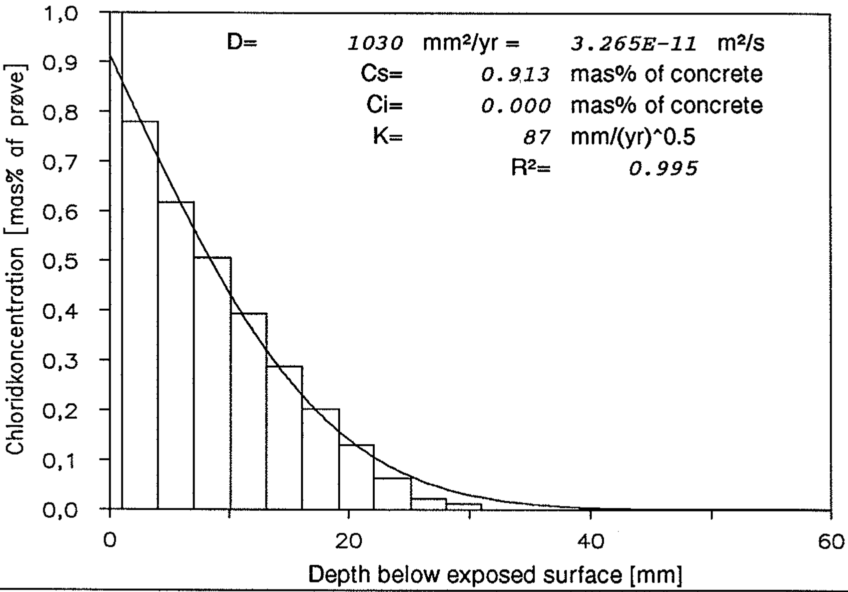
Concentration of solutions
AgNO3 *0.1009* mol/l
NH4SCN *0.1010* mol/l

Dilution: *3.0* times

Layer no.	1	2	3	4	5	6
Flask no.	30	31	38	39	40	43
Flask [g]	130.21	126.94	129.21	127.87	130.81	127.89
Flask + sample [g]	141.61	155.13	154.42	150.98	153.33	148.61
Sample mass [g]	11.40	28.19	25.21	23.11	22.52	20.72
AgNO3 [ml]	20.00	25.00	20.00	15.00	10.00	10.00
NH4SCN [ml]	7.82	4.51	5.49	4.10	1.75	4.42
mas% Cl of sample	1.146	0.780	0.617	0.506	0.393	0.289
Layer no.	**7**	**8**	**9**	**10**	**11**	**12**
Flask no.	44	45	51	55	37	54
Flask [g]	129.94	126.97	129.89	128.29	127.57	132.37
Flask + sample [g]	153.34	148.31	149.83	148.99	146.26	155.08
Sample mass [g]	23.40	21.34	19.94	20.70	18.69	22.71
AgNO3 [ml]	10.00	5.00	5.00	5.00	5.00	5.00
NH4SCN [ml]	5.59	2.41	3.81	4.56	4.78	5.01
mas% Cl of sample	0.202	0.130	0.064	0.023	0.012	-0.001

Chloride profile

Centre [mm]	Cl-conc [mas%]
0.50	1.146
2.50	0.780
5.50	0.617
8.55	0.506
11.60	0.393
14.60	0.289
17.65	0.202
20.65	0.130
23.65	0.064
26.65	0.023
29.55	0.012
32.85	-0.001



Version: 4.1 1994.10.12

File: 95044.21/680
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Accelerated Chloride Penetration

acc. to NT BUILD 443

AEClaboratory
Staktoften 20
DK-2950 Vedbæk
Tel +45 45 66 12 66

Lab no: *680*
Sample no: *01-2*
Init: *jh/HS*
Printed: *14/06/96*

Exposure conditions

Exposure start:		Date:	30/01/96	Time:	12:00	
Exposure stop:		Date:	05/03/96	Time:	14:00	
Exposure time:	842.0	hours =	35.1	days =	0.1	yr
NaCl conc. in solution	167.1	g/l solution	Liquid temperature:		22	°C
Casting:		Date:	02/01/96	Time:	11:17	
Sample age at start:	672.7	hours =	28.0	days =	0.1	yr

Profile geometry

No of points: 12

Layer no.	1	2	3	4	5	6
Layer start [mm]	0.0	1.0	4.0	7.0	10.0	13.0
Layer stop [mm]	1.0	4.0	7.0	10.0	13.0	16.0
Layer no.	**7**	**8**	**9**	**10**	**11**	**12**
Layer start [mm]	16.0	20.0	24.2	28.0	32.0	36.1
Layer stop [mm]	20.0	24.2	28.0	32.0	36.1	40.3

Chloride content according to DS 423.28

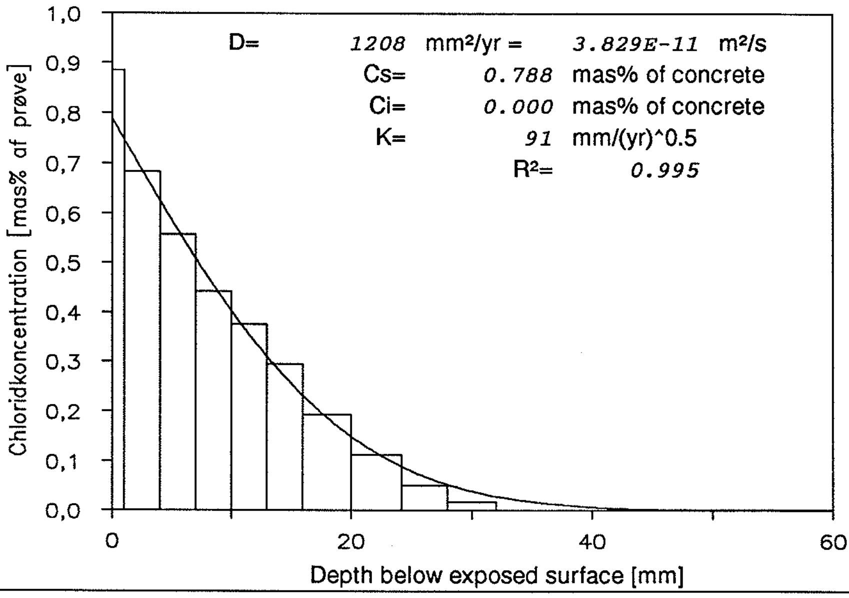
Concentration of solutions
AgNO3 0.1009 mol/l
NH4SCN 0.1010 mol/l

Dilution: 3.0 times

Layer no.	1	2	3	4	5	6
Flask no.	3	4	7	9	11	13
Flask [g]	109.41	108.47	107.77	111.41	112.61	108.26
Flask + sample [g]	121.64	134.55	127.90	131.26	131.32	127.72
Sample mass [g]	12.23	26.08	20.13	19.85	18.71	19.46
AgNO3 [ml]	20.00	20.00	20.00	15.00	15.00	10.00
NH4SCN [ml]	9.91	3.40	9.53	6.81	8.45	4.65
mas% Cl of sample	0.884	0.683	0.558	0.442	0.375	0.295
Layer no.	**7**	**8**	**9**	**10**	**11**	**12**
Flask no.	14	18	19	21	22	23
Flask [g]	107.90	109.01	108.33	106.54	111.93	113.56
Flask + sample [g]	127.77	125.08	122.33	121.02	127.56	130.51
Sample mass [g]	19.87	16.07	14.00	14.48	15.63	16.95
AgNO3 [ml]	10.00	5.00	5.00	5.00	5.00	5.00
NH4SCN [ml]	6.43	3.32	4.33	4.77	5.07	5.07
mas% Cl of sample	0.192	0.112	0.051	0.017	-0.005	-0.005

Chloride profile

Centre [mm]	Cl-conc [mas%]
0.50	0.884
2.50	0.683
5.50	0.558
8.50	0.442
11.50	0.375
14.50	0.295
18.00	0.192
22.10	0.112
26.10	0.051
30.00	0.017
34.05	-0.005
38.20	-0.005



Version: 4.1 1994.10.12

D68001-2.WR1

Accelerated Chloride Penetration

acc. to NT BUILD 443

AEClaboratory
Staktoften 20
DK-2950 Vedbæk
Tel +45 45 66 12 66

Lab no: *680*
Sample no: *02-1*
Init: *jh/HS*
Printed: *14/06/96*

Exposure conditions

Exposure start:		Date:	05/02/96	Time:	09:00	
Exposure stop:		Date:	11/03/96	Time:	09:40	
Exposure time:	840.7	hours =	35.0	days =	0.1	yr
NaCl conc. in solution	166.9	g/l solution	Liquid temperature:		23	°C
Casting:		Date:	08/01/96	Time:	13:52	
Sample age at start:	667.1	hours =	27.8	days =	0.1	yr

Profile geometry

No of points: *9*

Layer no.	1	2	3	4	5	6
Layer start [mm]	0.0	1.0	4.0	7.0	10.0	13.0
Layer stop [mm]	1.0	4.0	7.0	10.0	13.0	16.1
Layer no.	**7**	**8**	**9**	**10**	**11**	**12**
Layer start [mm]	16.1	20.1	24.0			
Layer stop [mm]	20.1	24.0	28.0			

Chloride content according to DS 423.28

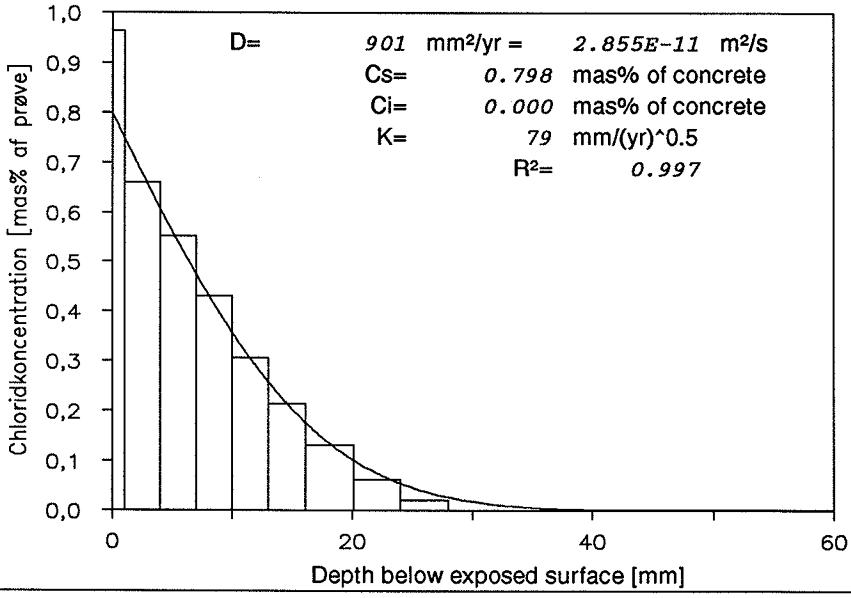
Concentration of solutions
AgNO3 *0.1009* mol/l
NH4SCN *0.1010* mol/l

Dilution: *3.0* times

Layer no.	1	2	3	4	5	6
Flask no.	30	31	38	40	43	44
Flask [g]	130.21	126.95	129.22	130.81	127.88	129.94
Flask + sample [g]	143.32	149.66	151.71	151.61	149.27	150.40
Sample mass [g]	13.11	22.71	22.49	20.80	21.39	20.46
AgNO3 [ml]	20.00	20.00	15.00	10.00	10.00	10.00
NH4SCN [ml]	8.22	6.03	3.44	1.65	3.88	5.92
mas% Cl of sample	0.964	0.660	0.551	0.431	0.307	0.214
Layer no.	**7**	**8**	**9**	**10**	**11**	**12**
Flask no.	45	53	55			
Flask [g]	126.96	127.01	128.28			
Flask + sample [g]	146.32	145.09	147.83			
Sample mass [g]	19.36	18.08	19.55			
AgNO3 [ml]	5.00	5.00	5.00			
NH4SCN [ml]	2.62	3.95	4.60			
mas% Cl of sample	0.132	0.062	0.022			

Chloride profile

Centre [mm]	Cl-conc [mas%]
0.50	0.964
2.50	0.660
5.50	0.551
8.50	0.431
11.50	0.307
14.55	0.214
18.10	0.132
22.05	0.062
26.00	0.022



File: 95044.21/680
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* NT BUILD 443 *

Accelerated Chloride Penetration

acc. to NT BUILD 443

AEClaboratory
Staktoften 20
DK-2950 Vedbæk
Tel +45 45 66 12 66

Lab no: *680*
Sample no: *02-2*
Init: *jh/HS*
Printed: *14/06/96*

Exposure conditions

Exposure start:		Date:	*05/02/96*	Time:	*10:30*	
Exposure stop:		Date:	*11/03/96*	Time:	*13:30*	
Exposure time:	*843.0*	hours =	*35.1*	days =	*0.1*	yr
NaCl conc. in solution	*164.9*	g/l solution		Liquid temperature:	*23*	°C
Casting:		Date:	*08/01/96*	Time:	*13:52*	
Sample age at start:	*668.6*	hours =	*27.9*	days =	*0.1*	yr

Profile geometry

No of points: *9*

Layer no.	1	2	3	4	5	6
Layer start [mm]	*0.0*	*1.0*	*4.0*	*7.0*	*9.9*	*13.0*
Layer stop [mm]	*1.0*	*4.0*	*7.0*	*9.9*	*13.0*	*16.0*
Layer no.	**7**	**8**	**9**	**10**	**11**	**12**
Layer start [mm]	*16.0*	*20.0*	*24.0*			
Layer stop [mm]	*20.0*	*24.0*	*28.5*			

Chloride content according to DS 423.28

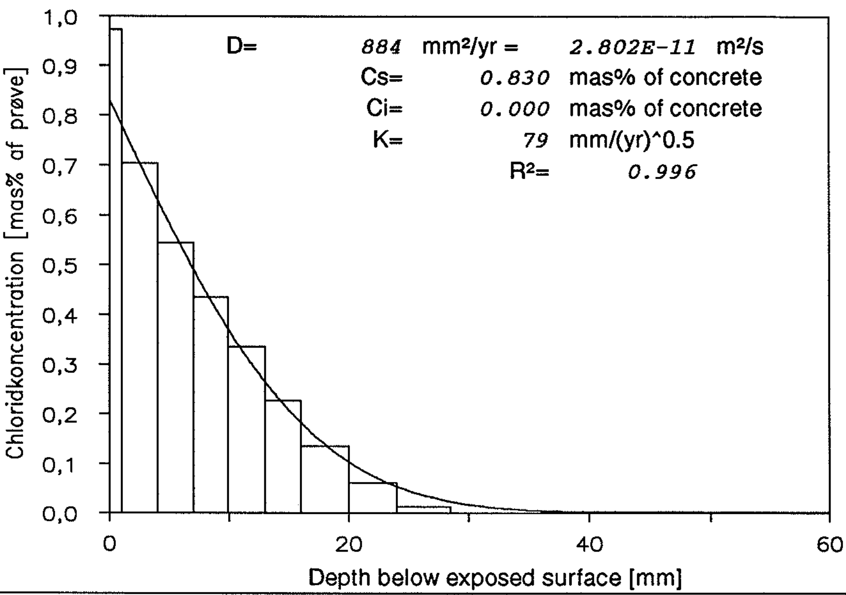
Concentration of solutions
AgNO3 *0.1009* mol/l
NH4SCN *0.1010* mol/l

Dilution: *3.0* times

Layer no.	1	2	3	4	5	6
Flask no.	*34*	*35*	*36*	*37*	*41*	*42*
Flask [g]	*128.84*	*130.54*	*129.35*	*127.58*	*130.16*	*128.38*
Flask + sample [g]	*143.73*	*156.32*	*153.89*	*147.80*	*155.09*	*150.30*
Sample mass [g]	*14.89*	*25.78*	*24.54*	*20.22*	*24.93*	*21.92*
AgNO3 [ml]	*15.00*	*20.00*	*15.00*	*15.00*	*10.00*	*10.00*
NH4SCN [ml]	*1.49*	*3.09*	*2.56*	*6.80*	*2.18*	*5.36*
mas% Cl of sample	*0.974*	*0.704*	*0.544*	*0.435*	*0.337*	*0.227*
Layer no.	**7**	**8**	**9**	**10**	**11**	**12**
Flask no.	*46*	*51*	*54*			
Flask [g]	*128.57*	*129.88*	*132.37*			
Flask + sample [g]	*149.20*	*148.10*	*157.43*			
Sample mass [g]	*20.63*	*18.22*	*25.06*			
AgNO3 [ml]	*5.00*	*5.00*	*5.00*			
NH4SCN [ml]	*2.39*	*3.95*	*4.67*			
mas% Cl of sample	*0.136*	*0.062*	*0.014*			

Chloride profile

Centre [mm]	Cl-conc [mas%]
0.50	*0.974*
2.50	*0.704*
5.50	*0.544*
8.45	*0.435*
11.45	*0.337*
14.50	*0.227*
18.00	*0.136*
22.00	*0.062*
26.25	*0.014*



Version: 4.1 1994.10.12

D68002-2.WR1

Accelerated Chloride Penetration

acc. to NT BUILD 443

AEClaboratory
Staktoften 20
DK-2950 Vedbæk
Tel +45 45 66 12 66

Lab no: *680*
Sample no: *03-1*
Init: *jh/HS*
Printed: *14/06/96*

Exposure conditions

Exposure start:		Date:	06/02/96	Time:	09:00	
Exposure stop:		Date:	12/03/96	Time:	10:00	
Exposure time:	841.0	hours =	35.0	days =	0.1	yr
NaCl conc. in solution	165.3	g/l solution	Liquid temperature:		23	°C
Casting:		Date:	09/01/96	Time:	11:45	
Sample age at start:	669.3	hours =	27.9	days =	0.1	yr

Profile geometry

No of points: 9

Layer no.	1	2	3	4	5	6
Layer start [mm]	0.0	1.0	4.0	7.1	10.0	13.2
Layer stop [mm]	1.0	4.0	7.1	10.0	13.2	16.1
Layer no.	**7**	**8**	**9**	**10**	**11**	**12**
Layer start [mm]	16.1	19.2	22.0			
Layer stop [mm]	19.2	22.0	25.0			

Chloride content according to DS 423.28

Concentration of solutions
AgNO3 0.1009 mol/l
NH4SCN 0.1010 mol/l

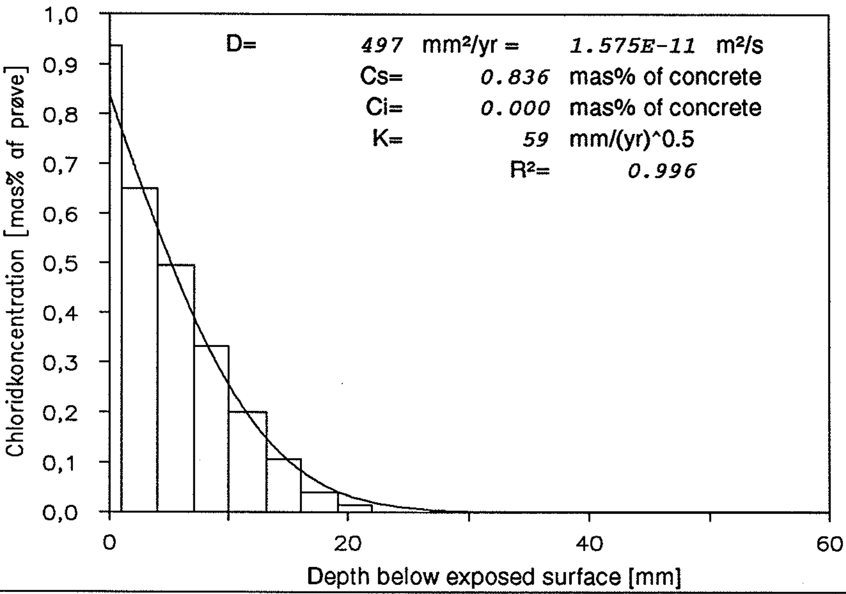
Dilution: 3.0 times

Layer no.	1	2	3	4	5	6
Flask no.	3	9	11	13	14	18
Flask [g]	109.41	111.42	112.62	108.27	107.90	109.00
Flask + sample [g]	121.60	131.22	130.78	122.19	126.19	124.48
Sample mass [g]	12.19	19.80	18.16	13.92	18.29	15.48
AgNO3 [ml]	15.00	15.00	10.00	10.00	5.00	5.00
NH4SCN [ml]	4.36	3.01	1.63	5.68	1.59	3.48
mas% Cl of sample	0.936	0.650	0.494	0.333	0.200	0.105
Layer no.	**7**	**8**	**9**	**10**	**11**	**12**
Flask no.	19	21	22			
Flask [g]	108.33	106.54	111.94			
Flask + sample [g]	123.71	120.56	127.22			
Sample mass [g]	15.38	14.02	15.28			
AgNO3 [ml]	5.00	5.00	5.00			
NH4SCN [ml]	4.42	4.80	5.02			
mas% Cl of sample	0.040	0.015	-0.002			

Chloride profile

Centre [mm]	Cl-conc [mas%]
0.50	0.936
2.50	0.650
5.55	0.494
8.55	0.333
11.60	0.200
14.66	0.105
17.65	0.040
20.60	0.015
23.50	-0.002

D= 497 mm²/yr = 1.575E-11 m²/s
Cs= 0.836 mas% of concrete
Ci= 0.000 mas% of concrete
K= 59 mm/(yr)^0.5
R^2= 0.996



Version: 4.1 1994.10.12

File: 95044.21/680
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* NT BUILD 443 *

Accelerated Chloride Penetration

acc. to NT BUILD 443

AEClaboratory
Staktoften 20
DK-2950 Vedbæk
Tel +45 45 66 12 66

Lab no: *680*
Sample no: *03-2*
Init: *jh/HS*
Printed: *14/06/96*

Exposure conditions

Exposure start:		Date:	06/02/96	Time:	12:00	
Exposure stop:		Date:	12/03/96	Time:	14:00	
Exposure time:	842.0	hours =	35.1	days =	0.1	yr
NaCl conc. in solution	165.4	g/l solution	Liquid temperature:		23	°C
Casting:		Date:	09/01/96	Time:	11:45	
Sample age at start:	672.3	hours =	28.0	days =	0.1	yr

Profile geometry

No of points: 9

Layer no.	1	2	3	4	5	6
Layer start [mm]	0.0	1.0	4.0	7.0	10.0	13.0
Layer stop [mm]	1.0	4.0	7.0	10.0	13.0	16.1
Layer no.	**7**	**8**	**9**	**10**	**11**	**12**
Layer start [mm]	16.1	19.2	22.0			
Layer stop [mm]	19.2	22.0	25.5			

Chloride content according to DS 423.28

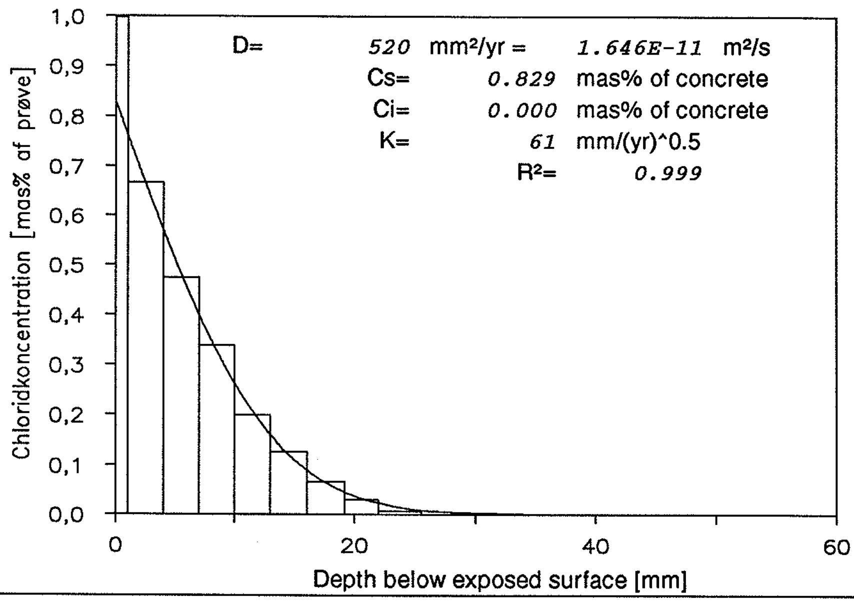
Concentration of solutions
AgNO3 0.1009 mol/l
NH4SCN 0.1010 mol/l

Dilution: 3.0 times

Layer no.	1	2	3	4	5	6
Flask no.	30	31	36	37	38	40
Flask [g]	130.22	126.92	129.43	127.59	129.20	130.81
Flask + sample [g]	140.49	148.15	146.74	144.49	144.38	147.11
Sample mass [g]	10.27	21.23	17.31	16.90	15.18	16.30
AgNO3 [ml]	15.00	15.00	10.00	10.00	5.00	5.00
NH4SCN [ml]	5.45	1.80	2.35	4.67	2.19	3.08
mas% Cl of sample	0.997	0.667	0.474	0.338	0.198	0.126
Layer no.	**7**	**8**	**9**	**10**	**11**	**12**
Flask no.	41	45	55			
Flask [g]	130.17	126.95	128.27			
Flask + sample [g]	147.14	140.70	145.45			
Sample mass [g]	16.97	13.75	17.18			
AgNO3 [ml]	5.00	5.00	5.00			
NH4SCN [ml]	3.95	4.62	4.89			
mas% Cl of sample	0.066	0.029	0.007			

Chloride profile

Centre [mm]	Cl-conc [mas%]
0.50	0.997
2.50	0.667
5.50	0.474
8.50	0.338
11.50	0.198
14.55	0.126
17.65	0.066
20.60	0.029
23.75	0.007



Version: 4.1 1994.10.12

D68003-2.WR1

File: 95044.21/680
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* NT BUILD 443 *

Accelerated Chloride Penetration

acc. to NT BUILD 443

AEClaboratory
Staktoften 20
DK-2950 Vedbæk
Tel +45 45 66 12 66

Lab no: 680
Sample no: 04-1
Init: jh/HS
Printed: 14/06/96

Exposure conditions

Exposure start:		Date:	12/02/96	Time:	14:30	
Exposure stop:		Date:	18/03/96	Time:	09:30	
Exposure time:	835.0	hours =	34.8	days =	0.1	yr
NaCl conc. in solution	165.8	g/l solution	Liquid temperature:		23	°C
Casting:		Date:	15/01/96	Time:	11:25	
Sample age at start:	675.1	hours =	28.1	days =	0.1	yr

Profile geometry

No of points: 9

Layer no.	1	2	3	4	5	6
Layer start [mm]	0.0	1.0	3.5	6.0	8.5	11.0
Layer stop [mm]	1.0	3.5	6.0	8.5	11.0	14.0
Layer no.	7	8	9	10	11	12
Layer start [mm]	14.0	17.0	20.0			
Layer stop [mm]	17.0	20.0	23.0			

Chloride content according to DS 423.28

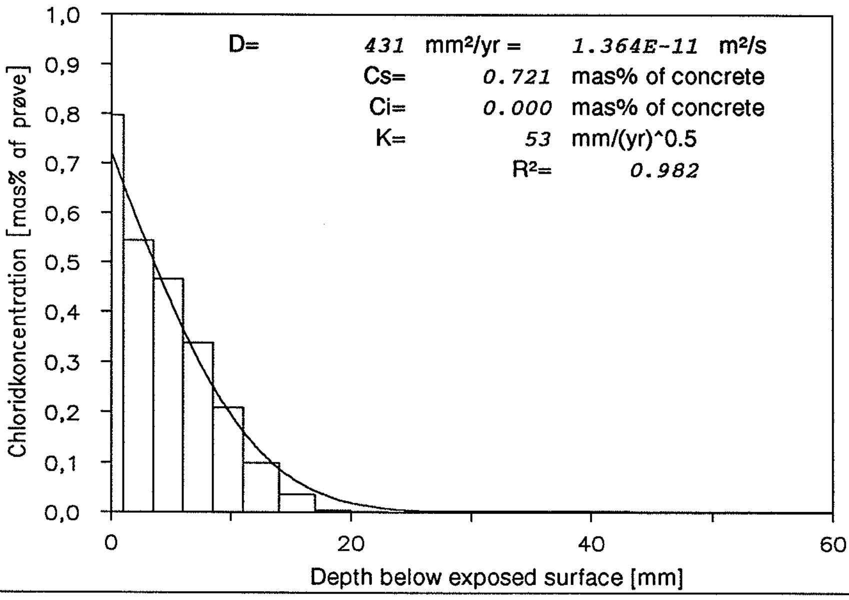
Concentration of solutions
AgNO3 0.1009 mol/l
NH4SCN 0.1010 mol/l

Dilution: 3.0 times

Layer no.	1	2	3	4	5	6
Flask no.	31	33	35	38	40	41
Flask [g]	126.95	130.99	130.54	129.22	130.80	130.16
Flask + sample [g]	136.96	149.49	146.11	146.68	146.95	148.94
Sample mass [g]	10.01	18.50	15.57	17.46	16.15	18.78
AgNO3 [ml]	15.00	15.00	15.00	10.00	10.00	5.00
NH4SCN [ml]	7.56	5.62	8.24	4.49	6.85	3.25
mas% Cl of sample	0.797	0.544	0.465	0.338	0.209	0.100
Layer no.	7	8	9	10	11	12
Flask no.	43	44	55			
Flask [g]	127.90	129.95	128.28			
Flask + sample [g]	147.39	148.86	145.23			
Sample mass [g]	19.49	18.91	16.95			
AgNO3 [ml]	5.00	5.00	5.00			
NH4SCN [ml]	4.34	4.91	4.96			
mas% Cl of sample	0.036	0.005	0.002			

Chloride profile

Centre [mm]	Cl-conc [mas%]
0.50	0.797
2.25	0.544
4.75	0.465
7.25	0.338
9.75	0.209
12.50	0.100
15.50	0.036
18.50	0.005
21.50	0.002



Version: 4.1 1994.10.12

D68004-1.WR1

Accelerated Chloride Penetration

acc. to NT BUILD 443

AEClaboratory
Staktoften 20
DK-2950 Vedbæk
Tel +45 45 66 12 66

Lab no: *680*
Sample no: *04-2*
Init: *jh/HS*
Printed: *14/06/96*

Exposure conditions

Exposure start:		Date:	12/02/96	Time:	14:30	
Exposure stop:		Date:	18/03/96	Time:	09:30	
Exposure time:	835.0	hours =	34.8	days =	0.1	yr
NaCl conc. in solution	165.3	g/l solution		Liquid temperature:	23	°C
Casting:		Date:	15/01/96	Time:	11:25	
Sample age at start:	675.1	hours =	28.1	days =	0.1	yr

Profile geometry

No of points: 9

Layer no.	1	2	3	4	5	6
Layer start [mm]	0.0	1.0	3.5	6.0	8.5	11.0
Layer stop [mm]	1.0	3.5	6.0	8.5	11.0	14.0
Layer no.	**7**	**8**	**9**	**10**	**11**	**12**
Layer start [mm]	14.0	17.0	20.0			
Layer stop [mm]	17.0	20.0	23.0			

Chloride content according to DS 423.28

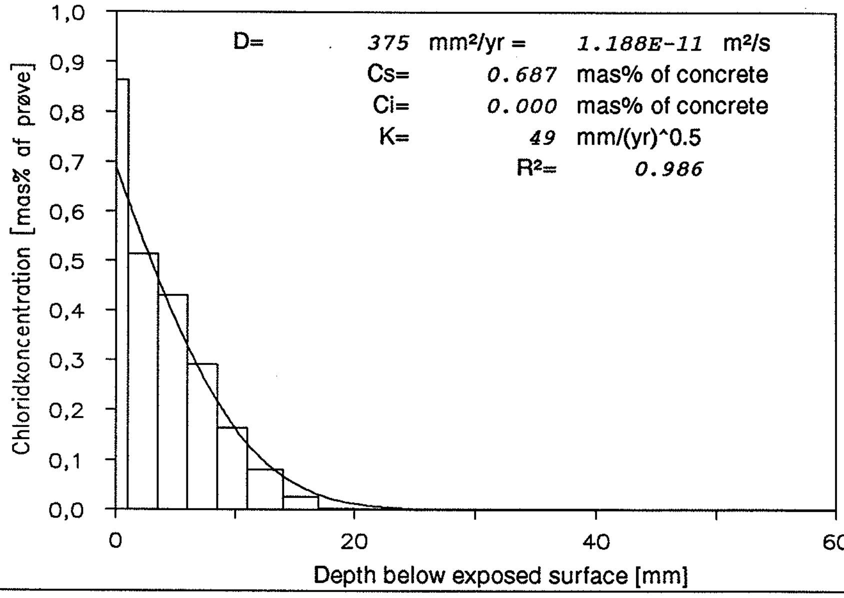
Concentration of solutions
AgNO3 0.1009 mol/l
NH4SCN 0.1010 mol/l

Dilution: 3.0 times

Layer no.	1	2	3	4	5	6
Flask no.	30	34	36	42	46	47
Flask [g]	130.22	128.85	129.36	128.39	128.58	128.90
Flask + sample [g]	138.56	148.07	144.99	147.51	144.70	146.85
Sample mass [g]	8.34	19.22	15.63	19.12	16.12	17.95
AgNO3 [ml]	15.00	15.00	10.00	10.00	5.00	5.00
NH4SCN [ml]	8.28	5.80	3.74	4.81	2.54	3.67
mas% Cl of sample	0.864	0.513	0.430	0.291	0.164	0.079
Layer no.	**7**	**8**	**9**	**10**	**11**	**12**
Flask no.	51	53	54			
Flask [g]	129.87	127.01	132.38			
Flask + sample [g]	148.33	144.58	149.11			
Sample mass [g]	18.46	17.57	16.73			
AgNO3 [ml]	5.00	5.00	5.00			
NH4SCN [ml]	4.54	4.94	4.98			
mas% Cl of sample	0.026	0.003	0.001			

Chloride profile

Centre [mm]	Cl-conc [mas%]
0.50	0.864
2.25	0.513
4.75	0.430
7.25	0.291
9.75	0.164
12.50	0.079
15.50	0.026
18.50	0.003
21.50	0.001



Version: 4.1 1994.10.12

File: 95044.21/680
HETEK

* NT BUILD 443 *

Accelerated Chloride Penetration

acc. to NT BUILD 443

AEClaboratory
Staktoften 20
DK-2950 Vedbæk
Tel +45 45 66 12 66

Lab no: *680*
Sample no: *05-1*
Init: *jh/HS*
Printed: *14/06/96*

Exposure conditions

Exposure start:		Date:	*13/02/96*	Time:	*15:00*	
Exposure stop:		Date:	*19/03/96*	Time:	*10:30*	
Exposure time:	*835.5*	hours =	*34.8*	days =	*0.1*	yr
NaCl conc. in solution	*165.0*	g/l solution	Liquid temperature:		*23*	°C
Casting:		Date:	*16/01/96*	Time:	*09:40*	
Sample age at start:	*677.3*	hours =	*28.2*	days =	*0.1*	yr

Profile geometry

No of points: *9*

Layer no.	1	2	3	4	5	6
Layer start [mm]	*0.0*	*1.0*	*3.1*	*5.1*	*7.0*	*9.0*
Layer stop [mm]	*1.0*	*3.1*	*5.1*	*7.0*	*9.0*	*11.0*
Layer no.	**7**	**8**	**9**	**10**	**11**	**12**
Layer start [mm]	*11.0*	*13.9*	*17.0*			
Layer stop [mm]	*13.9*	*17.0*	*20.2*			

Chloride content according to DS 423.28

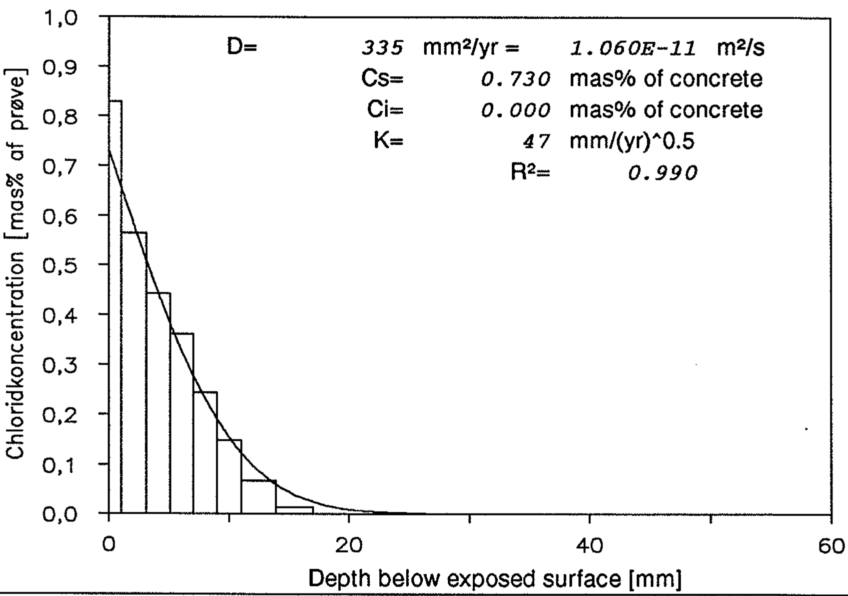
Concentration of solutions
AgNO3 *0.1009* mol/l
NH4SCN *0.1010* mol/l

Dilution: *3.0* times

Layer no.	1	2	3	4	5	6
Flask no.	*31*	*33*	*35*	*38*	*41*	*40*
Flask [g]	*126.94*	*130.99*	*130.53*	*129.21*	*130.15*	*130.81*
Flask + sample [g]	*135.07*	*146.71*	*144.96*	*140.77*	*143.83*	*143.13*
Sample mass [g]	*8.13*	*15.72*	*14.43*	*11.56*	*13.68*	*12.32*
AgNO3 [ml]	*15.00*	*15.00*	*10.00*	*10.00*	*10.00*	*5.00*
NH4SCN [ml]	*8.71*	*6.71*	*4.05*	*6.10*	*6.89*	*3.29*
mas% Cl of sample	*0.829*	*0.565*	*0.442*	*0.361*	*0.243*	*0.149*
Layer no.	**7**	**8**	**9**	**10**	**11**	**12**
Flask no.	*43*	*44*	*55*			
Flask [g]	*127.88*	*129.94*	*128.29*			
Flask + sample [g]	*147.88*	*151.53*	*145.67*			
Sample mass [g]	*20.00*	*21.59*	*17.38*			
AgNO3 [ml]	*5.00*	*5.00*	*5.00*			
NH4SCN [ml]	*3.74*	*4.74*	*5.02*			
mas% Cl of sample	*0.067*	*0.013*	*-0.002*			

Chloride profile

Centre [mm]	Cl-conc [mas%]
0.50	*0.829*
2.05	*0.565*
4.10	*0.442*
6.05	*0.361*
8.00	*0.243*
10.00	*0.149*
12.45	*0.067*
15.45	*0.013*
18.60	*-0.002*



Version: 4.1 1994.10.12

D68005-1.WR1

Accelerated Chloride Penetration

acc. to NT BUILD 443

AEClaboratory
Staktoften 20
DK-2950 Vedbæk
Tel +45 45 66 12 66

Lab no: *680*
Sample no: *05-2*
Init: *jh/HS*
Printed: *14/06/96*

Exposure conditions

Exposure start:		Date:	13/02/96	Time:	15:00	
Exposure stop:		Date:	19/03/96	Time:	14:00	
Exposure time:	839.0	hours =	35.0	days =	0.1	yr
NaCl conc. in solution	165.3	g/l solution		Liquid temperature:	23	°C
Casting:		Date:	16/01/96	Time:	09:40	
Sample age at start:	677.3	hours =	28.2	days =	0.1	yr

Profile geometry

No of points: 9

Layer no.	1	2	3	4	5	6
Layer start [mm]	0.0	1.0	3.1	5.0	7.0	9.0
Layer stop [mm]	1.0	3.1	5.0	7.0	9.0	11.1
Layer no.	**7**	**8**	**9**	**10**	**11**	**12**
Layer start [mm]	11.1	14.1	17.0			
Layer stop [mm]	14.1	17.0	20.1			

Chloride content according to DS 423.28

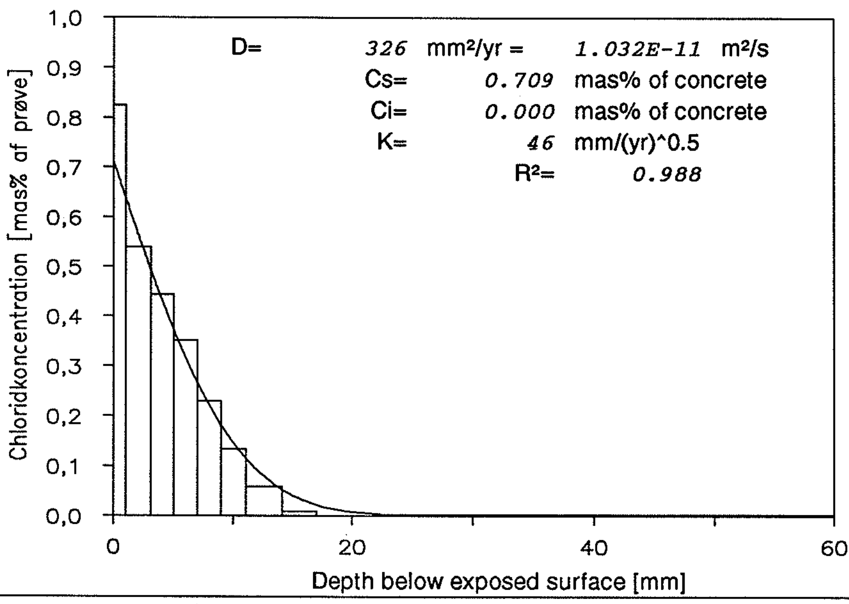
Concentration of solutions
AgNO3 0.1009 mol/l
NH4SCN 0.1010 mol/l

Dilution: 3.0 times

Layer no.	1	2	3	4	5	6
Flask no.	30	34	36	42	46	47
Flask [g]	130.22	128.84	129.35	128.39	128.58	128.89
Flask + sample [g]	141.04	143.07	140.19	140.85	141.00	141.49
Sample mass [g]	10.82	14.23	10.84	12.46	12.42	12.60
AgNO3 [ml]	10.00	10.00	10.00	10.00	10.00	5.00
NH4SCN [ml]	1.68	2.85	5.51	5.91	7.34	3.43
mas% Cl of sample	0.825	0.539	0.444	0.352	0.229	0.133
Layer no.	**7**	**8**	**9**	**10**	**11**	**12**
Flask no.	51	53	54			
Flask [g]	129.89	126.99	132.38			
Flask + sample [g]	145.71	143.28	152.02			
Sample mass [g]	15.82	16.29	19.64			
AgNO3 [ml]	5.00	5.00	5.00			
NH4SCN [ml]	4.14	4.85	5.01			
mas% Cl of sample	0.058	0.010	-0.001			

Chloride profile

Centre [mm]	Cl-conc [mas%]
0.50	0.825
2.05	0.539
4.05	0.444
6.00	0.352
8.00	0.229
10.05	0.133
12.60	0.058
15.55	0.010
18.55	-0.001



Version: 4.1 1994.10.12

File: 95044.21/680
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* NT BUILD 443 *

Accelerated Chloride Penetration

acc. to NT BUILD 443

AEClaboratory
Staktoften 20
DK-2950 Vedbæk
Tel +45 45 66 12 66

Lab no: *680*
Sample no: *06-1*
Init: *jh/HS*
Printed: *14/06/96*

Exposure conditions

Exposure start:		Date:	19/02/96	Time:	11:00	
Exposure stop:		Date:	25/03/96	Time:	09:30	
Exposure time:	838.5	hours =	34.9	days =	0.1	yr
NaCl conc. in solution	165.2	g/l solution		Liquid temperature:	23	°C
Casting:		Date:	22/01/96	Time:	14:45	
Sample age at start:	668.3	hours =	27.8	days =	0.1	yr

Profile geometry

No of points: 9

Layer no.	1	2	3	4	5	6
Layer start [mm]	0.0	1.0	3.0	5.1	7.0	9.0
Layer stop [mm]	1.0	3.0	5.1	7.0	9.0	11.0
Layer no.	**7**	**8**	**9**	**10**	**11**	**12**
Layer start [mm]	11.0	13.0	15.0			
Layer stop [mm]	13.0	15.0	17.2			

Chloride content according to DS 423.28

Concentration of solutions
AgNO3 0.1011 mol/l
NH4SCN 0.1016 mol/l

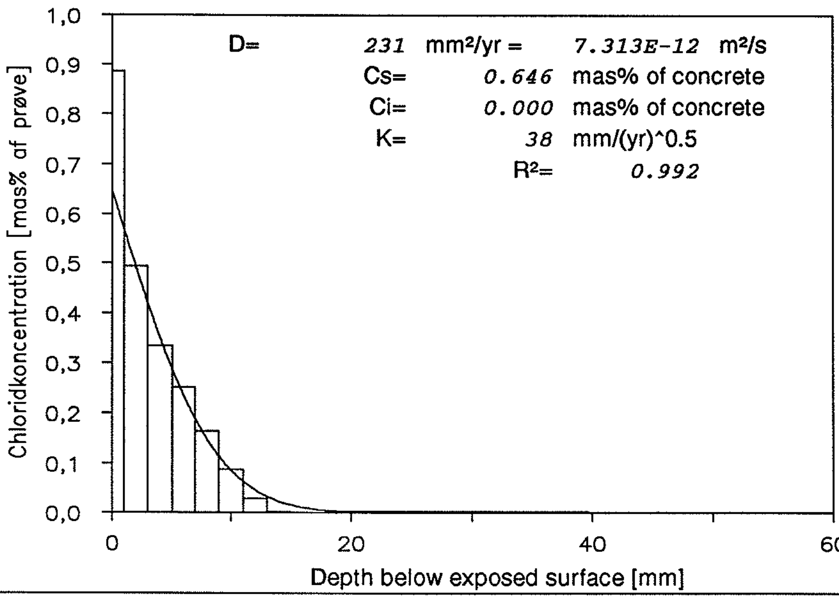
Dilution: 3.0 times

Layer no.	1	2	3	4	5	6
Flask no.	30	33	34	36	37	42
Flask [g]	130.22	131.00	128.85	129.35	127.59	128.39
Flask + sample [g]	138.22	149.72	144.86	143.09	141.51	142.58
Sample mass [g]	8.00	18.72	16.01	13.74	13.92	14.19
AgNO3 [ml]	10.00	10.00	10.00	10.00	10.00	5.00
NH4SCN [ml]	3.39	1.40	4.99	6.75	7.85	3.83
mas% Cl of sample	0.886	0.494	0.335	0.252	0.163	0.087
Layer no.	**7**	**8**	**9**	**10**	**11**	**12**
Flask no.	46	51	54			
Flask [g]	128.58	129.87	132.38			
Flask + sample [g]	143.71	144.33	148.57			
Sample mass [g]	15.13	14.46	16.19			
AgNO3 [ml]	5.00	5.00	5.00			
NH4SCN [ml]	4.58	4.96	5.02			
mas% Cl of sample	0.028	0.001	-0.003			

Chloride profile

Centre [mm]	Cl-conc [mas%]
0.50	0.886
2.00	0.494
4.05	0.335
6.05	0.252
8.00	0.163
10.00	0.087
12.00	0.028
14.00	0.001
16.10	-0.003

D= 231 mm²/yr = 7.313E-12 m²/s
Cs= 0.646 mas% of concrete
Ci= 0.000 mas% of concrete
K= 38 mm/(yr)^0.5
R^2= 0.992



Version: 4.1 1994.10.12

D68006-1.WR1

File: 95044.21/680
HETEK

* NT BUILD 443 *

Accelerated Chloride Penetration

acc. to NT BUILD 443

AEClaboratory
Staktoften 20
DK-2950 Vedbæk
Tel +45 45 66 12 66

Lab no: 680
Sample no: 06-2
Init: jh/HS
Printed: 14/06/96

Exposure conditions

Exposure start:		Date:	19/02/96	Time:	13:00	
Exposure stop:		Date:	25/03/96	Time:	14:00	
Exposure time:	841.0	hours =	35.0	days =	0.1	yr
NaCl conc. in solution	165.0	g/l solution		Liquid temperature:	23	°C
Casting:		Date:	22/01/96	Time:	14:45	
Sample age at start:	670.3	hours =	27.9	days =	0.1	yr

Profile geometry

No of points: 9

Layer no.	1	2	3	4	5	6
Layer start [mm]	0.0	1.0	3.0	5.0	7.1	9.0
Layer stop [mm]	1.0	3.0	5.0	7.1	9.0	11.0
Layer no.	**7**	**8**	**9**	**10**	**11**	**12**
Layer start [mm]	11.0	13.0	15.0			
Layer stop [mm]	13.0	15.0	17.0			

Chloride content according to DS 423.28

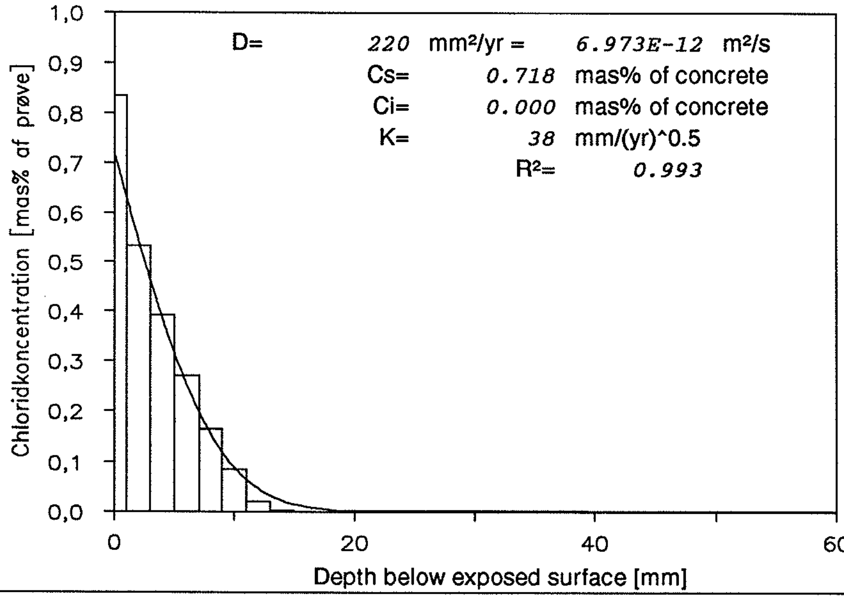
Concentration of solutions
AgNO3 0.1011 mol/l
NH4SCN 0.1016 mol/l

Dilution: 3.0 times

Layer no.	1	2	3	4	5	6
Flask no.	11	18	22	31	35	38
Flask [g]	112.62	109.00	111.94	126.95	130.55	129.22
Flask + sample [g]	121.64	124.30	127.24	143.25	144.54	143.68
Sample mass [g]	9.02	15.30	15.30	16.30	13.99	14.46
AgNO3 [ml]	10.00	10.00	10.00	10.00	10.00	5.00
NH4SCN [ml]	2.98	2.41	4.39	5.88	7.83	3.83
mas% Cl of sample	0.835	0.533	0.393	0.270	0.164	0.086
Layer no.	**7**	**8**	**9**	**10**	**11**	**12**
Flask no.	40	43	55			
Flask [g]	130.81	127.88	128.29			
Flask + sample [g]	143.99	144.00	143.50			
Sample mass [g]	13.18	16.12	15.21			
AgNO3 [ml]	5.00	5.00	5.00			
NH4SCN [ml]	4.71	4.94	5.03			
mas% Cl of sample	0.022	0.002	-0.004			

Chloride profile

Centre [mm]	Cl-conc [mas%]
0.50	0.835
2.00	0.533
4.00	0.393
6.05	0.270
8.05	0.164
10.00	0.086
12.00	0.022
14.00	0.002
16.00	-0.004



Version: 4.1 1994.10.12

D68006-2.WR1

Accelerated Chloride Penetration

acc. to NT BUILD 443

AEClaboratory
Staktoften 20
DK-2950 Vedbæk
Tel +45 45 66 12 66

Lab no: *680*
Sample no: *07-1*
Init: *jh/HS*
Printed: *14/06/96*

Exposure conditions

Exposure start:		Date:	20/02/96	Time:	09:30	
Exposure stop:		Date:	26/03/96	Time:	10:30	
Exposure time:	841.0	hours =	35.0	days =	0.1	yr
NaCl conc. in solution	165.5	g/l solution	Liquid temperature:		23	°C
Casting:		Date:	23/01/96	Time:	13:50	
Sample age at start:	667.7	hours =	27.8	days =	0.1	yr

Profile geometry

No of points: 9

Layer no.	1	2	3	4	5	6
Layer start [mm]	0.0	1.0	2.6	4.2	5.7	7.3
Layer stop [mm]	1.0	2.6	4.2	5.7	7.3	8.8
Layer no.	**7**	**8**	**9**	**10**	**11**	**12**
Layer start [mm]	8.8	10.4	12.0			
Layer stop [mm]	10.4	12.0	14.0			

Chloride content according to DS 423.28

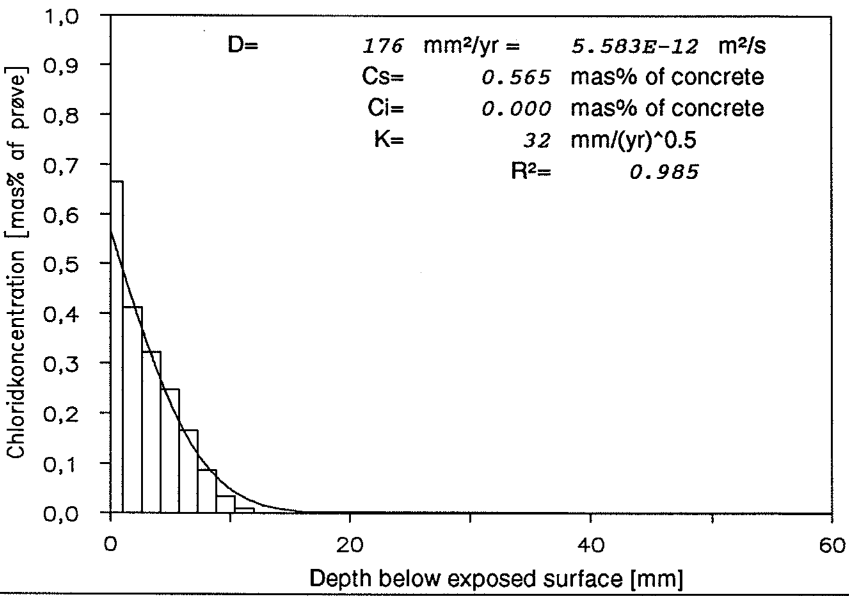
Concentration of solutions
AgNO3 0.1011 mol/l
NH4SCN 0.1016 mol/l

Dilution: 3.0 times

Layer no.	1	2	3	4	5	6
Flask no.	31	34	41	42	46	47
Flask [g]	126.94	128.84	130.16	128.38	128.57	128.90
Flask + sample [g]	138.11	141.44	141.81	138.80	141.34	138.41
Sample mass [g]	11.17	12.60	11.65	10.42	12.77	9.51
AgNO3 [ml]	10.00	10.00	10.00	10.01	5.00	5.00
NH4SCN [ml]	3.08	5.15	6.48	7.58	3.03	4.21
mas% Cl of sample	0.665	0.412	0.322	0.247	0.165	0.087
Layer no.	**7**	**8**	**9**	**10**	**11**	**12**
Flask no.	51	53	54			
Flask [g]	129.86	126.99	132.36			
Flask + sample [g]	142.26	139.05	145.67			
Sample mass [g]	12.40	12.06	13.31			
AgNO3 [ml]	5.00	5.00	5.00			
NH4SCN [ml]	4.58	4.87	4.98			
mas% Cl of sample	0.034	0.009	-0.000			

Chloride profile

Centre [mm]	Cl-conc [mas%]
0.50	0.665
1.80	0.412
3.40	0.322
4.95	0.247
6.50	0.165
8.05	0.087
9.60	0.034
11.20	0.009
13.00	-0.000



Version: 4.1 1994.10.12

D68007-1.WR1

File: 95044.21/680
HETEK

* NT BUILD 443 *

Accelerated Chloride Penetration

acc. to NT BUILD 443

AEClaboratory
Staktoften 20
DK-2950 Vedbæk
Tel +45 45 66 12 66

Lab no: 680
Sample no: 07-2
Init: jh/HS
Printed: 14/06/96

Exposure conditions

Exposure start:		Date:	20/02/96	Time:	13:00	
Exposure stop:		Date:	26/03/96	Time:	14:30	
Exposure time:	841.5	hours =	35.1	days =	0.1	yr
NaCl conc. in solution	166.2	g/l solution	Liquid temperature:		23	°C
Casting:		Date:	23/01/96	Time:	13:50	
Sample age at start:	671.2	hours =	28.0	days =	0.1	yr

Profile geometry

No of points: 9

Layer no.	1	2	3	4	5	6
Layer start [mm]	0.0	1.0	2.5	4.0	5.4	7.0
Layer stop [mm]	1.0	2.5	4.0	5.4	7.0	8.7
Layer no.	**7**	**8**	**9**	**10**	**11**	**12**
Layer start [mm]	8.7	10.3	12.0			
Layer stop [mm]	10.3	12.0	14.0			

Chloride content according to DS 423.28

Concentration of solutions
AgNO3 0.1011 mol/l
NH4SCN 0.1016 mol/l

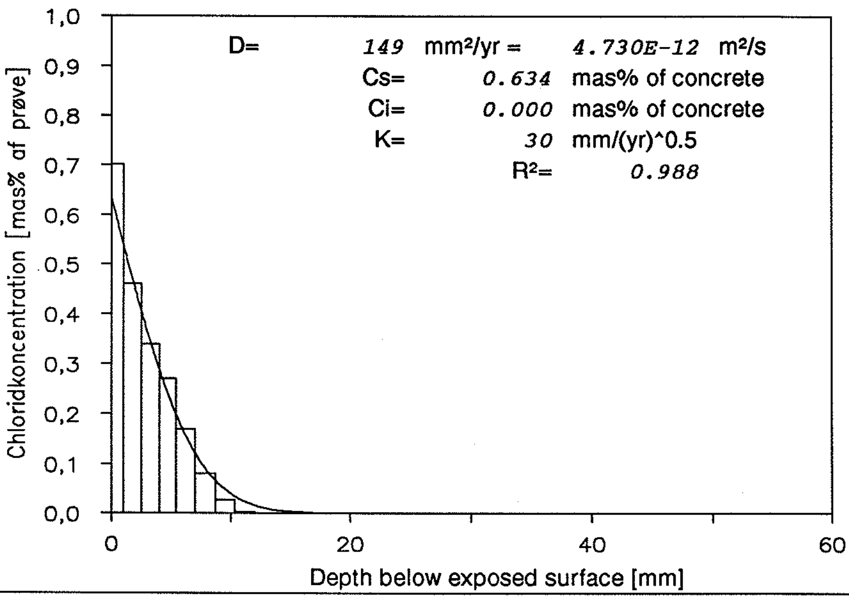
Dilution: 3.0 times

Layer no.	1	2	3	4	5	6
Flask no.	30	33	35	36	37	38
Flask [g]	130.19	130.99	130.54	129.36	127.57	129.19
Flask + sample [g]	141.62	141.89	142.06	139.04	138.62	142.58
Sample mass [g]	11.43	10.90	11.52	9.68	11.05	13.39
AgNO3 [ml]	10.00	10.00	10.00	10.00	5.00	5.00
NH4SCN [ml]	2.53	5.30	6.33	7.53	3.25	3.98
mas% Cl of sample	0.702	0.461	0.340	0.270	0.169	0.080
Layer no.	**7**	**8**	**9**	**10**	**11**	**12**
Flask no.	40	43	55			
Flask [g]	130.79	127.86	128.25			
Flask + sample [g]	141.06	140.91	143.17			
Sample mass [g]	10.27	13.05	14.92			
AgNO3 [ml]	5.00	5.00	5.00			
NH4SCN [ml]	4.72	4.94	5.01			
mas% Cl of sample	0.027	0.003	-0.003			

Chloride profile

Centre [mm]	Cl-conc [mas%]
0.50	0.702
1.75	0.461
3.25	0.340
4.70	0.270
6.20	0.169
7.85	0.080
9.50	0.027
11.15	0.003
13.00	-0.003

D= 149 mm²/yr = 4.730E-12 m²/s
Cs= 0.634 mas% of concrete
Ci= 0.000 mas% of concrete
K= 30 mm/(yr)^0.5
R^2= 0.988



Version: 4.1 1994.10.12

D68007-2.WR1

Determination of Chloride Diffusion Coefficient

Chalmers university of technology

Method: "Recommended Procedure for Determination of Chloride Diffusion Coefficient by Using CTH Rapid method" by Tang Luping

Sample:1a

Test conducted by: Johan Aavik Date: 300196

Potential:	40 V	Start:11^{25}	
al Current:	169 mA	Stop:14^{45}	
Recommended Duration		*h*	

			Duration:	200 min
Sample	Height:	50 mm	penetratio	17 mm
	Diameter:	100 mm	*penetration*	*min*
			penetration	*max*

Notes:W/C-ratio 0,7

D_{CTH} 3,90E-11 mm2 s-1

Observations:

stopp current 175 mA

Controlled Alf Andersen Date

Determination of Chloride Diffusion Coefficient

Chalmers university of technology

Method: "Recommended Procedure for Determination of Chloride Diffusion Coefficient by Using CTH Rapid method" by Tang Luping

Sample:1b

Test conducted by: Johan Aavik Date: 300196

Potential: 40 V Start:11^{25}

al Current: 172 mA Stop:14^{45}

Recommended Duration *h*

Duration: 200 min

Sample Height: 50 mm penetratio 18 mm

Diameter: 100 mm *penetration* *min*

penetration *max*

Notes:W/C-ratio 0,7

D_{CTH} 4,15E-11 mm2 s-1

Observations:

stopp current 194 mA

Controlled Alf Andersen Date

Determination of Chloride Diffusion Coefficient

Chalmers university of technology

Method: "Recommended Procedure for Determination of Chloride Diffusion Coefficient by Using CTH Rapid method" by Tang Luping

Sample:2a

Test conducted by: Johan Aavik Date:050296

Potential:	40 V	Start:15^{15}
al Current:	147,6 mA	Stop:21^{15}
Recommended Duration		*h*

			Duration:	360 min
Sample	Height:	50 mm	penetratio	26 mm
	Diameter:	100 mm	*penetration*	*min*
			penetration	*max*

Notes:W/C-ratio 0,6

D_{CTH} 3,41E-11 mm2 s-1

Observations:

stopp current 162,5 mA

Controlled Alf Andersen Date

Determination of Chloride Diffusion Coefficient

Chalmers university of technology

Method: "Recommended Procedure for Determination of Chloride Diffusion Coefficient by Using CTH Rapid method" by Tang Luping

Sample:2b

Test conducted by: Johan Aavik Date:050296

Potential: 40 V Start:15^{15}
al Current: 148,2 mA Stop:21^{15}
Recommended Duration *h*

Sample Height: 50 mm
Diameter: 100 mm

Duration: 360 min
penetratio 25 mm
penetration *min*
penetration *max*

Notes:W/C-ratio 0,6

D_{CTH} 3,27E-11 mm2 s-1

Observations:
stopp current 160,0 mA

Controlled Alf Andersen Date

Determination of Chloride Diffusion Coefficient

Chalmers university of technology

Method: "Recommended Procedure for Determination of Chloride Diffusion Coefficient by Using CTH Rapid method" by Tang Luping

Sample:3a

Test conducted by: Johan Aavik Date:060296

Potential: 40 V Start:9^{40}

al Current: 118,6 mA Stop:20^{40}

Recommended Duration *h*

Duration: 660 min

Sample Height: 50 mm penetratio 27 mm

Diameter: 100 mm *penetration* *min*

penetration *max*

Notes:W/C-ratio 0,5

D_{CTH} 1,93E-11 mm2 s-1

Observations:

stopp current 127,8 mA

Controlled Alf Andersen Date

Determination of Chloride Diffusion Coefficient

Chalmers university of technology

Method: "Recommended Procedure for Determination of Chloride Diffusion Coefficient by Using CTH Rapid method" by Tang Luping

Sample:3b

Test conducted by: Johan Aavik Date:060296

Potential:	40 V	Start:9[40]
al Current:	115,1 mA	Stop:20[40]
Recommended Duration		*h*

			Duration:	660	min
Sample	Height:	50 mm	penetratio	25	mm
	Diameter:	100 mm	*penetration*		*min*
			penetration		*max*

Notes:W/C-ratio 0,5

D_{CTH} 1,78E-11 mm2 s-1

Observations:

stopp current 120,0 mA

Controlled Alf Andersen Date

Determination of Chloride Diffusion Coefficient

Chalmers university of technology

Method: "Recommended Procedure for Determination of Chloride Diffusion Coefficient by Using CTH Rapid method" by Tang Luping

Sample:4a

Test conducted by: Johan Aavik Date:120296

Potential: 40 V Start:9^{40}
al Current: 116,8 mA Stop:21^{55}
Recommended Duration *h*

Duration: 735 min

Sample Height: 50 mm
Diameter: 100 mm

penetratio 28 mm
penetration *min*
penetration *max*

Notes:W/C-ratio 0,45

D_{CTH} 1,80E-11 mm2 s-1

Observations:
stopp current 117,2 mA

Controlled Alf Andersen Date

Determination of Chloride Diffusion Coefficient

Chalmers university of technology

Method: "Recommended Procedure for Determination of Chloride Diffusion Coefficient by Using CTH Rapid method" by Tang Luping

Sample:4b

Test conducted by: Johan Aavik Date:120296

Potential: 40 V Start:9^{40}
al Current: 111,9 mA Stop:21^{55}
Recommended Duration *h*

Duration: 735 min
Sample Height: 50 mm penetratio 27 mm
Diameter: 100 mm *penetration* *min*
penetration *max*

Notes:W/C-ratio 0,45

D_{CTH} 1,74E-11 mm2 s-1

Observations:
stopp current 111,4 mA

Controlled Alf Andersen Date

Determination of Chloride Diffusion Coefficient

Chalmers university of technology

Method: "Recommended Procedure for Determination of Chloride Diffusion Coefficient by Using CTH Rapid method" by Tang Luping

Sample:5a

Test conducted by: Johan Aavik Date:130296

Potential: 40 V Start130296-17^{25}

al Current: 109,8 mA Stop:140296-09^{05}

Recommended Duration *h*

Duration: 960 min

Sample Height: 50 mm penetratio 30 mm

Diameter: 100 mm *penetration* *min*

penetration *max*

Notes:W/C-ratio 0,4

D_{CTH} 1,49E-11 mm2 s-1

Observations:

stopp current 105,0 mA

Controlled Alf Andersen Date

Determination of Chloride Diffusion Coefficient

Chalmers university of technology

Method: "Recommended Procedure for Determination of Chloride Diffusion Coefficient by Using CTH Rapid method" by Tang Luping

Sample:5b

Test conducted by: Johan Aavik Date:130296

Potential: 40 V Start130296-17[25]
al Current: 108,8 mA Stop:140296-09[05]
Recommended Duration *h*

Sample Height: 50 mm
Diameter: 100 mm

Duration: 960 min
penetratio 28 mm
penetration *min*
penetration *max*

Notes:W/C-ratio 0,4

D_{CTH} 1,38E-11 mm2 s-1

Observations:

stopp current 103,0 mA

Controlled Alf Andersen Date

Determination of Chloride Diffusion Coefficient

Chalmers university of technology

Method: "Recommended Procedure for Determination of Chloride Diffusion Coefficient by Using CTH Rapid method" by Tang Luping

Sample:6a

Test conducted by: Johan Aavik Date:170296

Potential: 40 V Start170296-16[00]

al Current: 87,2 mA Stop:180296-09[00]

Recommended Duration *h*

Duration: 1020 min

Sample Height: 50 mm penetratio 24 mm

Diameter: 100 mm *penetration* *min*

penetration *max*

Notes:W/C-ratio 0,35

D_{CTH} 1,10E-11 mm2 s-1

Observations:

stopp current 85,6 mA

Controlled Alf Andersen Date

Determination of Chloride Diffusion Coefficient

Chalmers university of technology

Method: "Recommended Procedure for Determination of Chloride Diffusion Coefficient by Using CTH Rapid method" by Tang Luping

Sample:6b

Test conducted by: Johan Aavik Date:170296

Potential: 40 V Start170296-16^{00}

al Current: 84,9 mA Stop:180296-09^{00}

Recommended Duration *h*

Duration: 1020 min

Sample Height: 50 mm penetratio 24 mm

Diameter: 100 mm *penetration* *min*

penetration *max*

Notes:W/C-ratio 0,35

D_{CTH} 1,10E-11 mm2 s-1

Observations:

stopp current 85,0 mA

Controlled Alf Andersen Date

Determination of Chloride Diffusion Coefficient

Chalmers university of technology

Method: "Recommended Procedure for Determination of Chloride Diffusion Coefficient by Using CTH Rapid method" by Tang Luping

Sample:7a

Test conducted by: Johan Aavik Date:180296

Potential: 40 V Start180296-17[30]
al Current: 68,4 mA Stop:190296-17[30]
Recommended Duration *h*

Sample Height: 50 mm
Diameter: 100 mm

Duration: 1440 min
penetratio 24 mm
penetration *min*
penetration *max*

Notes:W/C-ratio 0,3

D_{CTH} 7,83E-12 mm2 s-1

Observations:
stopp current 58,4 mA

Controlled Alf Andersen Date

Determination of Chloride Diffusion Coefficient

Chalmers university of technology

Method: "Recommended Procedure for Determination of Chloride Diffusion Coefficient by Using CTH Rapid method" by Tang Luping

Sample:7b

Test conducted by: Johan Aavik Date:180296

Potential: 40 V Start180296-17[30]
al Current: 70 mA Stop:190296-17[30]
Recommended Duration *h*

Sample Height: 50 mm
Diameter: 100 mm

Duration: 1440 min
penetratio 24 mm
penetration ______ *min*
penetration ______ *max*

Notes:W/C-ratio 0,3

D_{CTH} 7,83E-12 mm2 s-1

Observations:
stopp current 58,9 mA

Controlled Alf Andersen Date

FORCE INSTITUTE

Project:

HETEK

Client: AEC-Laboratoriet A/S
J. Frederiksen / H Sørensen

FORCE Institute ATV
Park Alle 345, Brondby, Denmark
Our ref.: K5 4620/osk

Measurements of Concrete Resistivity.

Description of test sample.

Recipe:	*no. 1*
Water/cement-ratio:	*0.7*
Identification:	*L680-1*
Cast:	*1/2/96 11:15*

Dimensions (cm):			*Area factor:*
1A	*length*	*5.042*	
	diameter	*9.99*	*78.34*
1B	*length*	*4.976*	
	diameter	*9.98*	*78.19*

Measurements:

Core 1A:

Real time	*Acc. time*	*R (sp)*	*R (s+sp)*	*R (s)*	**Resistivity**
	days	*kohm*	*kohm*	*kohm*	**kohm cm**
1/9/96 11:15	*7.0*	*0.0161*	*0.264*	*0.248*	**3.85**
1/30/96 16:30	*28.2*	*0.0686*	*0.33*	*0.261*	**4.06**
4/15/96 10:00	*103.9*	*0.0706*	*0.354*	*0.283*	**4.40**
7/30/96 10:00	*209.9*	*0.081*	*0.405*	*0.324*	**5.03**

Core 1B:

Real time	*Acc. time*	*R (sp)*	*R (s+sp)*	*R (s)*	**Resistivity**
	days	*kohm*	*kohm*	*kohm*	**kohm cm**
1/9/96 11:15	*7.0*	*0.02*	*0.252*	*0.232*	**3.60**
1/30/96 16:30	*28.2*	*0.0686*	*0.329*	*0.260*	**4.04**
4/15/96 10:00	*103.9*	*0.066*	*0.348*	*0.282*	**4.37**
7/30/96 10:00	*209.9*	*0.0842*	*0.398*	*0.313*	**4.86**

FORCE INSTITUTE

Project:

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Client: AEC-Laboratoriet A/S
J. Frederiksen / H Sørensen

FORCE Institute ATV
Park Alle 345, Brondby, Denmark
Our ref.: K5 4620/osk

Measurements of Concrete Resistivity.

Description of test sample.

Recipe:	*no. 2*
Water/cement-ratio:	*0.6*
Identification:	*680-2*
Cast:	*1/8/96 13:52*

Dimensions			*Area factor:*
2A	*length*	*5.035*	
	diameter	*9.99*	*78.34*
2B	*length*	*5.02*	
	diameter	*9.99*	*78.34*

Measurements:

Core 2A:

Real time	*Acc. time*	*R (sp)* *kohm*	*R (s+sp)* *kohm*	*R (s)* *kohm*	**Resistivity kohm cm**
1/15/96 13:15	*7.0*	*0.0704*	*0.36*	*0.290*	**4.51**
2/5/96 13:30	*28.0*	*0.097*	*0.38*	*0.283*	**4.40**
4/15/96 10:15	*97.8*	*0.0648*	*0.336*	*0.271*	**4.22**
7/29/96 10:15	*202.8*	*0.0831*	*0.3845*	*0.301*	**4.69**

Core 2B:

Real time	*Acc. time*	*R (sp)* *kohm*	*R (s+sp)* *kohm*	*R (s)* *kohm*	**Resistivity kohm cm**
1/15/96 13:15	*7.0*	*0.0715*	*0.347*	*0.276*	**4.29**
2/5/96 13:30	*28.0*	*0.097*	*0.36*	*0.263*	**4.09**
4/15/96 10:15	*97.8*	*0.0644*	*0.33*	*0.266*	**4.13**
7/29/96 10:15	*202.8*	*0.0841*	*0.391*	*0.307*	**4.78**

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Project:

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Client: AEC-Laboratoriet A/S
J. Frederiksen / H Sørensen

FORCE Institute ATV
Park Alle 345, Brondby, Denmark
Our ref.: K5 4620/osk

Measurements of Concrete Resistivity.

Description of test sample.

Recipe:	*no. 3*
Water/cement-ratio:	*0.5*
Identification:	*L680-3*
Cast:	*1/9/96 11:45*

Dimensions			*Area factor:*
3A	*length*	*5.106*	
	diameter	*9.99*	*78.34*
3B	*length*	*5.114*	
	diameter	*9.99*	*78.34*

Measurements:

Core 3A:

Real time	*Acc. time*	*R (sp)*	*R (s+sp)*	*R (s)*	**Resistivity**
	days	*kohm*	*kohm*	*kohm*	**kohm cm**
1/16/96 13:30	*7.1*	*0.0873*	*0.396*	*0.309*	**4.74**
2/6/96 13:30	*28.1*	*0.096*	*0.408*	*0.312*	**4.79**
4/15/96 10:25	*96.9*	*0.0607*	*0.398*	*0.337*	**5.18**
7/16/96 10:25	*188.9*	*0.0946*	*0.511*	*0.416*	**6.38**

Core 3B:

Real time	*Acc. time*	*R (sp)*	*R (s+sp)*	*R (s)*	**Resistivity**
	days	*kohm*	*kohm*	*kohm*	**kohm cm**
1/16/96 13:30	*7.1*	*0.0806*	*0.409*	*0.328*	**5.04**
2/6/96 13:30	*28.1*	*0.096*	*0.411*	*0.315*	**4.83**
4/15/96 10:25	*96.9*	*0.0637*	*0.41*	*0.346*	**5.31**
7/16/96 10:25	*188.9*	*0.1053*	*0.532*	*0.426*	**6.54**

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Project:

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Client: AEC-Laboratoriet A/S
J. Frederiksen / H Sørensen

FORCE Institute ATV
Park Alle 345, Brondby, Denmark
Our ref.: K5 4620/osk

Measurements of Concrete Resistivity.

Description of test sample.

Recipe:	*no. 4*
Water/cement-ratio:	*0.45*
Identification:	*L680-4*
Cast:	*1/15/96 11:25*

Dimensions			*Area factor:*
4A	*length*	*5.029*	
	diameter	*9.99*	*78.34*
4B	*length*	*5.005*	
	diameter	*10*	*78.50*

Measurements:

Core 4A:

Real time	*Acc. time days*	*R (sp) kohm*	*R (s+sp) kohm*	*R (s) kohm*	**Resistivity kohm cm**
1/22/96 0:00	*6.5*	*0.1257*	*0.462*	*0.336*	**5.24**
2/12/96 13:00	*28.1*	*0.087*	*0.419*	*0.332*	**5.17**
4/15/96 10:35	*91.0*	*0.0578*	*0.443*	*0.385*	**6.00**
7/15/96 10:35	*182.0*	*0.09*	*0.586*	*0.496*	**7.72**

Core 4B:

Real time	*Acc. time days*	*R (sp) kohm*	*R (s+sp) kohm*	*R (s) kohm*	**Resistivity kohm cm**
1/22/96 12:00	*7.0*	*0.1257*	*0.461*	*0.335*	**5.23**
2/12/96 13:00	*28.1*	*0.087*	*0.419*	*0.332*	**5.18**
4/15/96 10:35	*91.0*	*0.0577*	*0.441*	*0.383*	**5.98**
7/15/96 10:35	*182.0*	*0.0763*	*0.560*	*0.483*	**7.54**

31.E.01.94

FORCE INSTITUTE

Project:

HETEK

Client: AEC-Laboratoriet A/S
J. Frederiksen / H Sørensen

FORCE Institute ATV
Park Alle 345, Brondby, Denmark
Our ref.: K5 4620/osk

Measurements of Concrete Resistivity.

Description of test sample.

Recipe:	*no. 5*
Water/cement-ratio:	*0.4*
Identification:	*L680-5*
Cast:	*1/16/96 9:40*

Dimensions(cm):			*Area factor:*
5A	*length*	*5.009*	
	diameter	*9.99*	*78.34*
5B	*length*	*4.931*	
	diameter	*10*	*78.50*

Measurements:

Core 5A:

Real time	*Acc. time days*	*R (sp) kohm*	*R (s+sp) kohm*	*R (s) kohm*	**Resistivity kohm cm**
1/23/96 9:20	*7.0*	*0.0781*	*0.395*	*0.317*	**4.96**
2/13/96 13:00	*28.1*	*0.1048*	*0.469*	*0.364*	**5.70**
4/15/96 10:45	*90.0*	*0.0599*	*0.509*	*0.449*	**7.02**
7/9/96 10:00	*175.0*	*0.076*	*0.634*	*0.558*	**8.72**

Core 5B:

Real time	*Acc. time days*	*R (sp) kohm*	*R (s+sp) kohm*	*R (s) kohm*	**Resistivity kohm cm**
1/23/96 9:20	*7.0*	*0.0781*	*0.39*	*0.312*	**4.89**
2/13/96 13:00	*28.1*	*0.1048*	*0.472*	*0.367*	**5.75**
4/15/96 10:45	*90.0*	*0.0597*	*0.529*	*0.469*	**7.35**
7/9/96 10:00	*175.0*	*0.0746*	*0.628*	*0.553*	**8.67**

31.E.01.94

FORCE INSTITUTE

Project:

HETEK

Client: AEC-Laboratoriet A/S
J. Frederiksen / H Sørensen

FORCE Institute ATV
Park Alle 345, Brondby, Denmark
Our ref.: K5 4620/osk

Measurements of Concrete Resistivity.

Description of test sample.

Recipe:	no. 6
Water/cement-ratio:	0.35
Identification:	L680-6
Cast:	1/22/96 14:45

Dimensions(cm):			Area factor:
6A	length	4.993	
	diameter	10	78.50
6B	length	4.983	
	diameter	10	78.50

Measurements:

Core 6A:

Real time	Acc. time days	R (sp) kohm	R (s+sp) kohm	R (s) kohm	**Resistivity kohm cm**
1/29/96 15:00	7.0	0.068	0.443	0.375	**5.90**
2/19/96 14:30	28.0	0.0745	0.528	0.4535	**7.13**
4/15/96 10:55	83.8	0.0528	0.609	0.5562	**8.74**
7/8/96 10:00	167.8	0.0909	0.87	0.7791	**12.25**

Core 6B:

Real time	Acc. time days	R (sp) ohm	R (s+sp) kohm	R (s) kohm	**Resistivity kohm cm**
1/29/96 15:00	7.0	0.068	0.448	0.380	**5.97**
2/19/96 14:30	28.0	0.0745	0.546	0.472	**7.41**
4/15/96 10:55	83.8	0.0528	0.625	0.572	**9.00**
7/8/96 10:00	167.8	0.0923	0.904	0.811	**12.75**

FORCE INSTITUTE

Project:

HETEK

Client: AEC-Laboratoriet A/S
J. Frederiksen / H Sørensen

FORCE Institute ATV
Park Alle 345, Brondby, Denmark
Our ref.: K5 4620/osk

Measurements of Concrete Resistivity.

Description of test sample.

Recipe:	*no. 7*
Water/cement-ratio:	*0.3*
Identification:	*L680-7*
Cast:	*1/23/96 13:50*

Dimensions(cm):			*Area factor:*
7A	*length*	*5.015*	
	diameter	*9.99*	*78.34*
7B	*length*	*5.046*	
	diameter	*10*	*78.50*

Measurements:

Core 7A:

Real time	*Acc. time days*	*R (sp) kohm*	*R (s+sp) kohm*	*R (s) kohm*	**Resistivity kohm cm**
1/30/96 14:30	*7.03*	*0.1082*	*0.55*	*0.442*	**6.90**
2/20/96 15:00	*28.05*	*0.0764*	*0.658*	*0.582*	**9.09**
4/15/96 11:05	*82.89*	*0.0487*	*0.778*	*0.729*	**11.39**
7/3/96 10:00	*161.84*	*0.11*	*1.128*	*1.018*	**15.90**

Core 7B:

Real time	*Acc. time days*	*R (sp) kohm*	*R (s+sp) kohm*	*R (s) kohm*	**Resistivity kohm cm**
1/30/96 14:30	*7.03*	*0.1082*	*0.537*	*0.429*	**6.71**
2/20/96 15:00	*28.05*	*0.0546*	*0.617*	*0.562*	**8.80**
4/15/96 11:05	*82.89*	*0.0469*	*0.758*	*0.711*	**11.13**
7/3/96 10:00	*161.84*	*0.0904*	*1.106*	*1.016*	**15.90**