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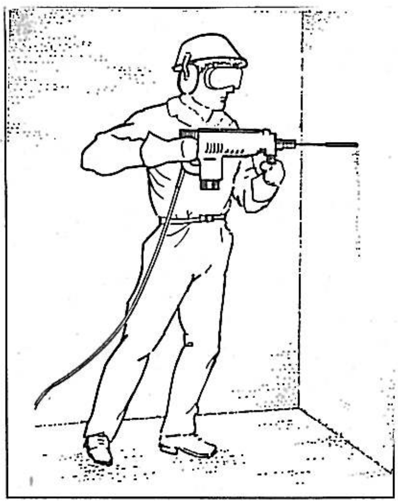
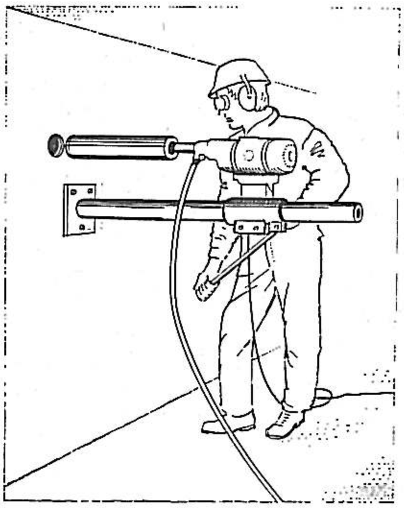
Tom Farstad, Hans Chr. Gran and
Kåre Reknes

Measurement of chlorides in concrete

Sampling techniques





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SUMMARY

A test has been performed to evaluate two different sampling techniques and their influence on the results of chloride measurements in concrete. The two techniques used were dry drilling (20 mm bore) using a hand held drill and water-cooled drilling of cores (Ø 98 mm) using a jig-mounted drill.

Samples were taken from concrete specimens cast with 0.0%, 1.0 % and 3.0 % chloride content by weight of concrete. The specimens also differed in maximum aggregate sizes, 11.2 mm, 16 mm and 32 mm. The specimens containing 0.0 % chloride were after hardening exposed to chloride solution to produce a concentration gradient. A comparison is done between a set of two cores and a material from five dry drilled holes.

The analysis shows good accuracy and precision in measured chloride contents for cores drilled from specimens of known concentration (1.0 % and 3.0 %). Correlation between parallel cores is good.

Measured chloride contents from dry drilled dust show poorer but acceptable accuracy and precision only for max. aggregate sizes below drilling diameter, i.e. 11.2 mm and 16 mm. For max. diameter 32 mm, absolute deviations of single measurements up to about 40 % from the mean chloride value is observed. The same pattern is reflected when chloride gradients/profiles are measured.

It is concluded that a bore diameter above maximum aggregate size is essential to obtain sufficient accuracy and precision in chloride measurements. A bore of 20 mm must be considered to be close to an upper practical limit. Five holes is therefore insufficient, and further gain in accuracy and precision may only be achieved through an increase in the number of holes.

MEASUREMENT OF CHLORIDES IN CONCRETE
Sampling techniques

1. INTRODUCTION

This investigation was designed to evaluate the influence of the sampling technique on the results of chloride measurements in concrete. The analysis of chlorides in concrete has received great current interest with the increasing knowledge about the extent of the damaging effects of chlorides on steel reinforcement. Chlorides penetrate into the concrete over a period of time. The depth of penetration is dependent on factors such as concrete permeability, humidity and chloride exposure. Therefore, in addition to the usual measurements of chlorides, there is often a wish to map the amount of penetration of chlorides into the concrete through the measurement of concentration gradients or profiles. This makes great demands not only to the chemical analysis [1], but also to the sampling technique.

Several sampling techniques for chloride analysis are in normal use. Among these are:

- chiselling by hand or machine
- dry drilling by using hand held drill
- water-cooled drilling of cores using a jig-mounted drill
- grinding using a profile grinding equipment

The chiselling technique suffers from poor controllability and is not suitable for accurate recording of chloride concentration gradients in concrete. Profile grinding is a highly accurate and promising sampling technique, but it's use is limited due to it's recent development.

This work deals with the second and third techniques, dry drilling and water-cooled drilling of cores, of which dry drilling is the most commonly used due to low costs and simplicity. Core drilling normally gives the best accuracy and precision, provided that the size of the aggregate is not too large compared to the core diameter. The technique requires heavier equipment on the sampling site and additional cutting before chemical analysis. It is therefore more costly in use. Both techniques are suitable for measurement of chloride profiles in concrete.

Following factors are investigated:

- influence of aggregate size on analysed chloride content
- number of sample parallels needed to meet requirement for adequate accuracy and precision, comparison of the two techniques
- ability to detect chloride profiles, comparison of the two techniques

- effect of chloride concentration

For this purpose 296 different samples were taken from concretes cast with known chloride content and concretes with a laboratory induced chloride profile. The chloride contents were determined by means of potentiometric titration.

2 SPECIMENS

2.1 Test specimens

Test specimens for the investigations were made in June 1991. The specimens consisted of twenty cubes (100 mm x100 mm x100 mm) for measurement of compressive strength, and twenty-four beams (150 mm x150 mm x 470 mm) for chloride sampling tests. All the beams and twelve of the cubes were cast with chloride contents of 1.0% and 3.0%. by weight related to the weight of the cement.

In addition, four plates (150 mm x 400 mm x 700 mm) were made without chlorides. These plates were to be exposed to chloride solution during a cycling process. The cycling process consisted of drying at 50° C for two weeks followed by immersion in 3% NaCl-solution to achieve a chloride profile.

2.2 Plates

The plates were made with an almost identical recipe. The only variation being a smaller volume-% of paste in mix I than in mix II, III and IV. For details concerning mix proportions see table 2.1.

Table 2.1
Mix proportions for plates

Material	Mix (kg)	
	I	II-III-IV
Cement type RP 38	16.80	18.00
Water	7.56	8.10
Fine aggregate, 0-8 mm	50.78	50.78
Coarse aggregate, 8-11.2 mm	23.08	23.08
Coarse aggregate, 11.2-16 mm	18.47	18.47
W/c-ratio	0.45	0.45
Vol-% paste	27.4	28.8
Batch volume (l)	47.5	48.5

Seven days after casting, the plates were demolded and stored under exposure to laboratory air. The cubes were demolded after one day and stored in water until tested for compressive strength after 28 days. The results from the testing of compressive strengths are shown in table 2.4.

The plates were left in storage for 17 months before commencing the cycling process.

2.3 Beams

The beams were made with three different maximum aggregate sizes and two different chloride concentrations, giving six different concrete recipes. Each of the recipes were used to make four beams (150 mm x 150 mm x 470 mm) for chloride measurements and cubes for compressive strength tests. The chlorides were dissolved in a part of the mix-water and then poured into the concrete mix.

For mix proportions see table 2.2.

Table 2.2
Mix proportion for beams

Material	Mix (kg)					
	1	2	3	4	5	6
Rapid cement RP 38	18.000	18.000	18.000	18.000	18.000	18.000
Water	8.100	8.100	8.100	8.100	8.100	8.100
Sand 0-8	46.160	46.160	50.750	50.780	50.780	50.780
Coarse aggregate 8-11.2	46.160	46.160	23.080	23.080	9.230	9.230
Coarse aggregate 11.2-16	-	-	18.470	18.470	9.230	9.230
Coarse aggregate 16-32	-	-	-	-	23.080	23.080
NaCl	0.297	0.890	0.297	0.890	0.297	0.890
W/c-ratio	0.45	0.45	0.45	0.45	0.45	0.45
Vol.paste (%)	28.8	28.8	28.8	28.8	28.8	28.8
Vol.aggregate (%)	71.2	71.2	71.2	71.2	71.2	71.2
Chloride content by m-% of cement	1.0	3.0	1.0	3.0	1.0	3.0
Batch volume (l)	48.5	48.5	48.5	48.5	48.5	48.5

Both the beams and the cubes were demolded one day after casting. The cubes were stored in water until tested for compressive strength after 28 days. Each beam was sealed separately with a strong plastic foil, placed with the others and finally covered with a second plastic foil. The beams were then stored in this way for fifteen months before sampling.

Measured slump and density of the fresh concretes are listed in table 2.3 and 2.4. As shown in the tables the slump was low. This was a result of avoiding plasticizers which could affect the chloride measurements.

The results from measurement of compressive strength and density of the hardened concrete are shown in table 2.5. All figures are mean values obtained from testing of two specimens.

Table 2.3
Fresh concrete properties - plate mixes

Properties	Mix			
of fresh concrete	I	II	III	IV
Slump (cm)	2.0	2.0	3.0	3.0
Density (g/cm³)	2.460	2.450	2.453	2.437

Table 2.4
Fresh concrete properties - beam mixes

Properties	Mix					
of fresh concrete	1	2	3	4	5	6
Slump (cm)	3.0	4.0	4.0	4.5	4.5	7.0
Density (g/cm³)	2.455	2.431	2.434	2.401	2.445	2.413

Table 2.5
Mechanical properties of hardened concrete (plates and beams)

Properties	Mix									
of hardened concrete	1	2	3	4	5	6	I	II	III	IV
Compressive strength (MPa)	58.1	54.8	56.1	53.5	55.0	52.0	52.7	49.9	54.1	51.9
Density (g/cm³)	2.438	2.434	2.420	2.428	2.407	2.441	2.459	2.461	2.440	2.421

3. EXPERIMENTAL

3.1 Sampling

3.1.1 Beams

To determine a representative mean value of the chloride content in the beams, a 50 mm thick slice was cut from the centre of each beam, as shown in Fig. 1. Each slice was cut to form an inner and outer part. The outer part consisted of the outer 25 mm of the slice measured from the beam surface. Each part was dried, ground and analysed separately.

Two cores (Ø 98 mm) were drilled from each beam using a jig mounted water cooled drill. See Fig. 2. The water cooling was kept at a minimum to reduce the danger of chlorides being washed out. Four slices with thickness 8 mm were cut from each core at the following depths measured from the concrete surface: 0-10 mm, 10-20 mm, 20-30 mm, 30-40 mm.

Five dry drilled samples were collected from each beam by drilling five 40 mm deep holes with diameter 20 mm. Dry drilled samples and cores were collected according to a fixed pattern, see Fig. 2. The drill was stabilized during sampling by a template to avoid damaging the concrete surface. To determine the chloride profile, dust samples were collected at the following depths: 0-10 mm, 10-20 mm, 20-30 mm, 30-40 mm. Between each drilling step dust was removed from the holes using compressed air.

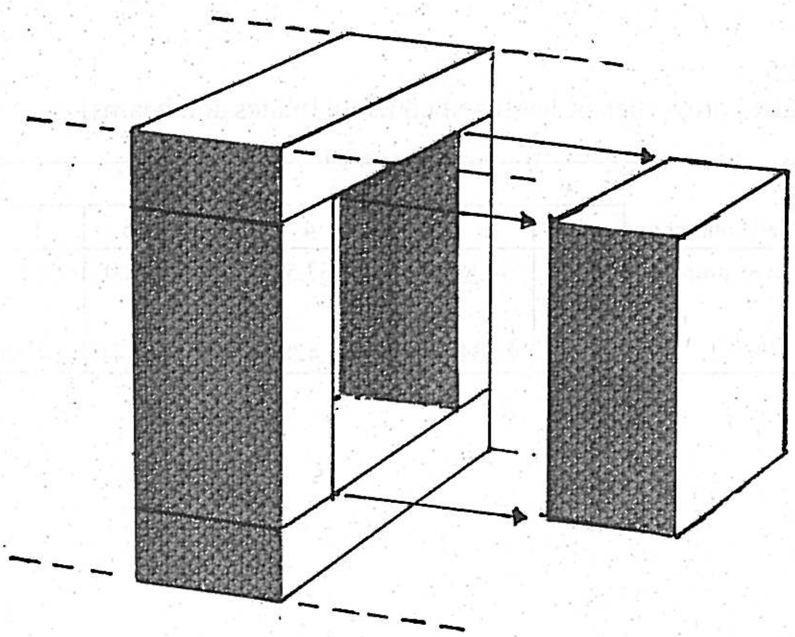


Fig. 1 Exploded view of 50 mm slice as cut from the centre of each beam.

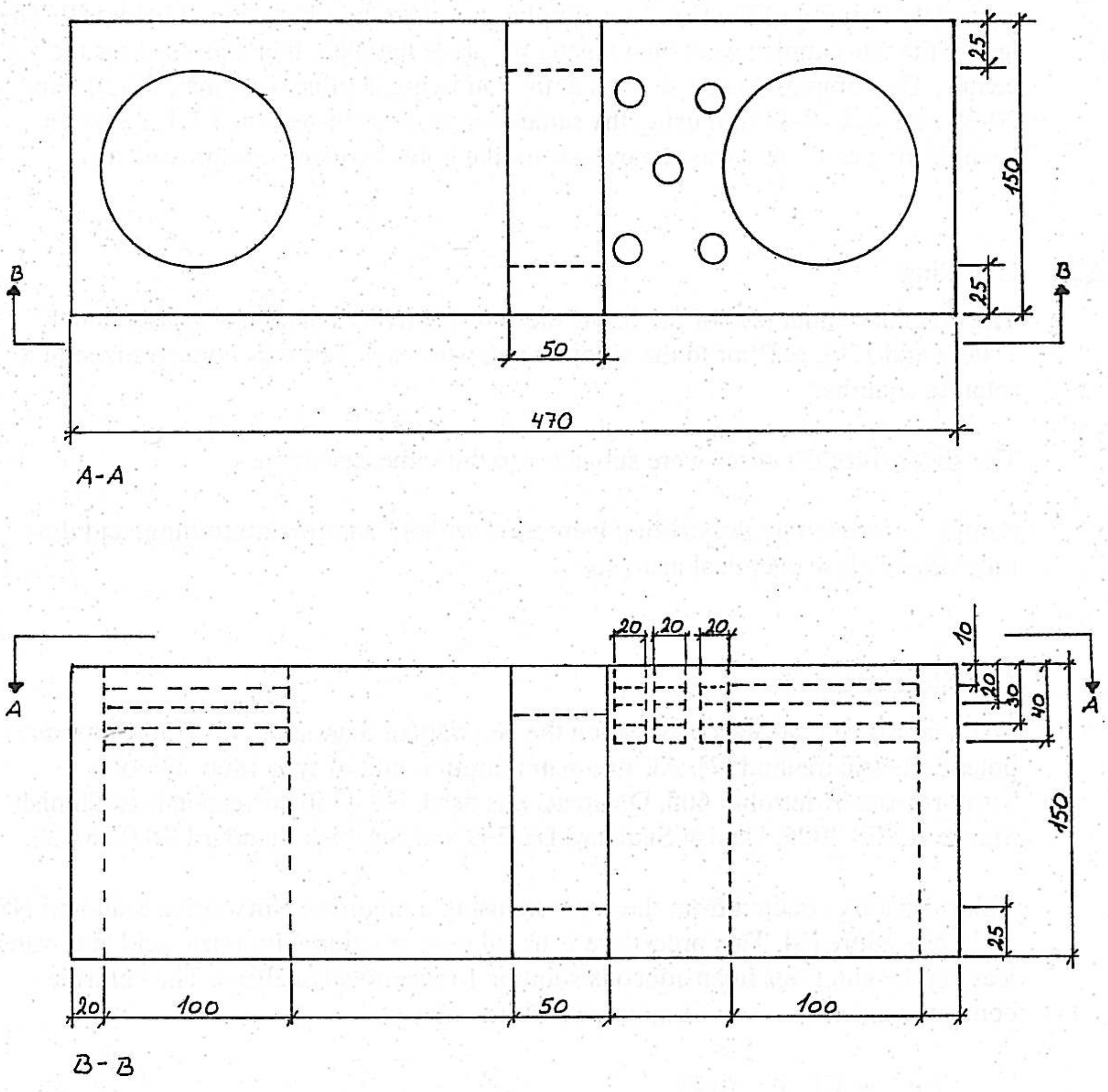


Fig. 2 The drawing shows the sampling pattern applied to each beam.

3.1.2 Plates

One core with diameter 98 mm was drilled from each plate using a water cooled core drilling equipment. As for beams the water cooling was kept at a minimum to avoid loss of chlorides. Six slices with thickness 8 mm were cut from each of the cores. These slices were cut at the following depths measured from the concrete surface: 0-10 mm, 10-20 mm, 20-30 mm, 30-40 mm, 40-50 mm and 50-60 mm.

Samples were also collected by dry drilling of ten 40 mm deep holes (Ø 20 mm) in each slab. Drilling of the first five samples was done by using a hand held drill. The last of the ten samples were taken using the same template that was used for the beams. The samples were collected at the following depths: 0-10 mm, 10-20 mm, 20-30 mm and 30-40 mm using the same procedure as in section 3.1.1. Between each drilling step, dust was removed from the holes by using compressed air.

3.2 Grinding

The outer and inner part of the beam slices respectively contained approximately 1500 g and 1200 g. Prior to the chloride analysis, each part was homogenized in a rotating chamber.

The slices from the cores were subjected to the same treatment.

Samples collected by dry drilling were used without additional grinding, and thus only dried before chemical analysis.

3.3 Chemical analysis

The analysis of chlorides is based on the Norwegian Standard, NS 4756 Chloride, potentiometric method [2]. An automatic titration unit of type Metrohm 686, Titroprocessor/Metrohm 665, Dosimat, was used. NS 4756 corresponds to Finnish Standard SFS 3006, Danish Standard DS 239 and Swedish Standard SS 02 81 36.

Chlorides are extracted from the concrete using a modified Norwegian Standard NS 3671 procedure [3]. This procedure is based on extraction with nitric acid and water, leaving the chlorides in an aqueous solution for chemical analysis. The chloride content is determined by titration with silver nitrate:

$$Ag^{+} + Cl^{-} \leftrightarrow AgCl$$

A silver electrode is used to monitor the change in potential in the solution.

A number of 35 samples of documented concrete reference dust containing known chloride concentrations [4] were randomly incorporated in the sample set to reduce the danger of possible errors in the analysis. These data are shown in Appendix 3.

4 RESULTS

Presentation of the results is divided into two sections. The first section covers the beams which were cast with known concentrations of chlorides. The second section covers the plates prepared to provide chloride profiles. For clarity, the presentation is based on mean values and the corresponding standard deviations.

Tables showing results of all the individual measurements are given in Appendix 1 at the end of the report.

4.1 Beams

Table 4.1 shows results from analysis of the central 50 mm slices. Tables 4.2 and 4.3 show values obtained from measurements on cores and dry drilled dust. It was chosen to present the results from cores and drilled dust in the same manner as in table 4.1, i.e. with an inner and outer part shown both separately and combined. The outer part combining measurements from the two outer levels (depth 0 mm-20 mm) and the inner part combining the two inner levels (depth 20 mm-40 mm).

Table 4.1
Mean chloride concentration and standard deviations in beam slices. Values are calculated from 3 parallels.

Beam	Inner part[1] Chloride concentration (% by concrete weight)		Outer part[2] Chloride concentration (% by concrete weight)	
	Mean value	Standard deviation	Mean value	Standard deviation
1	0.156	0.002	0.159	0.001
2	0.472	0.006	0.449	0.013
3	0.158	0.001	0.154	0.001
4	0.460	0.001	0.435	0.005
5	0.161	0.003	0.152	0.003
6	0.464	0.003	0.425	0.016

Beam	Inner and outer part Chloride concentration (% by concrete weight)	
	Mean value	Standard deviation
1	0.157	0.002
2	0.458	0.017
3	0.156	0.003
4	0.448	0.014
5	0.156	0.006
6	0.444	0.024

[1]Inner part is from 25 mm to the center.
[2]Outer part is depth 0 - 22 mm.

Table 4.2
Chloride concentration in cores drilled from beams. Each of the values are calculated from four parallels.

Beam	Core A and C Inner part[3] Chloride concentration (% by concrete weight)		Core A and C Outer part[4] Chloride concentration (% by concrete weight)	
	Mean value	Standard deviation	Mean value	Standard deviation
1	0.156	0.002	0.165	0.005
2	0.446	0.012	0.465	0.017
3	0.163	0.003	0.170	0.012
4	0.453	0.017	0.488	0.018
5	0.155	0.007	0.176	0.030
6	0.463	0.029	0.523	0.068

Beam	Core A and C Inner and outer part Chloride concentration (% by concrete weight)	
	Mean value	Standard deviation
1	0.160	0.006
2	0.456	0.019
3	0.167	0.010
4	0.471	0.026
5	0.165	0.026
6	0.493	0.065

3 Inner part is depth 20 - 40 mm.
4 Outer part is depth 0 - 20 mm.

Table 4.3
Chloride concentration in dry drilled dust. Each value has been calculated from ten parallels.

Beam	Inner part[5] Chloride concentration (% by concrete weight)		Outer part[6] Chloride concentration (% by concrete weight)	
	Mean value	Standard deviation	Mean value	Standard deviation
1	0.163	0.011	0.182	0.019
2	0.457	0.036	0.494	0.044
3	0.172	0.023	0.188	0.020
4	0.478	0.024	0.542	0.035
5	0.151	0.028	0.174	0.050
6	0.439	0.068	0.580	0.118

Beam	Inner and outer part Chloride concentration (% by concrete weight)	
	Mean value	Standard deviation
1	0.172	0.019
2	0.475	0.046
3	0.180	0.024
4	0.510	0.045
5	0.162	0.043
6	0.510	0.123

4.2 Plates

Two plates were used in the cycling experiments. These were plates corresponding to mixes III and IV. One core was drilled from each plate in order to measure the chloride profiles. The cores were cut into 10 mm slices, dried, ground in a rotary mill and homogenized before chemical analysis. The results are shown in table 4.4. Each figure represents one individual measurement.

As mentioned in section 3.1.2 sampling by dry drilling was performed both with and without the use of a template. This was done in order to distinguish between a hand held drill and a fixed drill. The results from these experiments are listed in tables 4.5 and 4.6.

[5]Inner part is depth 20 - 40 mm.
[6]Outer part is depth 0 - 20 mm.

Table 4.4
Chloride content of core slices from plates.

Depth (mm)	Plate III Chloride concentration (% by concrete weight)	Plate IV Chloride concentration (% by concrete weight)
0 - 10	0.292	0.272
10 - 20	0.140	0.129
20 - 30	0.074	0.064
30 - 40	0.029	0.026
40 - 50	0.009	0.009
50 - 60	0.000	0.009

Table 4.5
Chloride content of dry drilled dust from plates. Drilled without template.

Depth (mm)	Plate III Chloride concentration (% by concrete weight)		Plate IV Chloride concentration (% by concrete weight)	
	Mean value	Standard deviation	Mean value	Standard deviation
0 - 10	0.257	0.035	0.346	0.020
10 - 20	0.153	0.039	0.160	0.012
20 - 30	0.071	0.021	0.098	0.013
30 - 40	0.033	0.020	0.040	0.011

Table 4.6
Chloride content of dry drilled dust from plates. Drilled with template.

Depth (mm)	Plate III Chloride concentration (% by concrete weight)		Plate IV Chloride concentration (% by concrete weight)	
	Mean value	Standard deviation	Mean value	Standard deviation
0 - 10	0.312	0.022	0.342	0.029
10 - 20	0.172	0.025	0.185	0.009
20 - 30	0.109	0.034	0.111	0.022
30 - 40	0.063	0.029	0.069	0.026

5. DISCUSSION

There are two main possible causes for uncertainties in the chloride measurements in this work. The first is uncertainty in the chemical analysis. The second is the uncertainty inherent in the specimens. The autotitration equipment used in this work has proved to give good accuracy and precision [4]. The uncertainty in the chemical analysis may therefore be regarded as low compared to the inherent uncertainty. The uncertainty connected to the specimens is governed by several factors. Among these are:

- sample volume - number of samples
- maximum aggregate diameter
- bore size
- chloride concentration

In the following sections the core drilling technique and dry drilling technique are discussed with these factors in mind.

5.1 Sample volume - number of samples

The sample volume will have a great influence on the test results. As a consequence of the concrete being a composite material consisting of paste and a coarse fraction of aggregate, a decrease in sample volume will lead to a reduction in both precision and accuracy. The results show that the chosen diameter of Ø98 mm, gives measurements with very good precision and accuracy. The results from sampling by dry drilling, however, show results with reduced precision and accuracy. This is illustrated in Figures 5.1, 5.2, 5.3 and 5.4, and does probably reflect the effect of differences in sample volume achieved with the two techniques. To get the same amount of sample volume using a 20 mm drill as with 98 mm diameter drilled cores approximately 20 holes have to be drilled. This is of course neither a practical nor an economical solution to the problem. Often no more than three parallel holes are drilled when samples are collected from field constructions.

In table 5.1 the mean values and their standard deviations are listed for the analysis of samples collected by dry drilling. The calculation of the mean values and standard deviations are carried out with respectively (1) , 2 , 3 , 4 and 5 samples, in order to evaluate the effect of an increasing sample volume for the analysis. The dust from the first measurement was always drilled out first, the second measurement drilled as the second etc.

Profiles obtained with dry drilled dust samples show systematically higher values than the corresponding core slices. This behaviour is not observed for the beams cast with chlorides. The cause is not known.

Table 5.1 Effect of number of samples.

Number of parallells	5				4			
	0 - 10 mm	10 - 20 mm	20 - 30 mm	30 - 40 mm	0 - 10 mm	10 - 20 mm	20 - 30 mm	30 - 40 mm
Plate III with template								
Mean value	0,312	0,172	0,109	0,063	0,305	0,177	0,104	0,056
Standard deviation	0,025	0,028	0,038	0,032	0,023	0,030	0,042	0,032
Plate III without template								
Mean value	0,257	0,153	0,071	0,033	0,244	0,141	0,071	0,032
Standard deviation	0,039	0,044	0,024	0,023	0,031	0,040	0,028	0,028
Plate IV with template								
Mean value	0,342	0,185	0,111	0,069	0,346	0,187	0,106	0,061
Standard deviation	0,032	0,010	0,024	0,029	0,036	0,011	0,025	0,028
Plate IV without template								
Mean value	0,346	0,160	0,098	0,040	0,346	0,158	0,093	0,039
Standard deviation	0,023	0,014	0,014	0,013	0,026	0,015	0,009	0,014

Number of parallells	3				2			
	0 - 10 mm	10 - 20 mm	20 - 30 mm	30 - 40 mm	0 - 10 mm	10 - 20 mm	20 - 30 mm	30 - 40 mm
Plate III with template								
Mean value	0,301	0,163	0,084	0,040	0,286	0,157	0,078	0,036
Standard deviation	0,026	0,013	0,016	0,007	0,004	0,008	0,018	0,001
Plate III without template								
Mean value	0,230	0,122	0,058	0,016	0,222	0,117	0,053	0,016
Standard deviation	0,016	0,014	0,008	0,001	0,011	0,016	0,003	0,001
Plate IV with template								
Mean value	0,329	0,183	0,095	0,048	0,326	0,181	0,090	0,045
Standard deviation	0,006	0,009	0,015	0,008	0,004	0,011	0,017	0,008
Plate IV without template								
Mean value	0,340	0,151	0,088	0,034	0,331	0,152	0,087	0,028
Standard deviation	0,029	0,004	0,004	0,013	0,034	0,004	0,004	0,009

Number of parallells	1			
	0 - 10 mm	10 - 20 mm	20 - 30 mm	30 - 40 mm
Plate III with template				
Mean value	0,289	0,151	0,065	0,035
Standard deviation				
Plate III without template				
Mean value	0,230	0,106	0,051	0,016
Standard deviation				
Plate IV with template				
Mean value	0,323	0,189	0,102	0,039
Standard deviation				
Plate IV without template				
Mean value	0,307	0,149	0,089	0,034
Standard deviation				

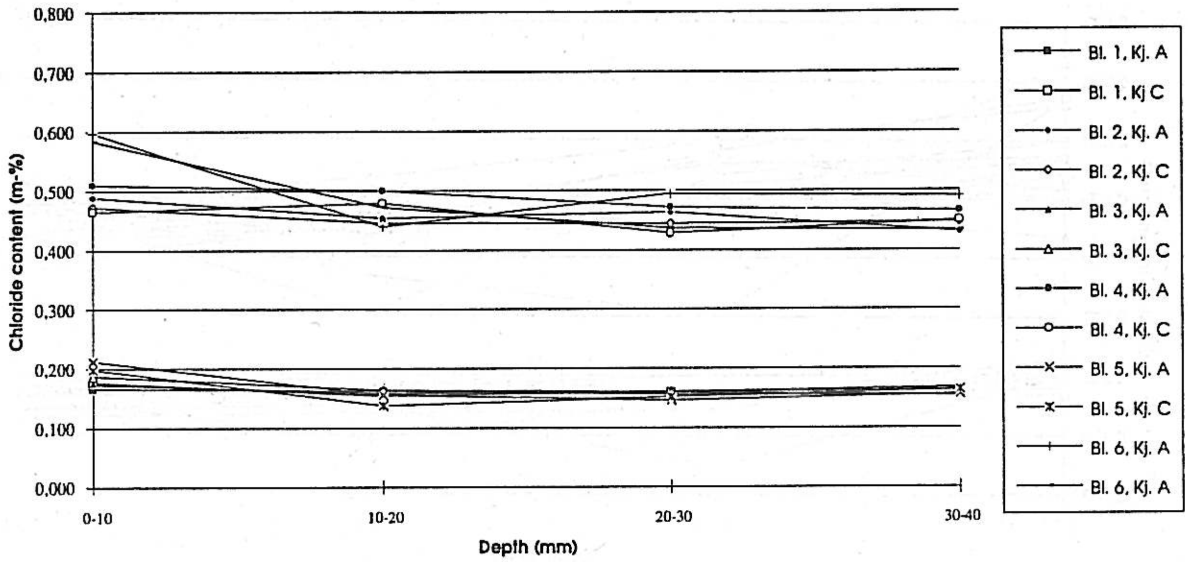


Fig. 5.1 Chloride content of beam slices.

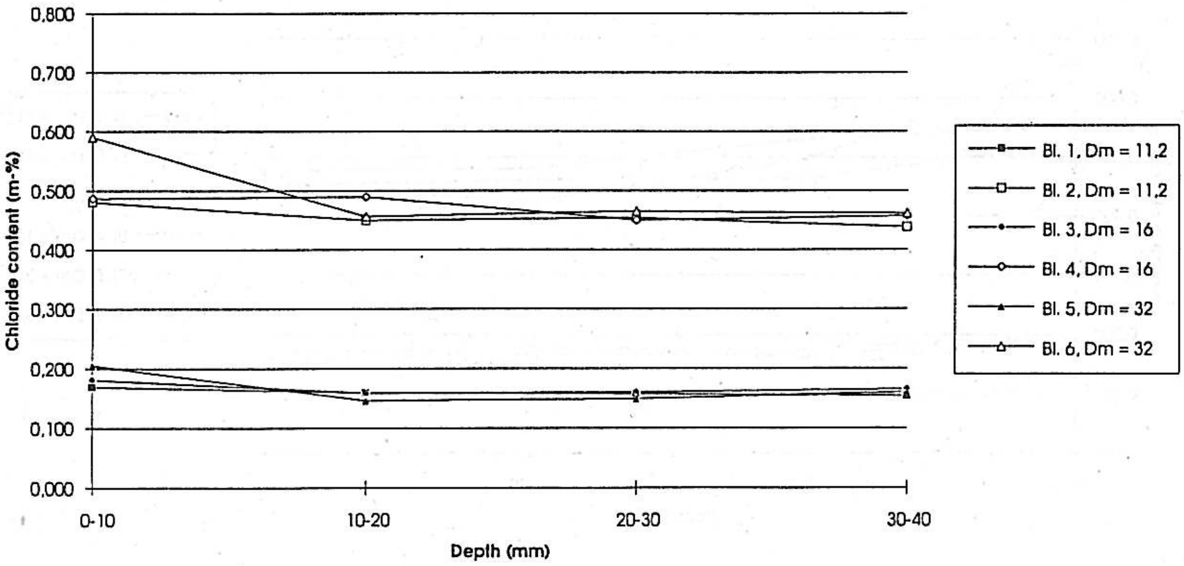


Fig. 5.2 Mean values of chloride content of beam slices.

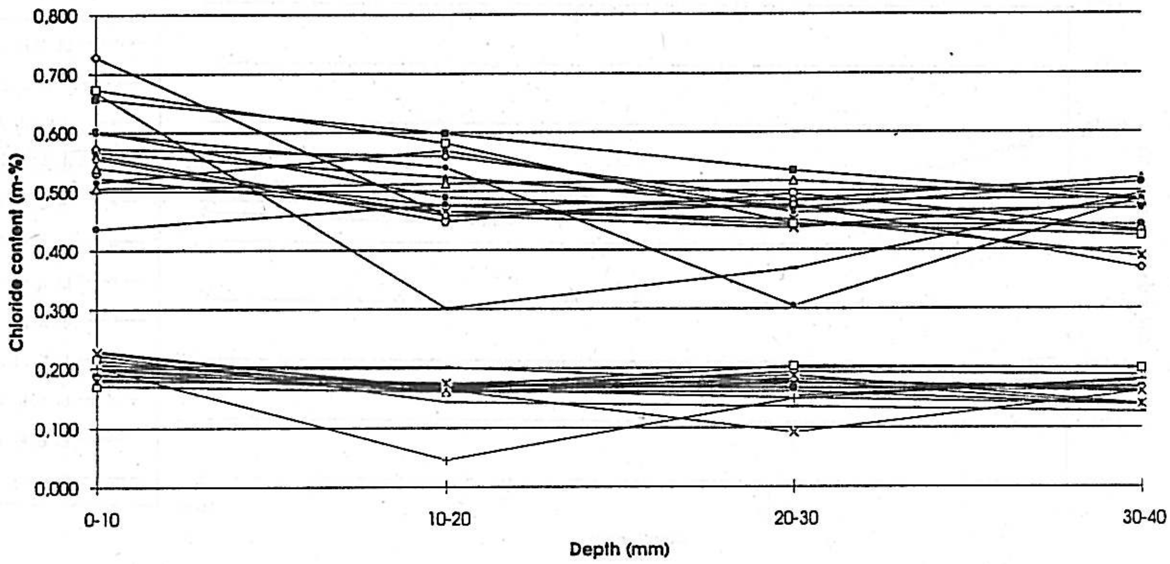


Fig. 5.3 Chloride content of dry drilled dust from beams.

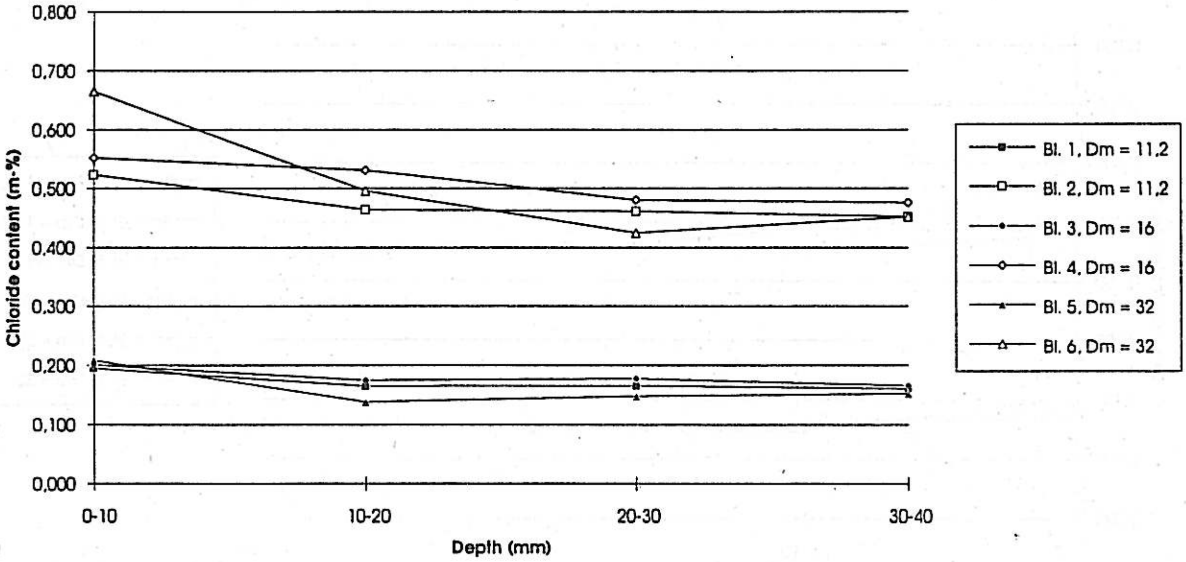


Fig. 5.4 Mean values of chloride content of dry drilled dust from beams.

5.2 Effect of maximum aggregate diameter

Chlorides in concrete exist mainly in the hydrated cement paste. When regarding the danger of corrosion to reinforcement steel it is therefore the chloride content expressed in relation to the amount of cement that is important. The presence of aggregate will add an uncertainty to the determination of a chloride content. and therefore displace the ratio between the amount of chloride and cement paste. The larger the aggregate diameter is compared to the sampling bore diameter, the larger is the uncertainity. This is also demonstrated by the results that are obtained in this work. The results are visualized in Fig 5.5 below, where observed maximum deviations are plotted against different maximum aggregate diametres.

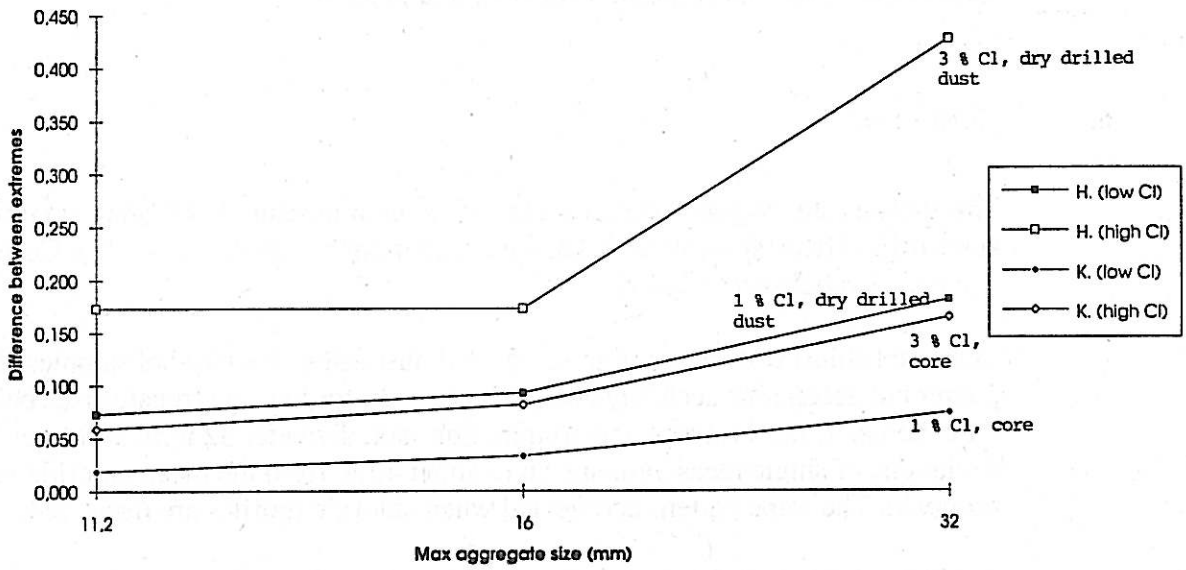


Fig 5.5 Maximum observed deviations in chloride measurements plotted vs. maximum aggregate diameter. The two lower curves represent values measured in cores (concentrations indicated on the plot). The two upper curves represent dry drilled samples.

The differences in deviations observed with the two sampling techniques is apparent. With 5 dry drilled samples as used here, there is also a distinct change in deviation between aggregate diametres above and below the bore diameter.

5.3 Bore size

As seen in the previous section, the bore size is a critical parameter. It has importance both for cores and dry drilled dust. The effect is considerably larger, however, for the latter sampling technique.

A bore diameter of 20 mm must be considered to be close to an upper practical limit for hand held operation. Five samples may therefore only be recommended for concretes with maximum aggregate sizes smaller than 16 mm. Larger aggregate sizes will require more samples to achieve acceptable certainty.

5.4 Effect of chloride concentration

The certificates from Taylor Woodrow [4] reported an increase in standard deviation for samples with a decreasing chloride content. The two chloride concentrations tested in this programme did not show similar results.

6. CONCLUSIONS

The analysis shows good accuracy and precision in measured chloride contents for cores drilled from specimens of known concentration (1.0 % and 3.0 %). Correlation between parallel cores is good.

Measured chloride contents from dry drilled dust using five parallel samples show poorer but acceptable accuracy and precision only for max. aggregate sizes below bore diameter, i.e. 11.2 mm and 16 mm. For max. diameter 32 mm, absolute deviations of single measurements up to about 40 % from the mean chloride value is observed. The same pattern is reflected when chloride profiles are measured.

Analysis of dry drilled dust therefore indicates that a bore diameter above maximum aggregate size is essential in order to obtain sufficient accuracy and precision in chloride measurements.

A bore diameter of 20 mm must be considered to be close to an upper practical limit for dry drilling. For maximum aggregate sizes above this a number of five holes must be regarded as insufficient. Further gain in accuracy and precision may only be achieved through an increase in the number of holes.

7. REFERENCES

[1] H. C. Gran, Measurement of chlorides in concrete. An evaluation of three different analysis techniques, NBI Project Report 1992.

[2] Norwegian Standard, NS 4756, Water analysis. Determination of chloride. Potentiometric titration, 1st edition Feb. 1992.

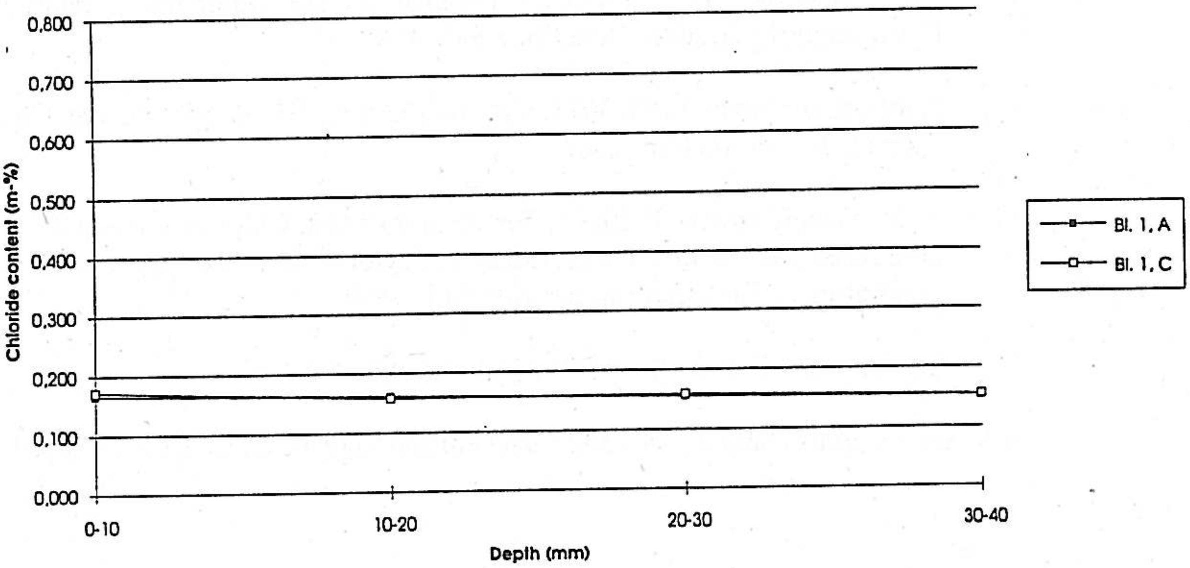
[3] Norwegian Standard, NS 3671, Concrete testing. Hardened concrete. Chloride content, 1st edition Feb. 1987.

[4] A. M. Waters and A. T. Blake, Certificates of test. Chloride content of reference dust. 14 different certificates, Taylor Woodrowe Research Laboratories, Taywood Engineering Ltd., 1991.

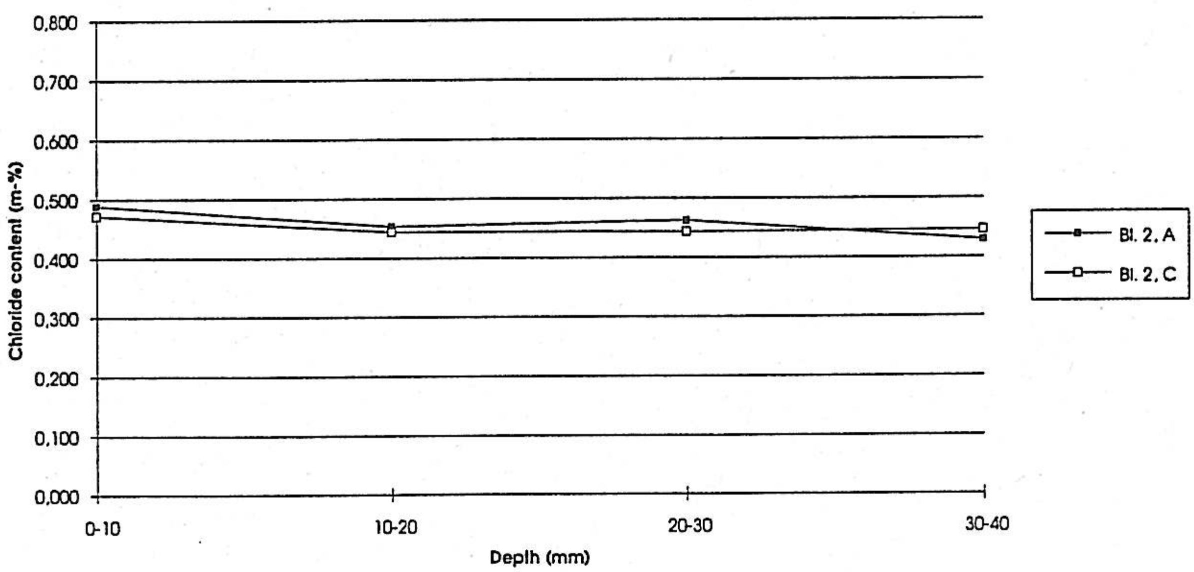
[5] Ø. Vennesland, Report SINTEF-FCB 65. A83005,1983.

[6] Norwegian Standard, NS 3420, 2nd edition May 1986, Chapter L5, pp. 154.

Appendix 1

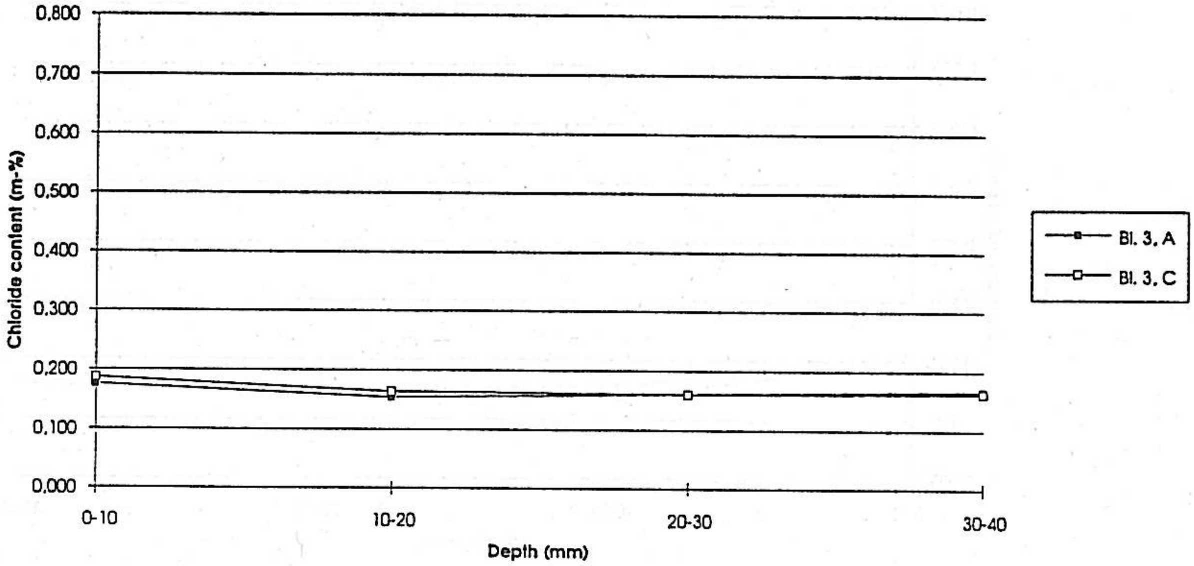


Mix 1, core A and C

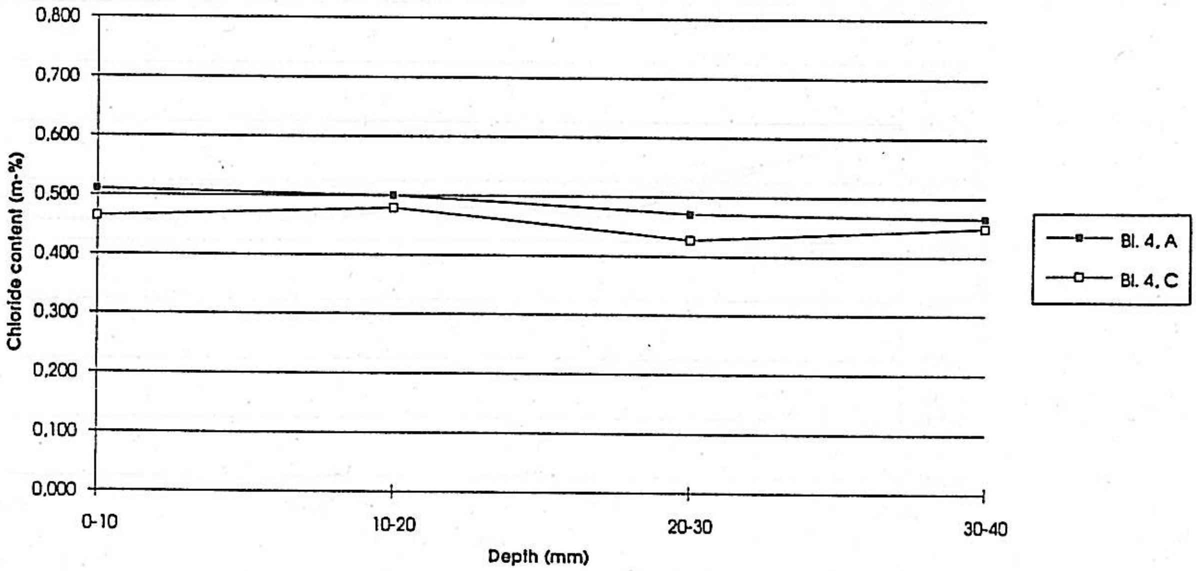


Mix 2, core A and C

Appendix 1

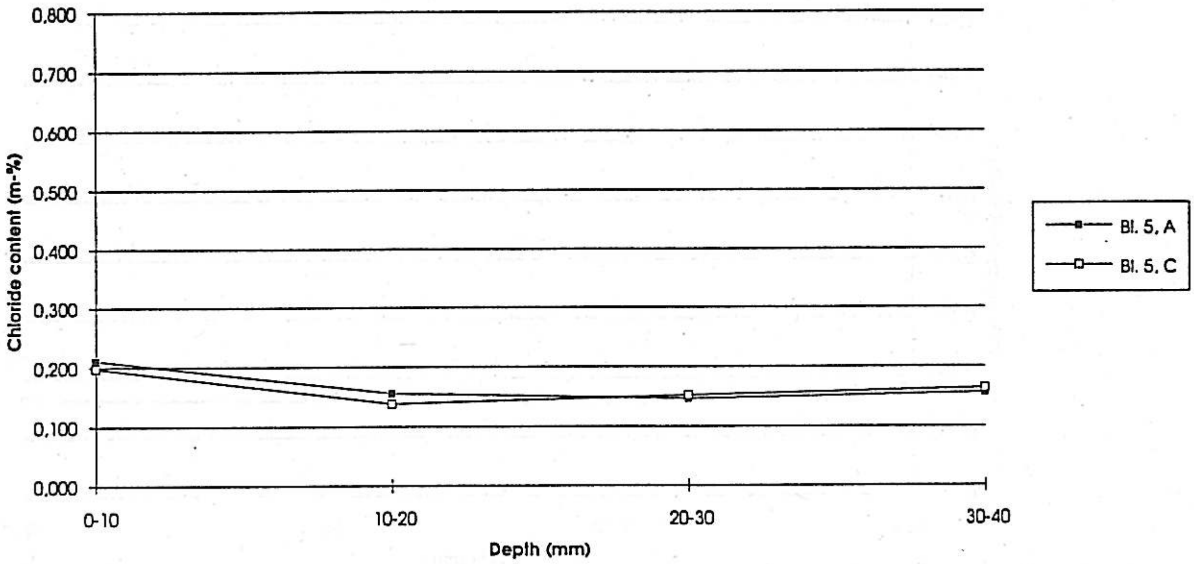


Mix 3, core A and C

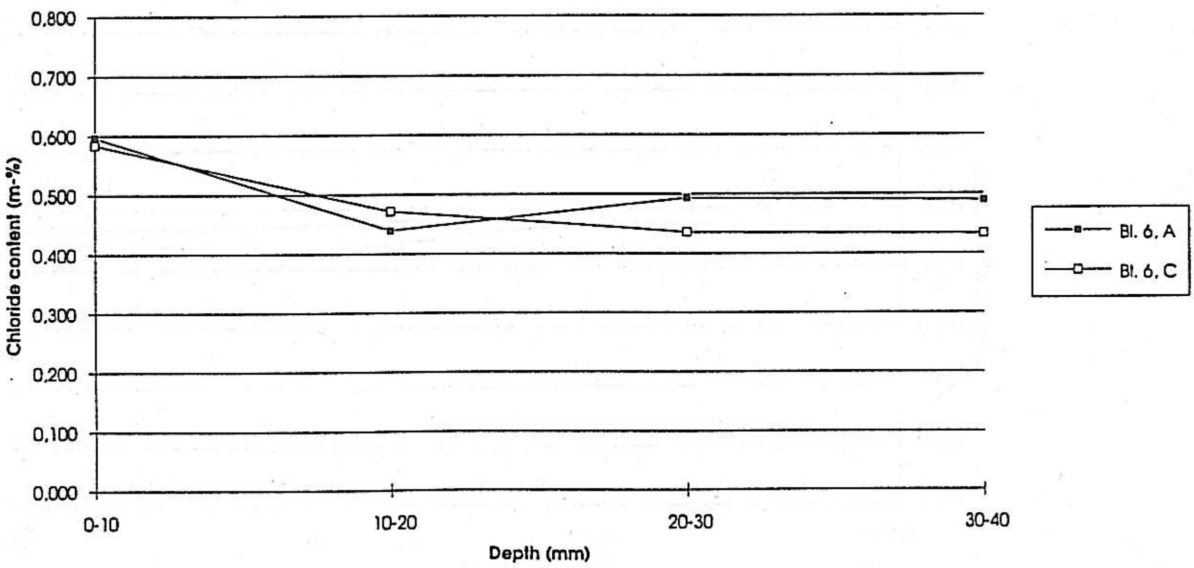


Mix 4, core A and C

Appendix 1

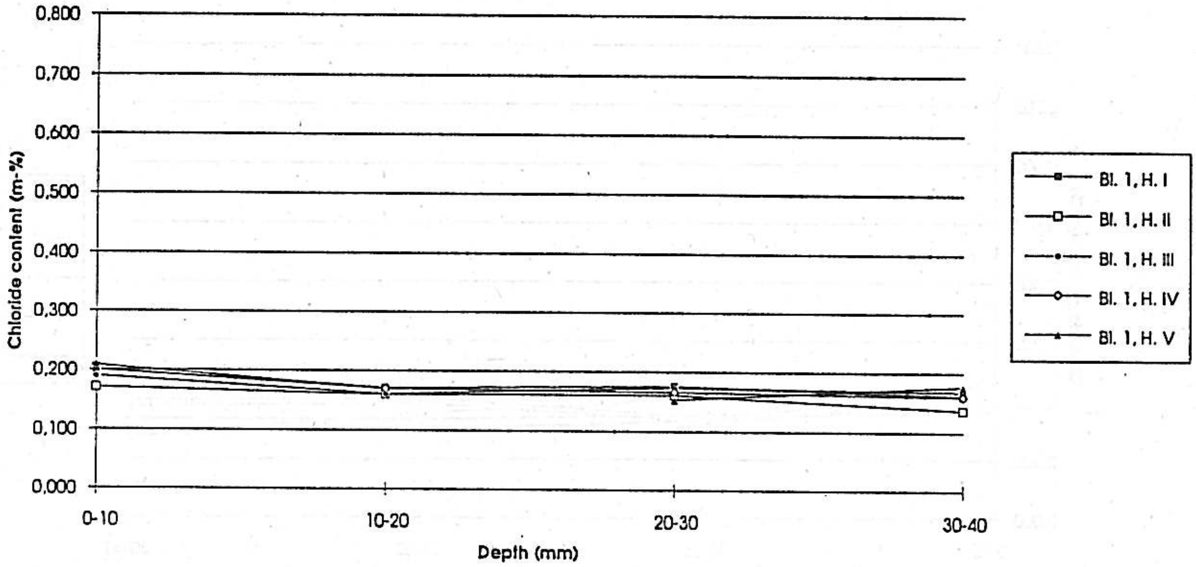


Mix 5, core A and C

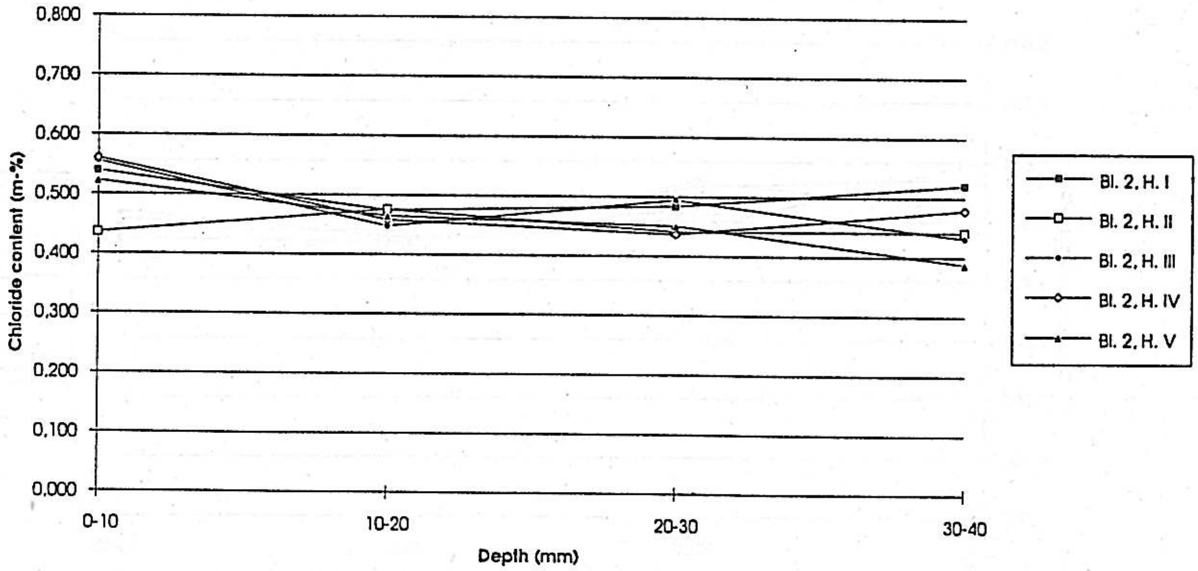


Mix 6, core A and C

Appendix 1

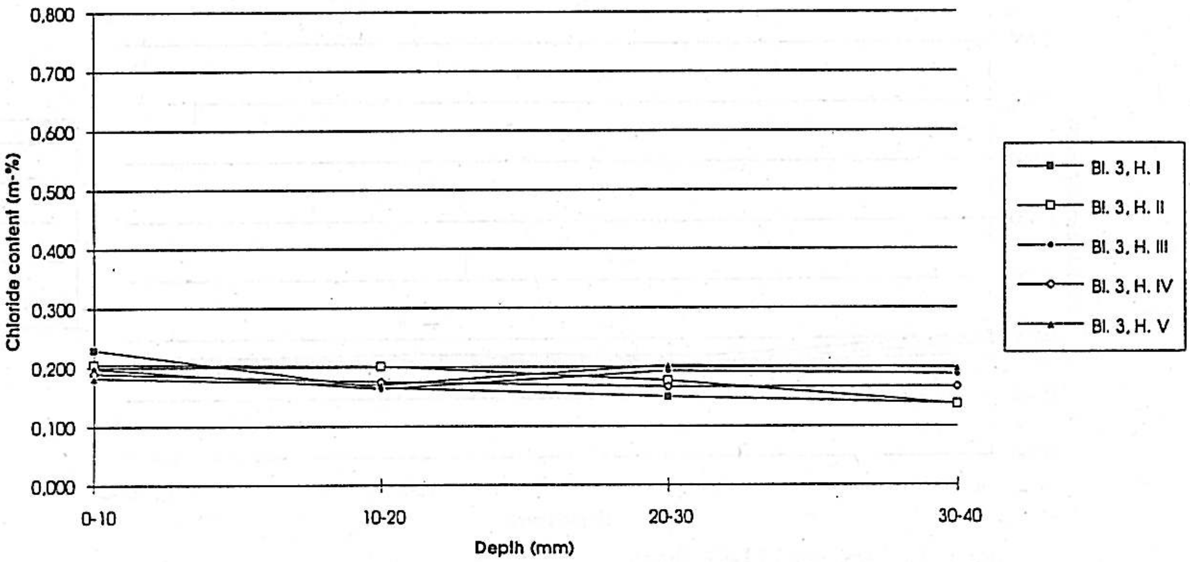


Mix 1, dry drilled dust

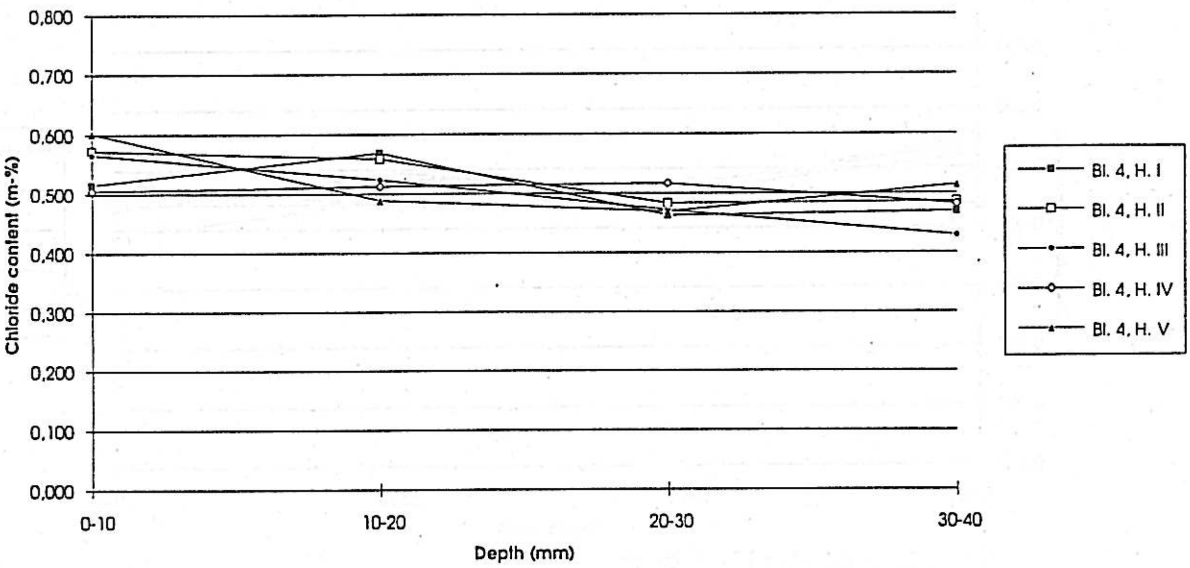


Mix 2, dry drilled dust

Appendix 1

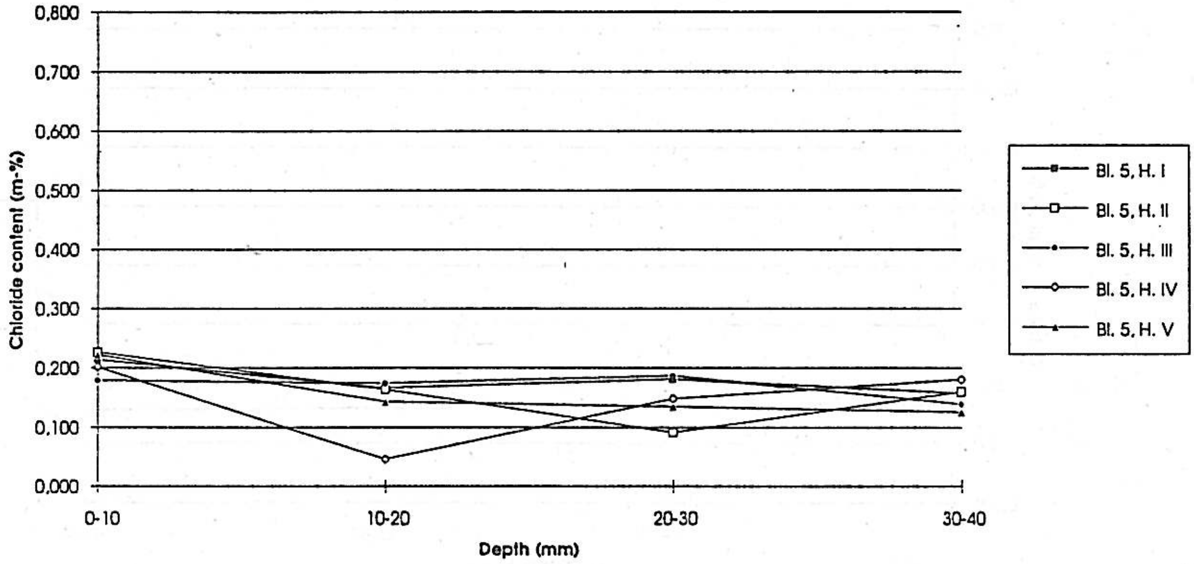


Mix 3, dry drilled dust

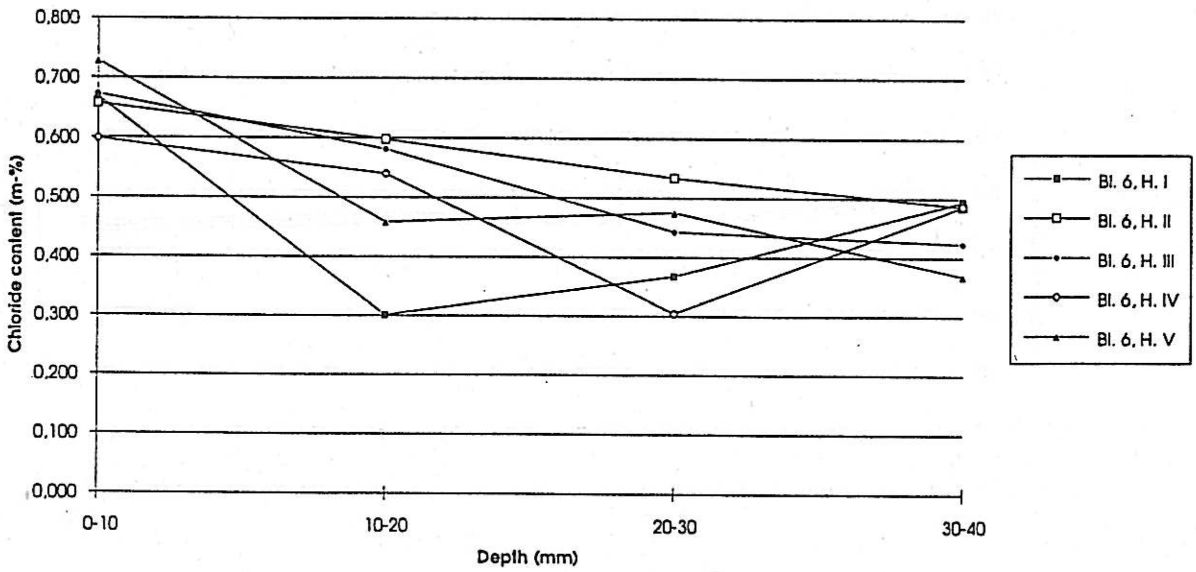


Mix 4, dry drilled dust

Appendix 1

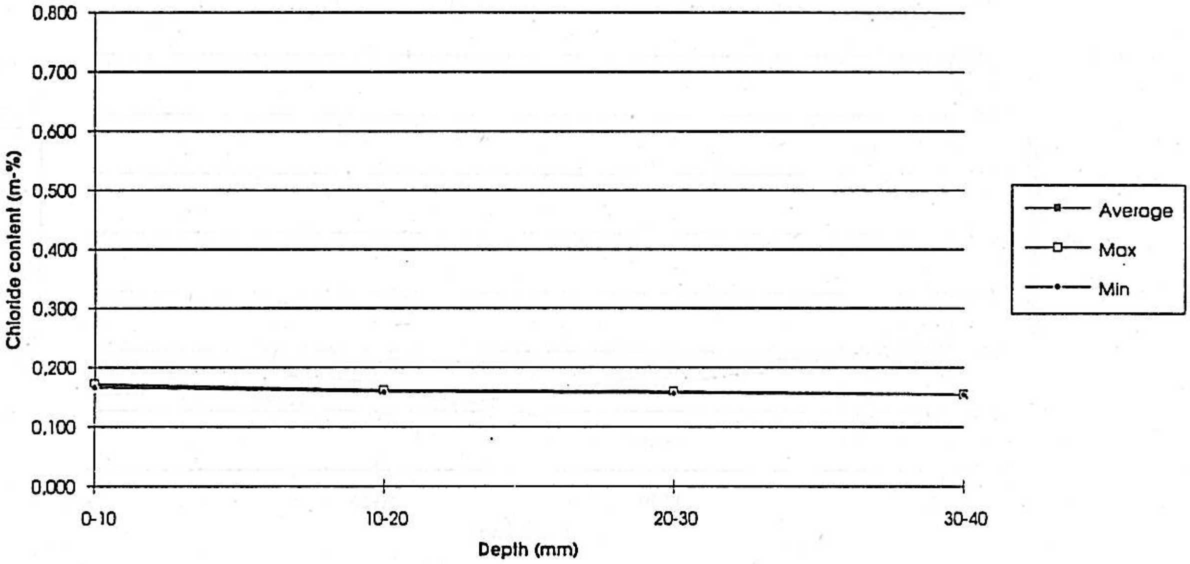


MIx 5, dry drilled dust

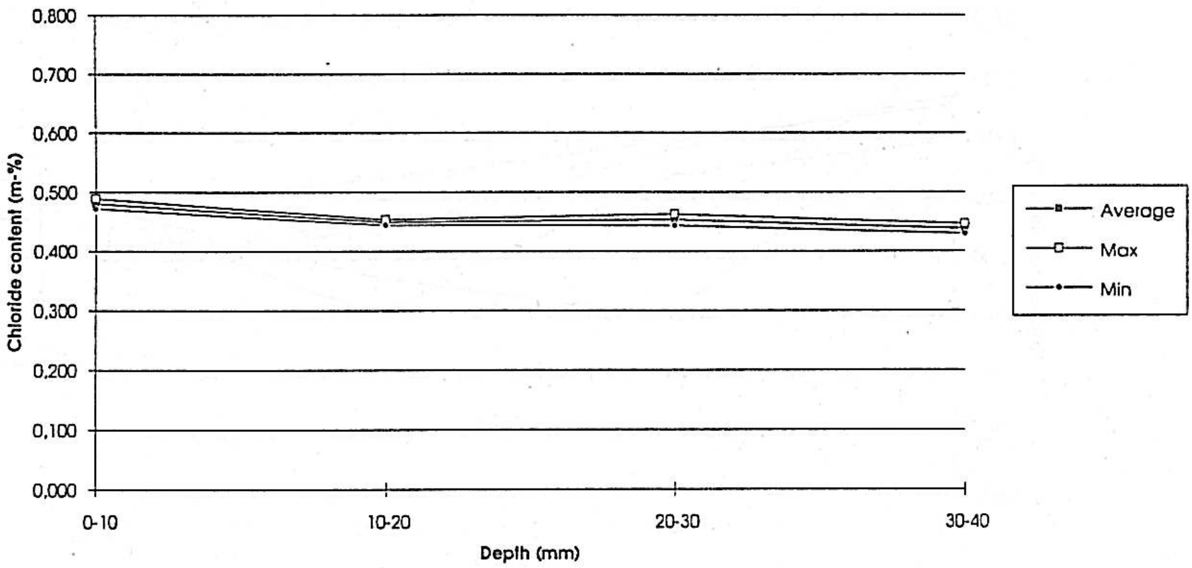


Mix 6, dry drilled dust

Appendix 1

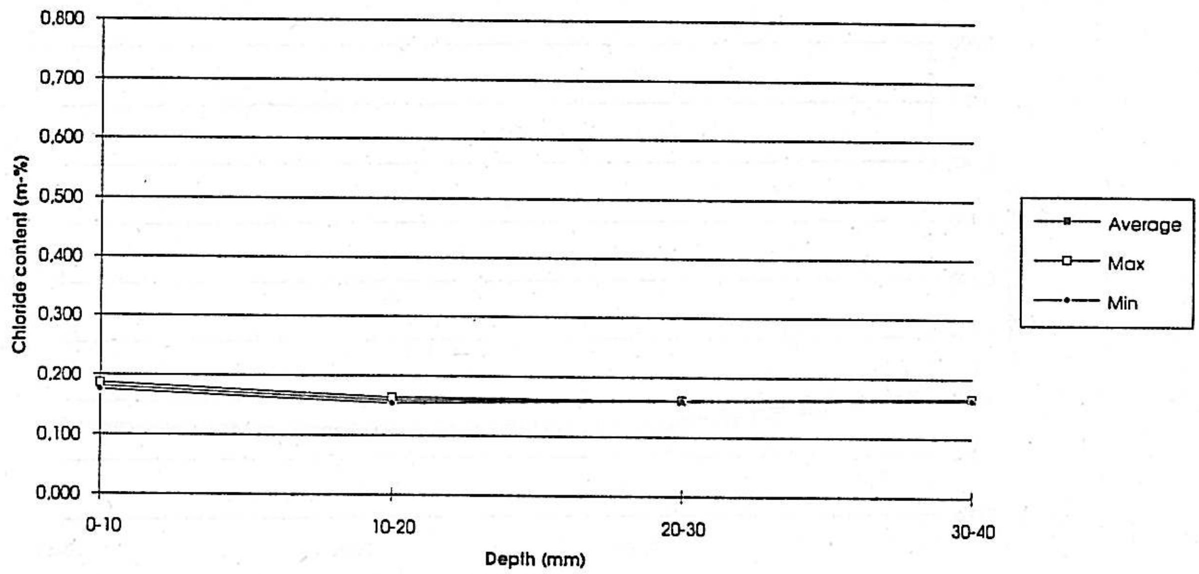


Mix 1, core A and C

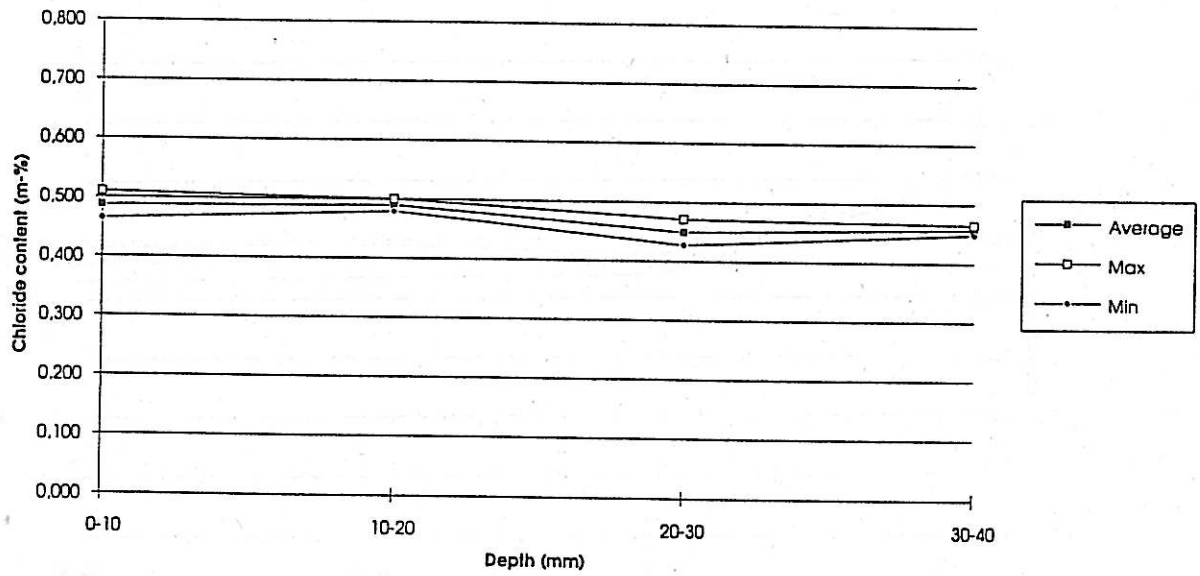


Mix 2, core A and C

Appendix 1

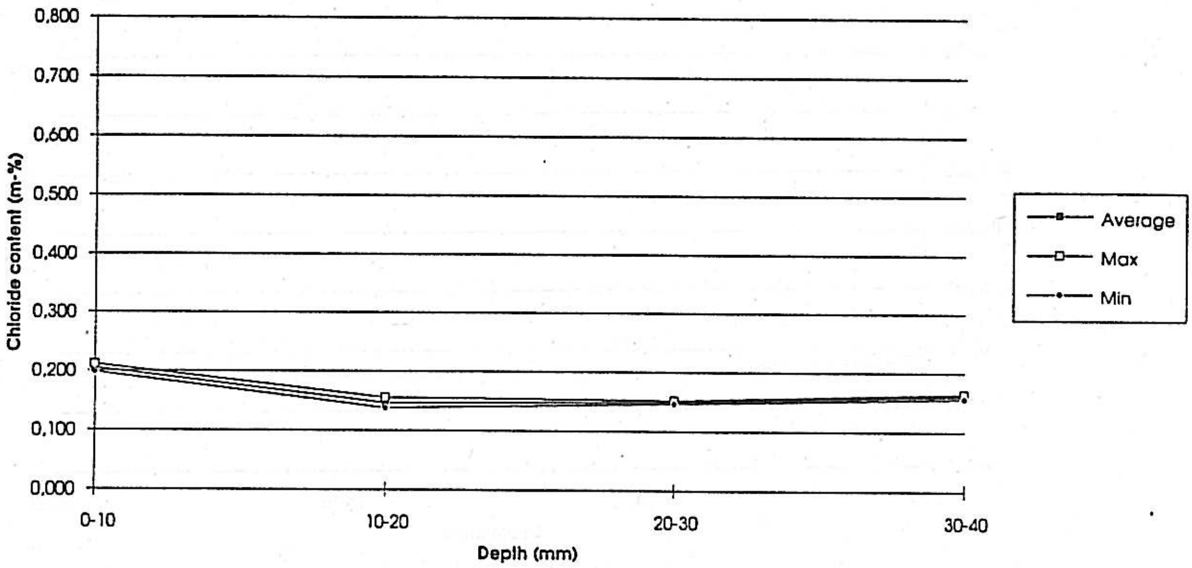


Mix 3, core A and C

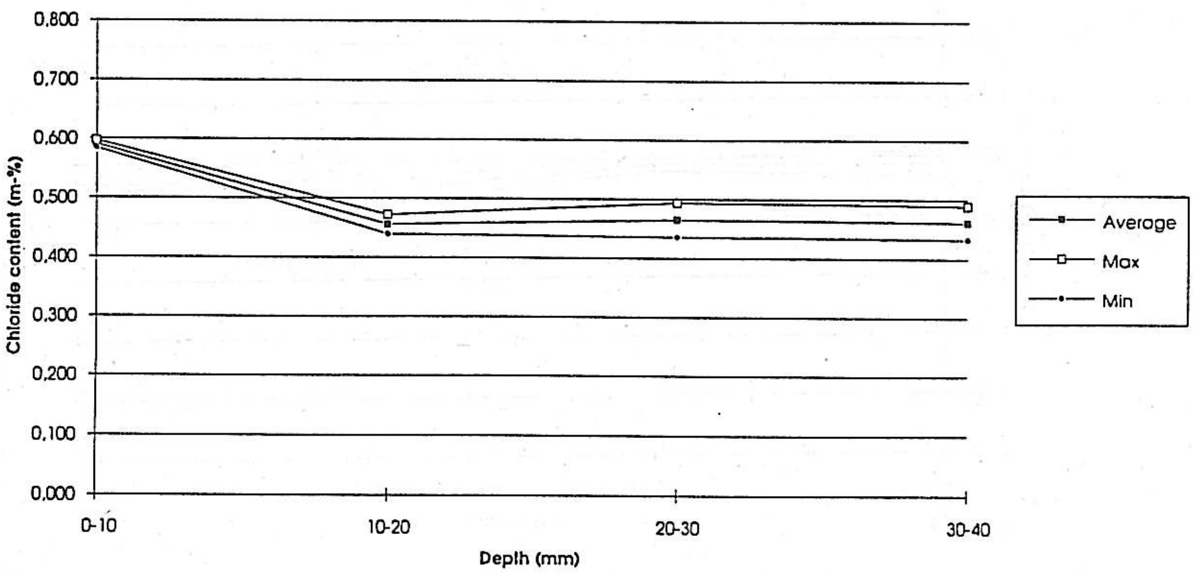


Mix 4, core A and C

Appendix 1

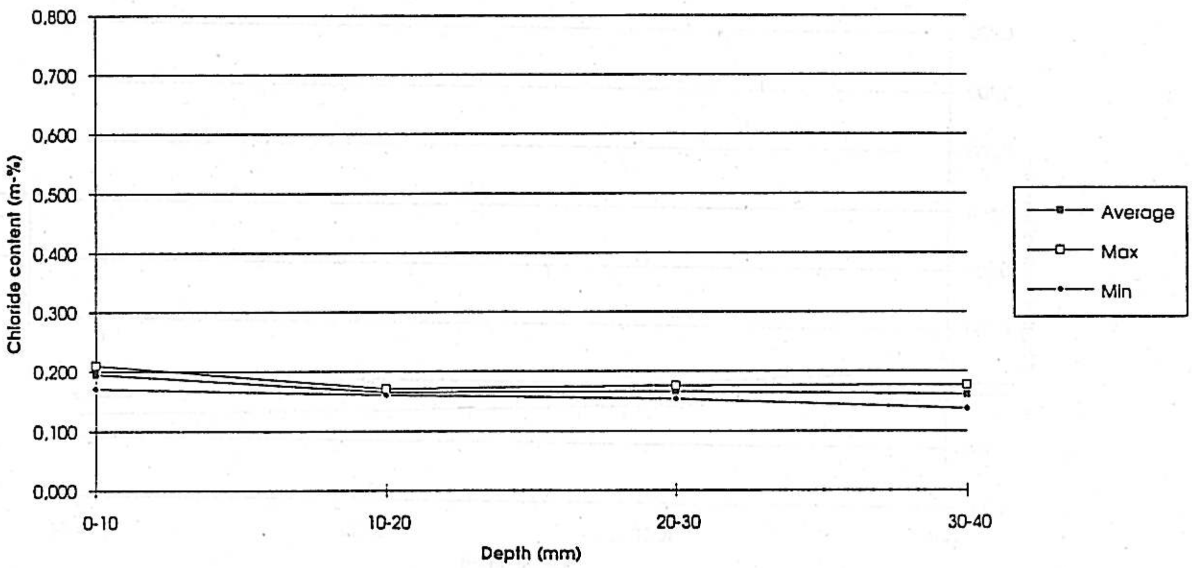


Mix 5, core A and C

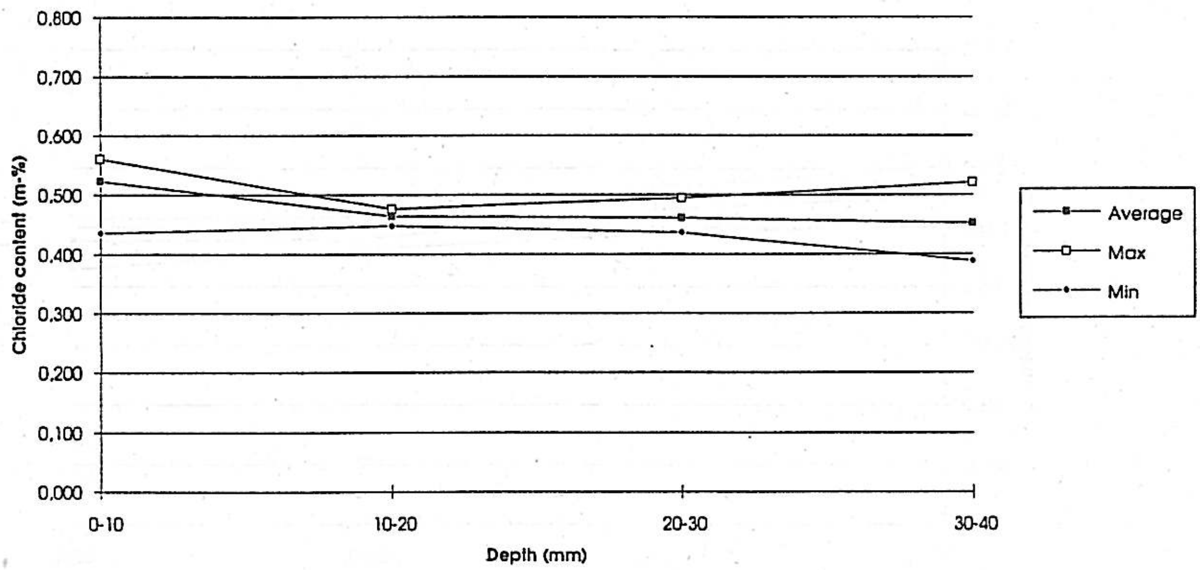


Mix 6, core A and C

Appendix 1

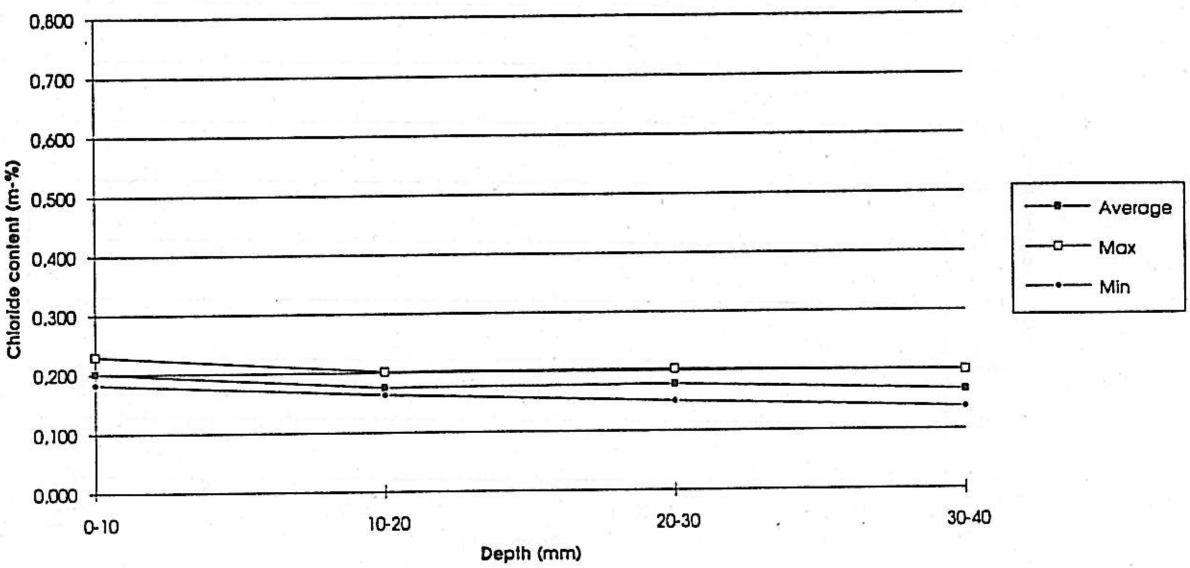


Mix 1, dry drilled dust

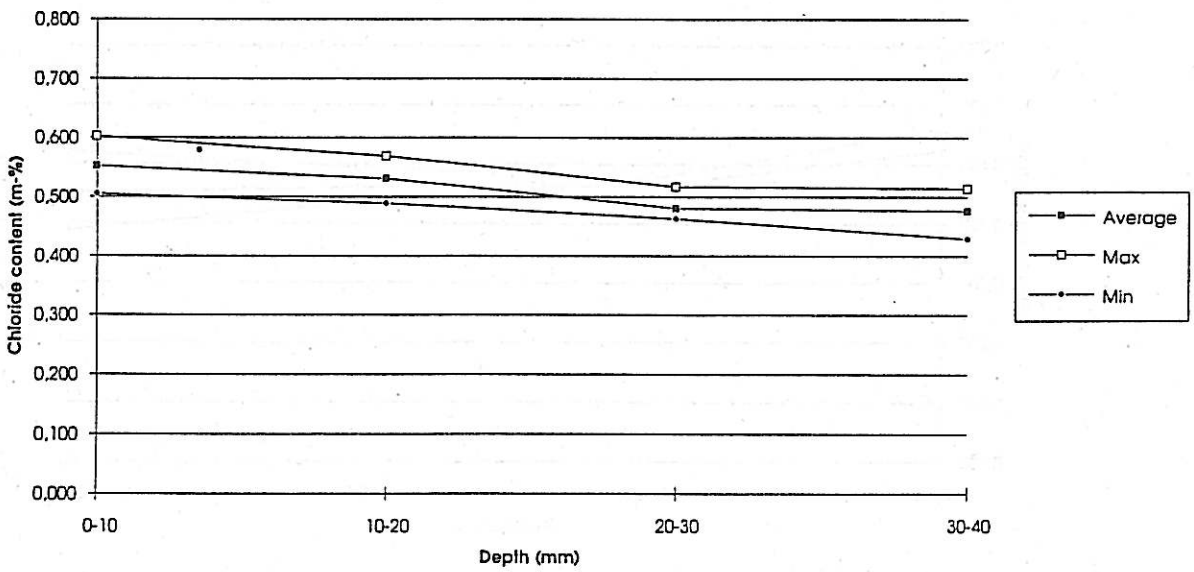


Mix 2, dry drilled dust

Appendix 1

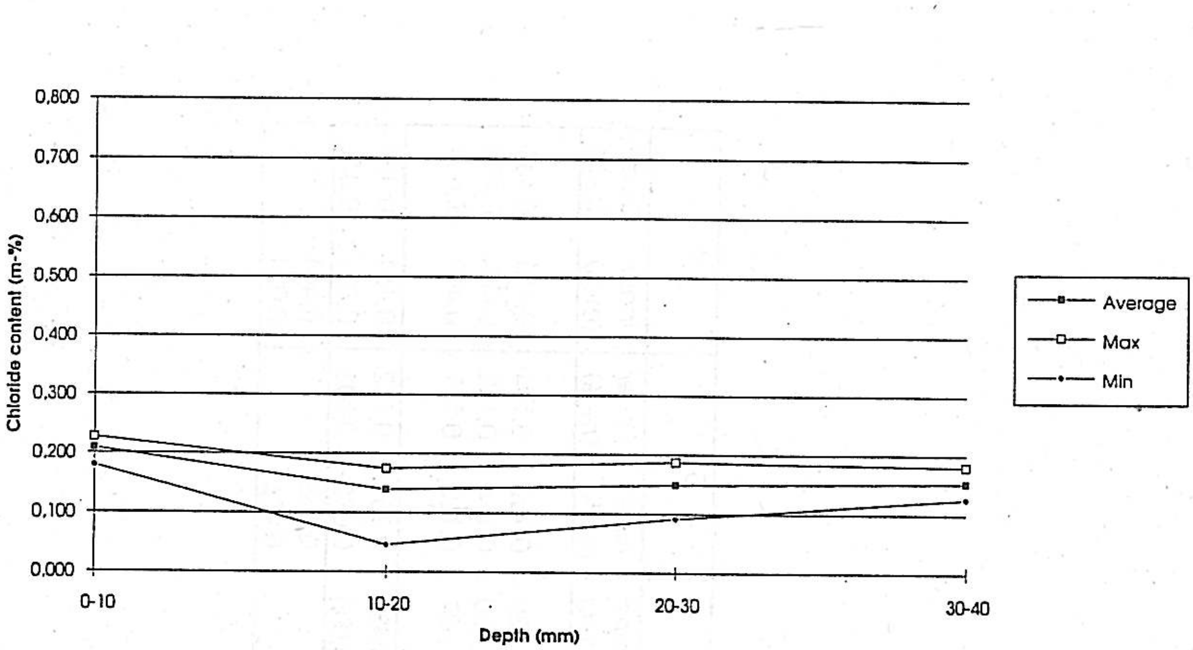


Mix 3, dry drilled dust

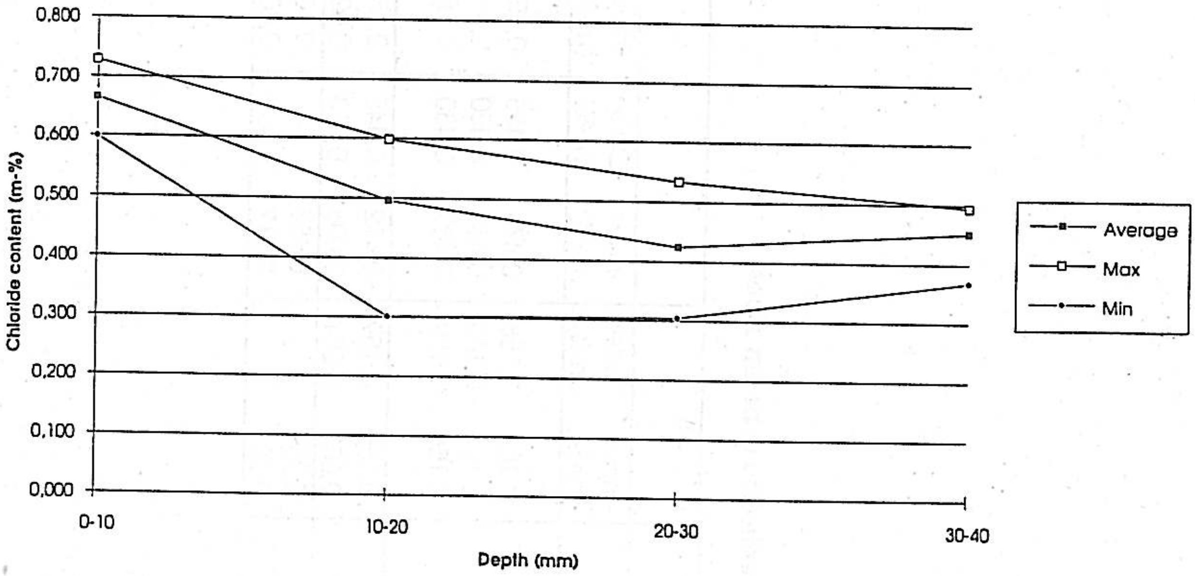


Mix 4, dry drilled dust

Appendix 1



Mix 5, dry drilled dust



Mix 6, dry drilled dust

Appendix 1

Chloride concentration in beam slices

Mix No.	1		2		3		4		5		6	
	Inner (m-%)	Outer (m-%)	Inner (m-%)	Outer (m-%)	Inner (m-%)	Outer (m-%)	Inner (m-%)	Outer (m-%)	Inner (m-%)	Outer (m-%)	Inner (m-%)	Outer (m-%)
Parallel No.												
1	0,157	0,158	0,478	0,455	0,159	0,153	0,459	0,439	0,159	0,154	0,465	0,434
2	0,154	0,160	0,468	0,450	0,159	0,155	0,460	0,430	0,164	0,152	0,466	0,406
3	0,156	0,159	0,469	0,430	0,157	0,154	0,461	0,437	0,160	0,149	0,460	0,434
Mean value	0,156	0,159	0,472	0,445	0,158	0,154	0,460	0,435	0,161	0,152	0,464	0,425
STD	0,002	0,001	0,006	0,013	0,001	0,001	0,001	0,005	0,003	0,003	0,003	0,016
Mean value	0,157		0,458		0,156		0,448		0,156		0,444	
STD	0,002		0,017		0,003		0,014		0,006		0,024	

Appendix 1

Chloride concentration in cores drilled from beams

Mix No.	1		2		3		4		5		6	
Core:	A (m-%)	C (m-%)	A (m-%)	C (m-%)	A (m-%)	C (m-%)	A (m-%)	C (m-%)	A (m-%)	C (m-%)	A (m-%)	C (m-%)
Depth (mm)												
0-10	0,166	0,173	0,489	0,472	0,176	0,187	0,510	0,464	0,212	0,198	0,597	0,584
10-20	0,162	0,158	0,454	0,445	0,154	0,164	0,500	0,479	0,155	0,138	0,440	0,472
20-30	0,156	0,159	0,463	0,444	0,161	0,160	0,471	0,428	0,146	0,152	0,494	0,436
30-40	0,154	0,155	0,430	0,447	0,167	0,163	0,465	0,449	0,156	0,164	0,490	0,433
Mean value	0,160	0,161	0,459	0,452	0,165	0,169	0,487	0,455	0,167	0,163	0,505	0,481
STD	0,006	0,008	0,024	0,013	0,009	0,012	0,022	0,022	0,030	0,026	0,066	0,071
Mean value	0,160		0,456		0,167		0,471		0,165		0,493	
STD	0,006		0,019		0,010		0,026		0,026		0,065	

Appendix 1

Chloride concentration in drilled dust from beams

Mix No.	1					2				
Drill hole No.	I (m-%)	II (m-%)	III (m-%)	IV (m-%)	V (m-%)	I (m-%)	II (m-%)	III (m-%)	IV (m-%)	V (m-%)
Depth (mm)										
0-10	0,200	0,171	0,190	0,208	0,210	0,540	0,436	0,556	0,561	0,523
10-20	0,171	0,160	0,161	0,170		0,475	0,476	0,448	0,459	0,465
20-30	0,176	0,161	0,174	0,166	0,153	0,484	0,441	0,495	0,437	0,451
30-40	0,162	0,137	0,168	0,160	0,177	0,521	0,442	0,432	0,479	0,388
Mean value	0,177	0,157	0,173	0,176	0,180	0,505	0,449	0,483	0,484	0,457
STD	0,016	0,014	0,012	0,022	0,029	0,031	0,018	0,056	0,054	0,055
Mean value	0,172					0,475				
STD	0,019					0,046				

Mix No.	3					4				
Drill hole No.	I (m-%)	II (m-%)	III (m-%)	IV (m-%)	V (m-%)	I (m-%)	II (m-%)	III (m-%)	IV (m-%)	V (m-%)
Depth (mm)										
0-10	0,230	0,205	0,198	0,190	0,182	0,516	0,573	0,566	0,505	0,602
10-20	0,165	0,202	0,163	0,175	0,170	0,569	0,559	0,524	0,513	0,489
20-30	0,150	0,177	0,193	0,167	0,203	0,463	0,483	0,472	0,517	0,469
30-40	0,138	0,137	0,188	0,167	0,199	0,469	0,486	0,429	0,482	0,514
Mean value	0,171	0,180	0,186	0,175	0,189	0,504	0,525	0,498	0,504	0,519
STD	0,041	0,031	0,016	0,011	0,015	0,049	0,047	0,060	0,016	0,059
Mean value	0,180					0,510				
STD	0,024					0,045				

Mix No.	5					6				
Drill hole No.	I (m-%)	II (m-%)	III (m-%)	IV (m-%)	V (m-%)	I (m-%)	II (m-%)	III (m-%)	IV (m-%)	V (m-%)
Depth (mm)										
0-10	0,215	0,227	0,180	0,202	0,223	0,668	0,657	0,673	0,599	0,728
10-20	0,167	0,164	0,174	0,046	0,144	0,301	0,598	0,582	0,540	0,459
20-30	0,181	0,091	0,187	0,149	0,135	0,368	0,534	0,443	0,305	0,476
30-40	0,158	0,160	0,139	0,180	0,126	0,495	0,487	0,424	0,487	0,369
Mean value	0,180	0,160	0,170	0,144	0,157	0,458	0,569	0,530	0,483	0,508
STD	0,025	0,055	0,021	0,069	0,045	0,161	0,074	0,118	0,127	0,154
Mean value	0,162					0,510				
STD	0,043					0,123				

Appendix 2

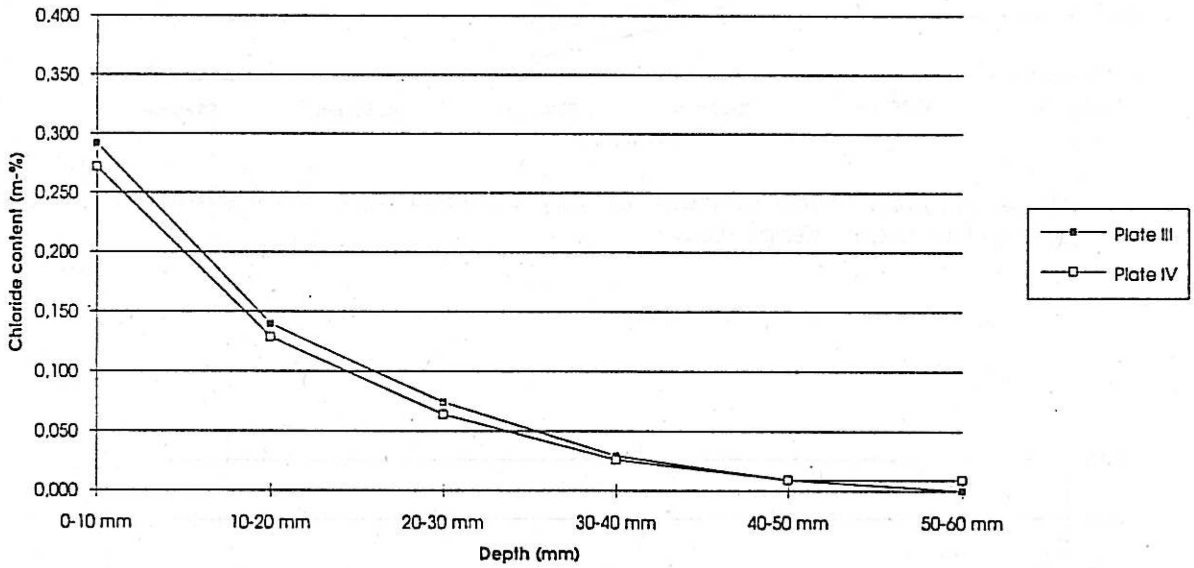


Plate III and IV, chloride content of slices from plates.

Appendix 2

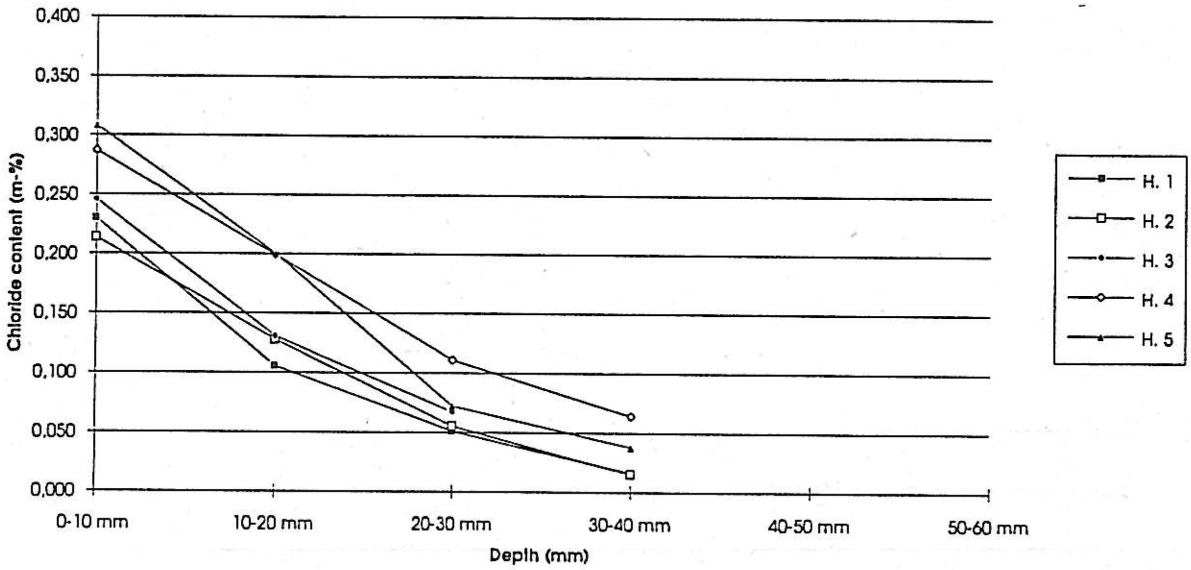


Plate III, chloride content of dry drilled dust from plates.
Drilled without template.

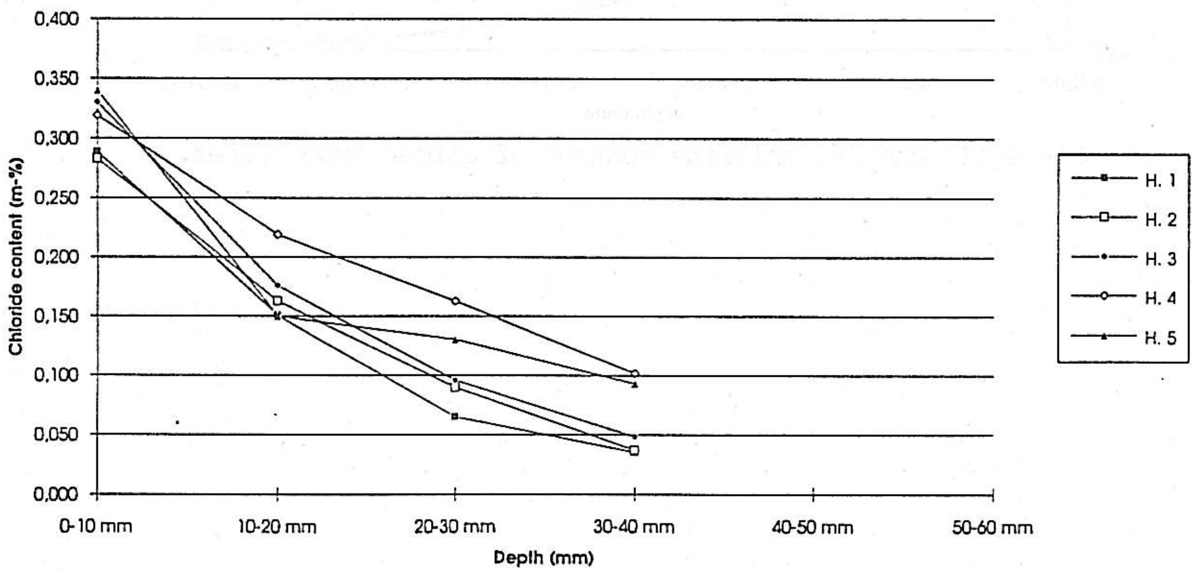


Plate III, chloride content of dry drilled dust from plates.
Drilled with template.

Appendix 2

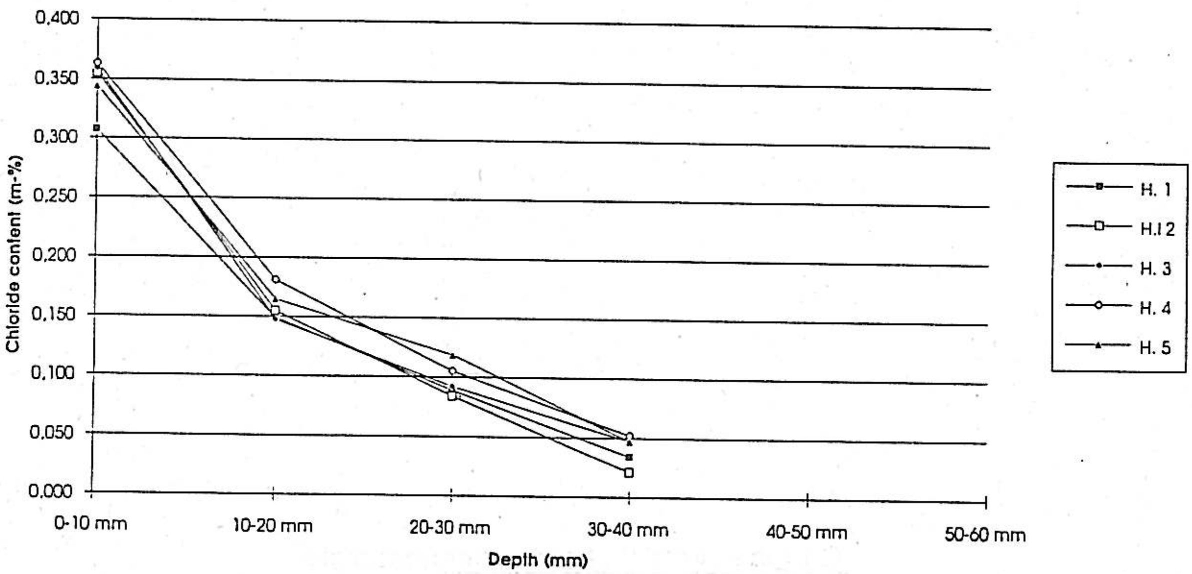


Plate IV, chloride content of dry drilled dust from plates.
Drilled without template.

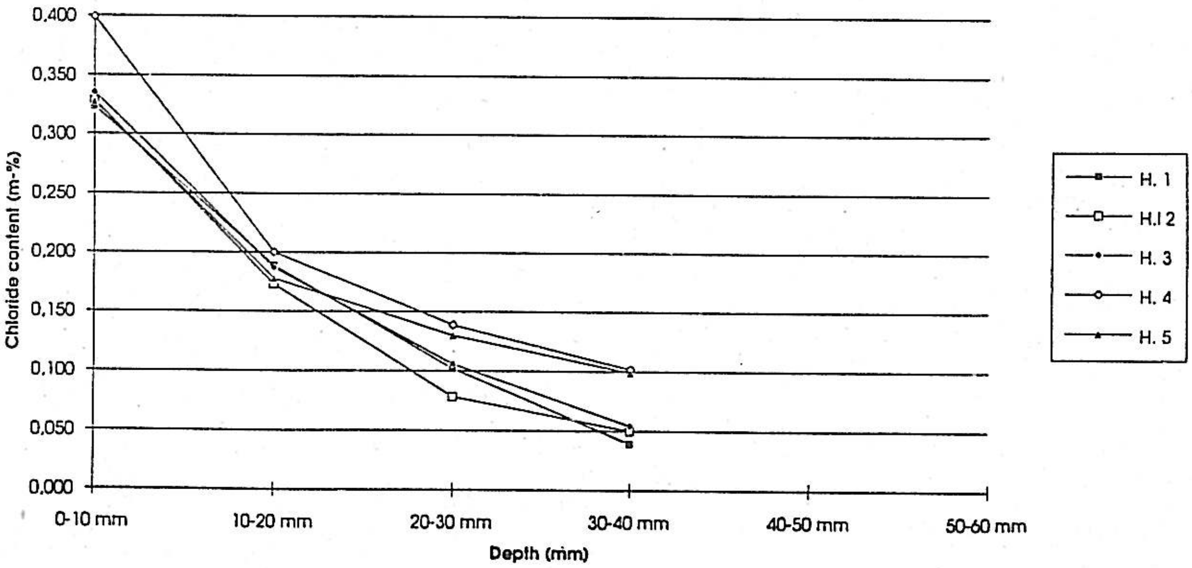


Plate IV, chloride content of dry drilled dust from plates.
Drilled with template.

Appendix 2

Chloride content of core slices from plates

Depth	Plate III	Plate IV
0-10 mm	0,292	0,272
10-20 mm	0,140	0,129
20-30 mm	0,074	0,064
30-40 mm	0,029	0,026
40-50 mm	0,009	0,009
50-60 mm	0,000	0,009

Appendix 2

Chloride content of dry drilled dust from plates. Drilled with template.

	Plate III						Plate IV				
Depth	H. 1	H. 2	H. 3	H. 4	H. 5	Depth	H. 1	H. 2	H. 3	H. 4	H. 5
0-10 mm	0,289	0,283	0,330	0,319	0,340	0-10 mm	0,323	0,328	0,335	0,399	0,327
10-20 mm	0,151	0,163	0,176	0,219	0,150	10-20 mm	0,189	0,173	0,187	0,200	0,178
20-30 mm	0,065	0,090	0,096	0,163	0,131	20-30 mm	0,102	0,078	0,106	0,139	0,130
30-40 mm	0,035	0,037	0,048	0,102	0,093	30-40 mm	0,039	0,050	0,054	0,102	0,099
40-50 mm						40-50 mm					
50-60 mm						50-60 mm					

Chloride content of dry drilled dust from plates. Drilled without template.

	Plate III						Plate IV				
Depth	H. 1	H. 2	H. 3	H. 4	H. 5	Depth	H. 1	H. 2	H. 3	H. 4	H. 5
0-10 mm	0,230	0,214	0,246	0,287	0,308	0-10 mm	0,307	0,355	0,359	0,363	0,344
10-20 mm	0,106	0,128	0,131	0,199	0,200	10-20 mm	0,149	0,155	0,148	0,181	0,165
20-30 mm	0,051	0,055	0,067	0,111	0,072	20-30 mm	0,089	0,084	0,092	0,105	0,119
30-40 mm	0,016	0,015		0,064	0,038	30-40 mm	0,034	0,021	0,047	0,052	0,047
40-50 mm						40-50 mm					
50-60 mm						50-60 mm					

Appendix 3

Referance samples

Real chloride content (m-%)	Measured chloride content (m-%)
0,100	0,100
0,200	0,200
0,500	0,490
0,500	0,484
0,500	0,489
0,100	0,103
0,200	0,205
0,200	0,198
0,025	0,031
0,025	0,031
0,100	0,101
0,500	0,488
0,500	0,500
0,100	0,104
0,200	0,205
0,025	0,032
0,200	0,202
0,100	0,102
0,200	0,205
0,200	0,199
0,500	0,486
0,500	0,493
0,025	0,030
0,025	0,033
0,100	0,104
0,100	0,106
0,200	0,195
0,200	0,196
0,100	0,098
0,500	0,480
0,100	0,103
0,200	0,197
0,500	0,485
0,025	0,029
0,100	0,102

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