Long-term mapping of the chloride load around a Swedish highway exposed to de-icing salt - with reference to reinforcement corrosion in concrete

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With reference to reinforcement corrosion in concrete

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TVBM-3127 Lund 2005

PREFACE

A project *"Durability De-icing Salts"* (BTB) was initiated in 1995. The purpose was to study how a de-icing environment affects the durability of concrete, but also to investigate how durability is affected by different concrete compositions and different types of binder. By "durability" is meant durability towards salt-frost scaling, internal frost damage and reinforcement corrosion.

The project is a follow up of the project *"Durability Marine Concrete"* (BMB) in which a similar study was made of the durability of concrete in the marine environment. The corrosion part of that project has been presented in reference /10/.

Both projects are based on exposure of concrete specimens at field exposure sites. These are supervised by the National Testing and Research Institute (SP) in the city of Borås in Sweden. The BTB-station is located at National Road Rv. 40, to the west of Borås. The station is provided by the Swedish National Road Administration (Vägverket) and is managed by SP.

Researchers from SP, Chalmers Technical University (CTH), Lund Institute of Technology (LTH) and Swedish Cement and Concrete Institute (CBI) participated in both projects. Furthermore, researchers from the Swedish, Finnish and Norwegian cement industries participated. Project BTB was sponsored by the industrial partners mentioned above, and by the Development Fund of the Swedish Construction Industry (SBUF).

A reference group was adjoined to the project. It contained representatives of the sponsors and experts from the Swedish company Skanska, and from Denmark.

In the present report, a long-term study of the chloride environment around a highway exposed to severe de-icing is presented. The aim of the study was to obtain data that might me used for predictions of chloride ingress in de-iced structures and thereby provide necessary input to models for service life prediction.

Raw data from the first year have previously been presented in a report by Wirje and Offrell /3/. These data, and also results after 5 winter seasons, have been presented in a report by Fagerlund and Svärd /4/. Both these reports are in Swedish. All data, and also data after 8 winter seasons, are presented and discussed in the present report.

The author wants to thank all who have participated in the laborious work of preparing, mounting and demounting all 222 specimens and determining the many thousands of chloride data. I specially thank Annika Wirje and Petra Offrell for their work with chloride data in 1996, and Jenny Svärd and Samuel Eriksson for their work in year 2000 and 2003 respectively. All these co-workers were students at Lund Institute of Technology when the work was done. I also want to bring a special thank to SP and Dr Peter Utgenannt for taking care of the exposure site in such an excellent way.

Lund in November 2005

Göran Fagerlund

CONTENTS

SUMMARY

In November 1995, 222 identical salt-frost resistant specimens produced from the same concrete batch were placed at an exposure site close to the main road Rv. 40 outside the city of Borås. The specimens were placed in different locations in order to make it possible to map the chloride load around a typical de-iced main road; from a couple of meters beside the salted roadway to about 4 m above this. The specimens were disc-shaped with diameter 10 cm and thickness 30 mm. One of the flat sides of each specimen was exposed. The other sides were isolated by polyester resin.

A number of specimens were investigated at 4 different occasions during a period of 8 years. The specimens were brought to the lab where the chloride profile was determined (total chloride was measured, i.e. bound+free chloride).

Main results are:

1. In locations *unprotected from rain* the chloride concentration reached a maximum ("peak value") already after the first winter. The peak value was not exceeded during the proceeding 7 years. The general trend was that the peak value is lower during summer and autumn than directly after the first winter. The total chloride uptake in the outermost 20 mm of the specimens was, however, almost constant over time. Thus, the chloride front gradually penetrates to deeper parts of the specimen, but with a lower peak value. The behaviour probably depends on a washing out of chloride during spring, summer and autumn. Thus, a sort of balance between uptake and emission of chloride is reached. The peak value occurs quite close to the surface but penetrates gradually to bigger depths.

   The peak value is too low to cause reinforcement corrosion in a concrete of the actual quality; w/c 0.45.

   The spread in chloride profile for specimens in the same location was remarkably small.

2. In locations *protected from rain*, the chloride concentration after the first year was considerably lower than in the unprotected location. The most plausible reason is that the moisture level in the concrete is reduced. Hence the chloride diffusivity is also reduced.

   The peak concentration, and the total amount of chloride taken up increases gradually with time which must depend on the fact that no, or small, washing out of chloride can take place.

   After 8 years, the chloride concentration is still too low to cause reinforcement corrosion, especially if the concrete cover is normal for the actual exposure type. One cannot exclude, however, that corrosion might start after longer exposure time due to the gradual increase in chloride concentration and uptake.

The data might be used for a calibration of theoretical models for chloride uptake in concrete intermittently exposed to de-icing salt and precipitation.

1 SPECIMENS

The specimens were concrete discs with diameter 100 mm and thickness 30 mm. All discs were sawn from the inner part of a number of concrete cylinders with diameter 100 mm and length 200 mm. 5 discs were sawn from each cylinder. The outer 2.5 centimetres at each end of the cylinders were discarded. All specimens were cast from the same concrete batch.

On each disc, one flat sawn surface was untreated and used for exposure, while all other sides were sealed by a thick polyester coating.

The properties of the concrete were as follows:

- "Microconcrete" with 3 mm maximum aggregate size.
- Low alkali, sulphate resistant and moderate heat of hydration cement (the Swedish "Anläggningscement"). (Na_2O_{eqiv} 0.5%, C_3A 2%).
- Cement content 556 kg/m^3. Water content 250 litres/m^3.
  The cement content expressed in terms of weight fraction of the dry concrete is 28% (based on the dry density 2010 kg/m^3, which in its turn is based on the known recipe and an assumed degree of hydration of 80%.)
- Water-cement ratio 0.45
- Air content 9.5% (very high frost resistance also when exposed to de-icing salt)
- Curing before exposure: 9 days in water followed by 26 days in room climate.
- 28 day compressive strength 52.8%.The coefficient of variation is only 1.8% indicating uniform concrete quality.

In total, 222 specimens were produced and set out at the exposure site at national highway 40. The specimens were set out on November 27, 1995.

- 186 specimens were used for measurement of the chloride profile.
- 12 specimens were used for determination of the carbonation depth after the first winter
- The rest of the specimens (24) were either lost during exposure, or accidentally destroyed during the mechanical preparation before determination of the chloride content.

2 THE EXPOSURE SITE AND PLACEMENT OF SPECIMENS

2.1 The exposure site

The exposure site is located a few kilometres outside the city of Borås, at the national highway 40 running between Borås and Gothenburg. The road has motorway standard with 2 roadways in each direction. The site is located just outside the westbound roadways. Most specimens were placed along, and quite close to the inner roadway on different height above this.

The highway is crossed by a concrete viaduct carried by concrete columns founded on the central reserve between the eastbound and westbound roadways. One of these columns was used for chloride mapping. A few specimens were mounted on the edge beam of the viaduct about 4.5 meters above the highway.

A few specimens were also mounted on the barrier of a footbridge running along the highway.

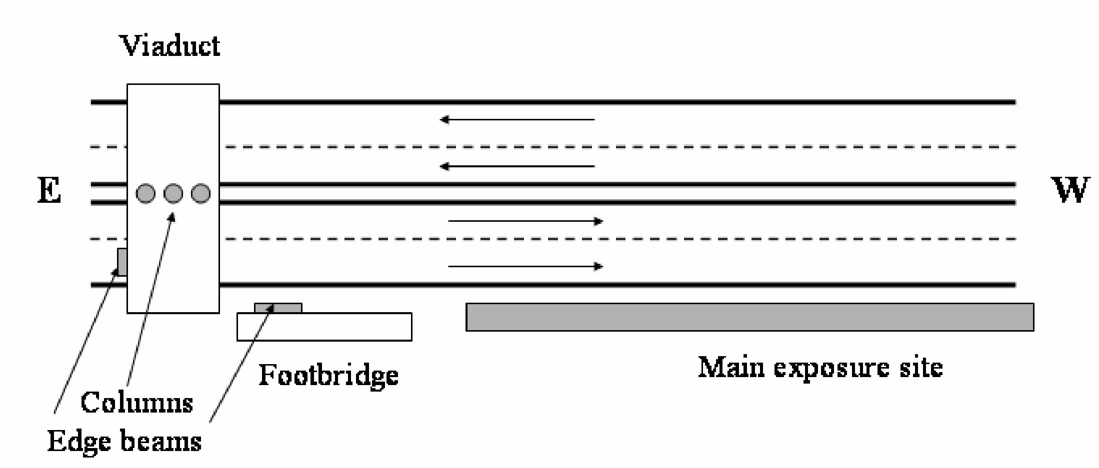


Figure 2.1 Principal plan of the exposure site

2.2 Salt on the exposure site

The amount of salt spread on the road surface during the winter seasons (October-March) is quite high. According to the road administration, 7 to15 g/m^2 NaCl is spread on a width of about 10 m each time the road is de-iced. Most salt, 15-20 g/m^2, is spread when there is snowfall. The number of de-icing occasions is between 130 and 160 each winter season. This means that as an average between 13 and 16 tonnes of salt per km, or 13 to16 kg per meter, is spread each year.

Specimens with the longest exposure time have been exposed to 8 winter seasons.

In Table 2.1 figures for the salt spread during the first winter from November 1995 to March 1996 are given.

Table 2.1: Salt spread during the first winter 1995/1996.

Month	Total number of salt spreads	Total number of salt spreads with snow fall	Total amount of salt (g/m²)
November	2	0	20
December	34	10	415
January	31	7	363
February	33	17	458
March	13	9	198
Total amount of salt for the whole winter			**1 454**

The amount of salt in air close to the westbound roadway was measured by collecting water in small containers placed on a stand beside the roadway, 0.8 m from the barrier and 3.5 m from the salted roadway. No less than 20 containers were mounted on different heights above the ground. The lowest container was 0.7 m above ground and the highest 2.8 m above ground. The vertical opening of each container was about 0.0058 m^2.

The stand is shown on Figure 2.2. In figure 2.3 the total amount of chloride collected in each container during the first winter 1995/1996 is shown; /1/. The chloride load is drastically reduced with increased height above the roadway.

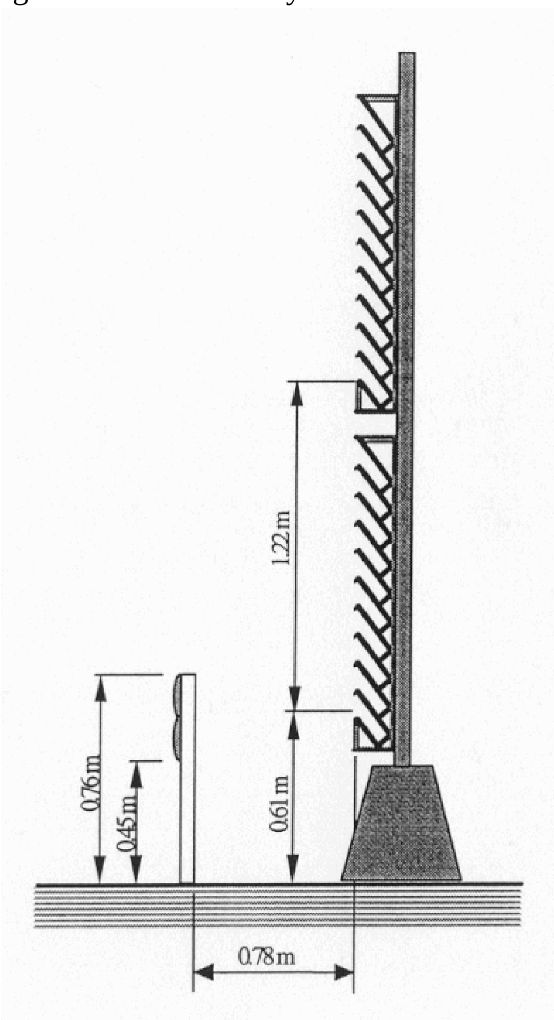


Figure 2.2: Stand with containers for collecting saline water from different height above the roadway, /1/.

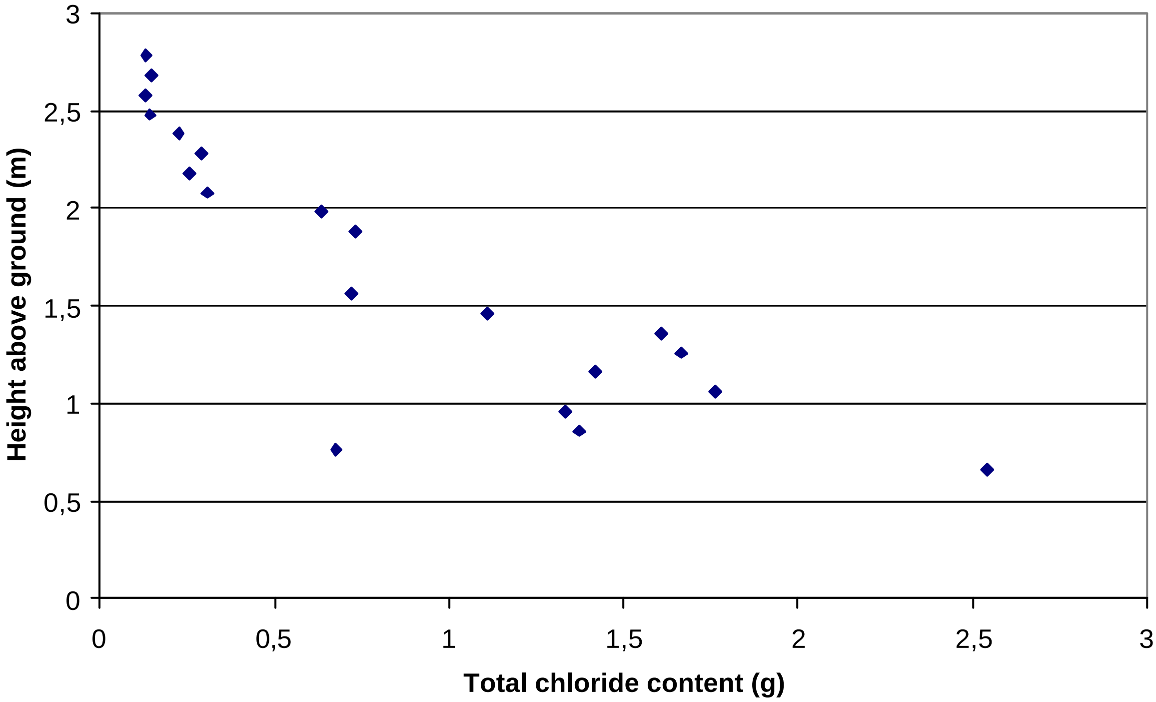


Figure 2.3: Total amount of chloride collected in different containers from November 1995 to February 1996; /1/.

2.3 Climate on the exposure site

The temperature, the relative humidity (RH) and the amount of precipitation on the test site was monitored. An example valid for March 1998 (winter season) is shown in Figure 2.4.

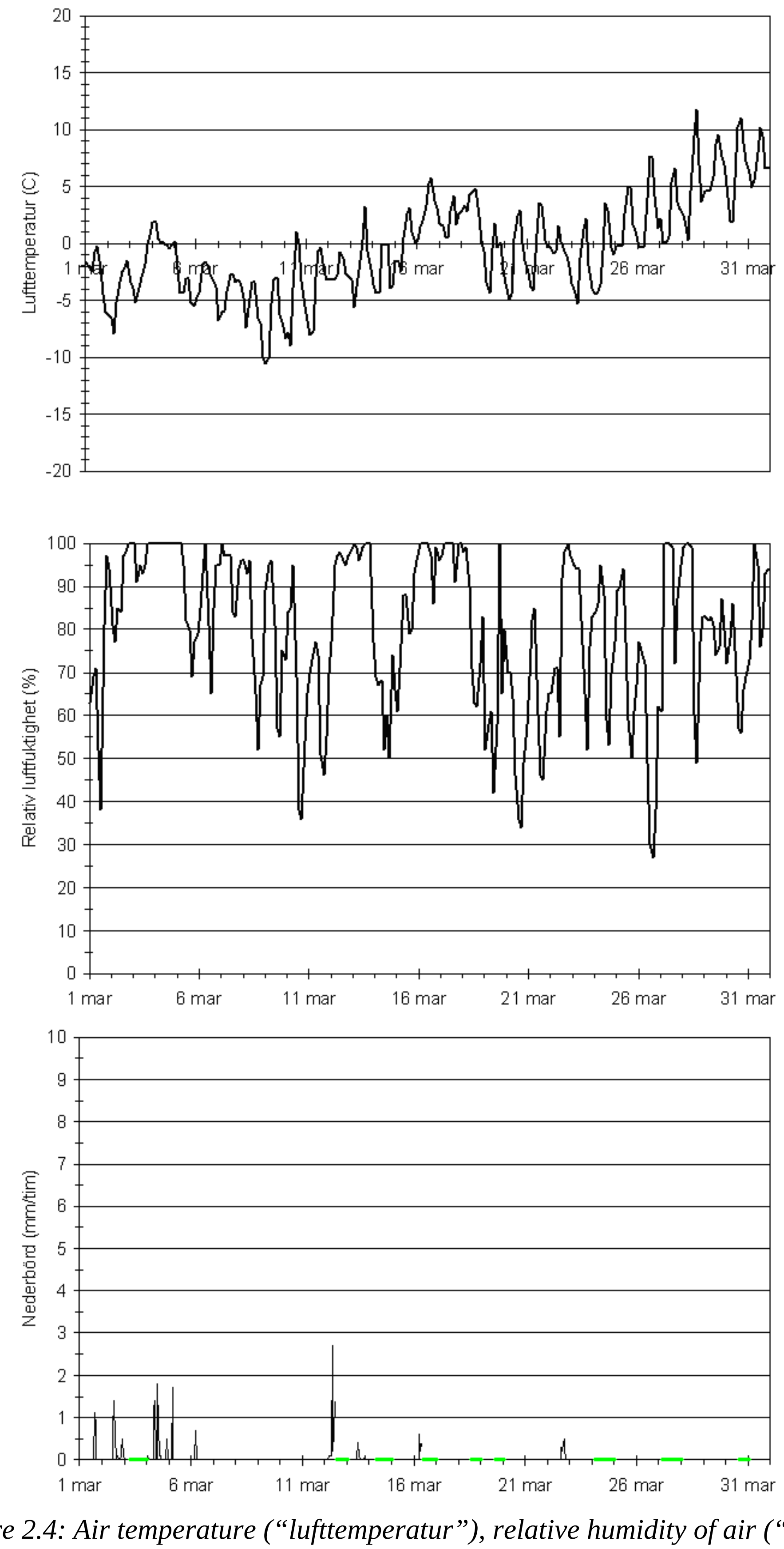


Figure 2.4: Air temperature ("lufttemperatur"), relative humidity of air ("relative luftfuktighet") and amount of precipitation ("nederbörd") in mm per hour for March 1998.

2.4 The specimen holders

The specimens were mounted in holders made of thick aluminum plate. Each holder had place for 4 specimens placed in recesses with diameter 105 mm milled in the plates. The specimens were locked mechanically by a screw in order to avoid that they fell out. The small space between the specimen and the plate was filled by polyester resin. (the two holders at location 2B, see below, contain 11 specimens each). The normal holder is shown in Figure 2.5.

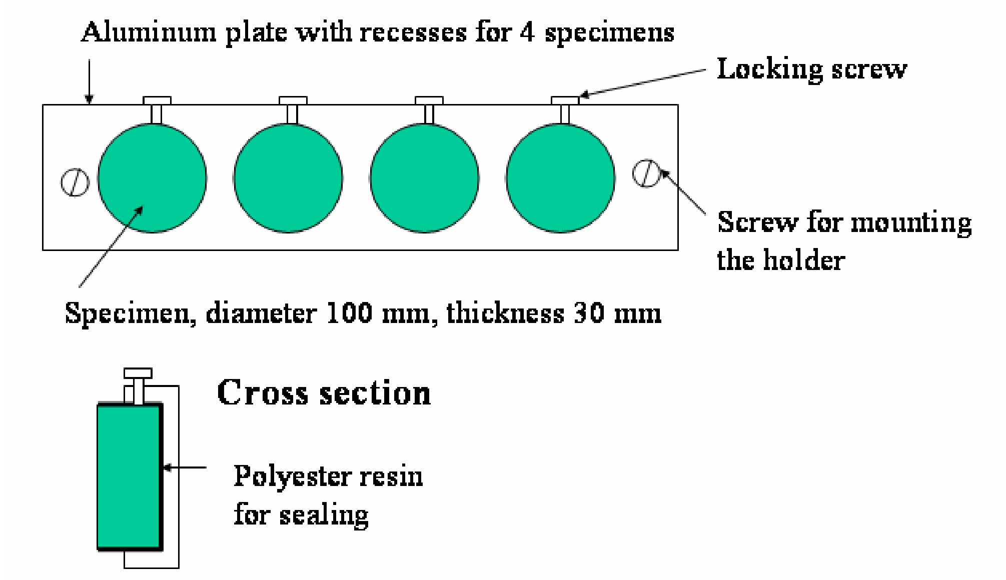


Figure 2.5. The specimen holder

2.5 Location of the specimen holders

The holders with their specimens were placed in the following locations.

Location 1A: Chloride load on different height above the roadway (Figure 2.6 and 2.8)

10 holders, each with 4 specimens, were mounted horizontally on a vertical stand placed 0.5 m behind the railing and 3.6 m from the salted roadway. The vertical distance between individual holders was 0.4 m The lowest holder was 0.45 m above the ground and the highest holder 4.1 m above the road.

Total number of specimens: 40.

Location 1B: Chloride load along the road (Figure 2.6 and 2.9)

25 holders, each with 4 specimens, were mounted on the railing. The distance from the salted roadway was 2.9 m. The height above ground was 0.2 m

Total number of specimens: 100.

Location 2A: Chloride load on different height above the roadway in rain-protected location below the viaduct (Figure 2.7 and 2.10)

10 holders, each with 10 specimens, were mounted horizontally on the same type of stand as in location 1A. The stand was placed close to a rain-protected central column of a viaduct crossing the highway. The distance from the stand to the salted road surface was about 3.5 m. The vertical distance between the holders was 0.4 m. The lowest holder was 0.6 m above ground and the highest 4.2 m above ground.

Total number of specimens: 40.

Location 2B: Chloride load around a bridge column, fairly protected from rain (Figure 2.7 and 2.11)

A aluminium belt with place for 11+11 specimens was mounted around one of the outer columns of the viaduct crossing the highway. The average distance of the belt from the roadway was about 3.5 m (the same as for location 2A). The height above ground was 1m. 11 specimens were facing the roadway in westbound direction, and 11 specimens facing the opposite roadway.

Total number of specimens: 22.

Location C: Chloride load on a foot- and bicycle bridge along the highway (Figure 2.12)

3 holders, each with 4 specimens, were mounted inside the railing of a footbridge running along the highway. The height above the bridge deck was 0.1 m. The distance to the salted roadway was 3 m.

Total number of specimens: 12.

Location D: Chloride load at the edge beam of a viaduct crossing the highway (Figure 2.7 and 2.13).

1 holder with 4 specimens was mounted on the side of the edge beam of the viaduct crossing the highway. Another holder with 4 specimens was mounted on the bottom face of the bridge. The height above the road surface was 4.6 m.

Total number of specimens: 8.

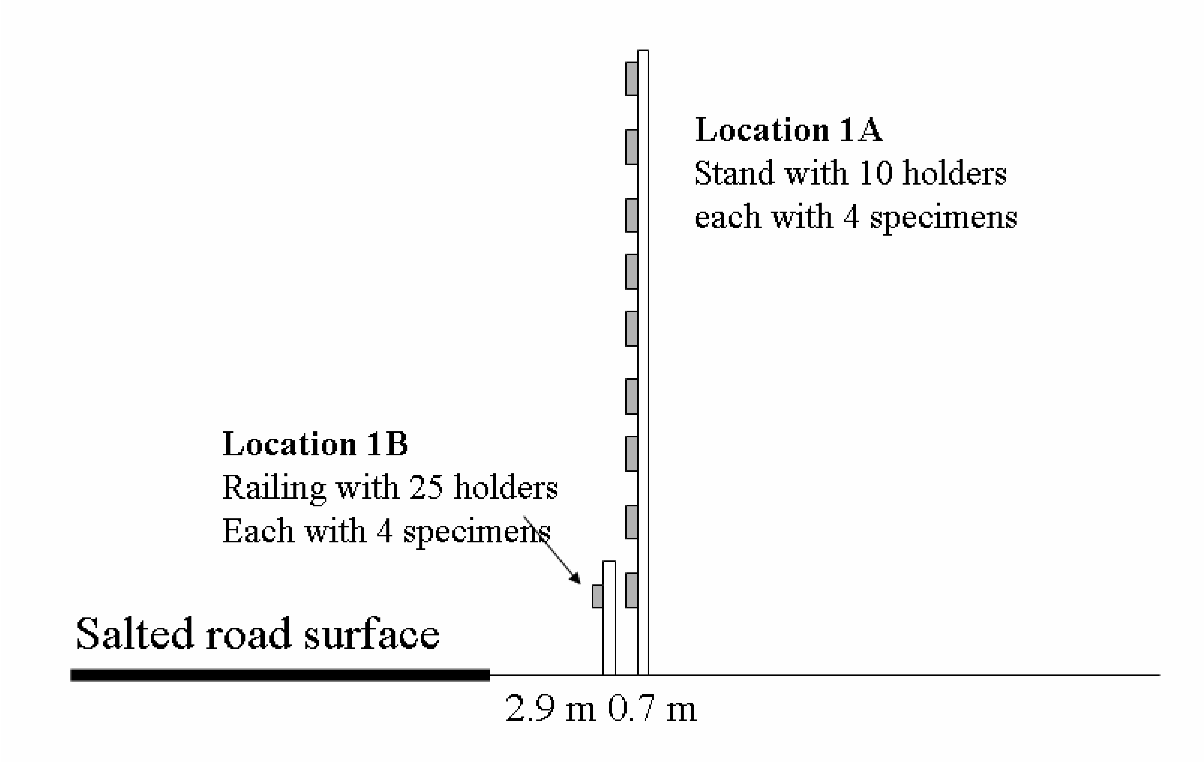


Figure 2.6: Locations 1A and 1B. Unprotected from rain.

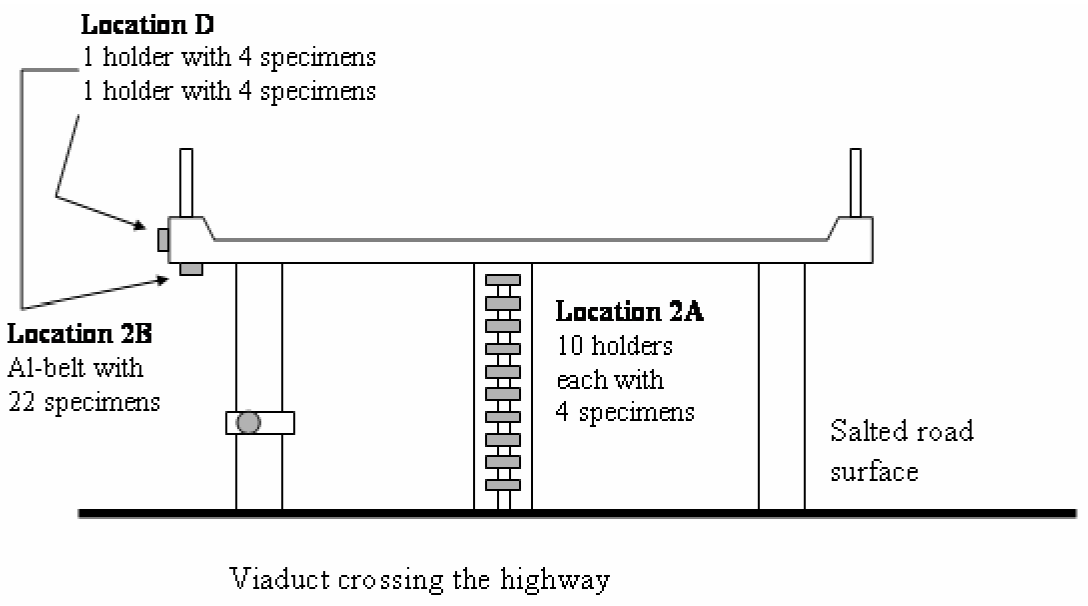


Figure 2.7a: Locations 2A and 2B, protected from rain, and location D.

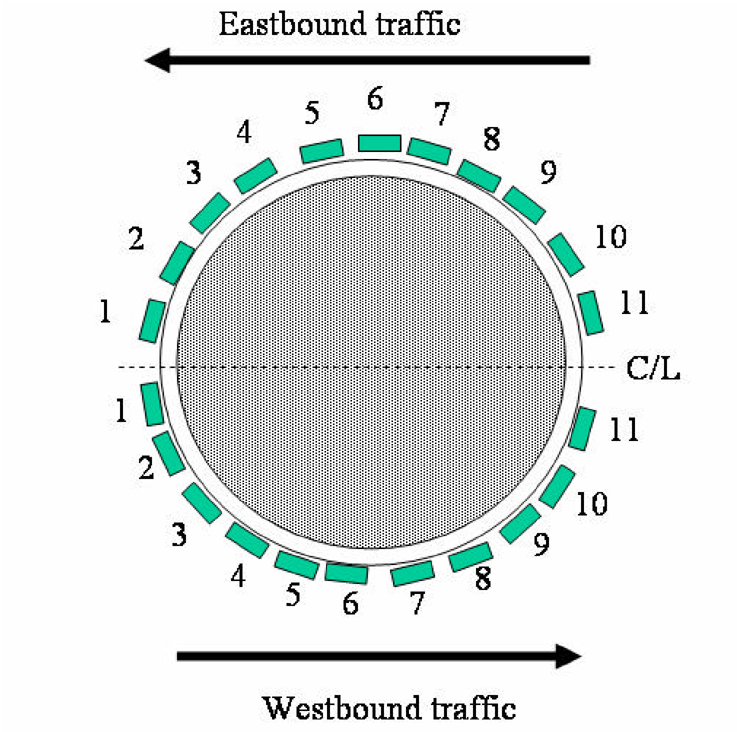


Figure 2.7b: Location 2B.Cross-section of column with belt of specimens.

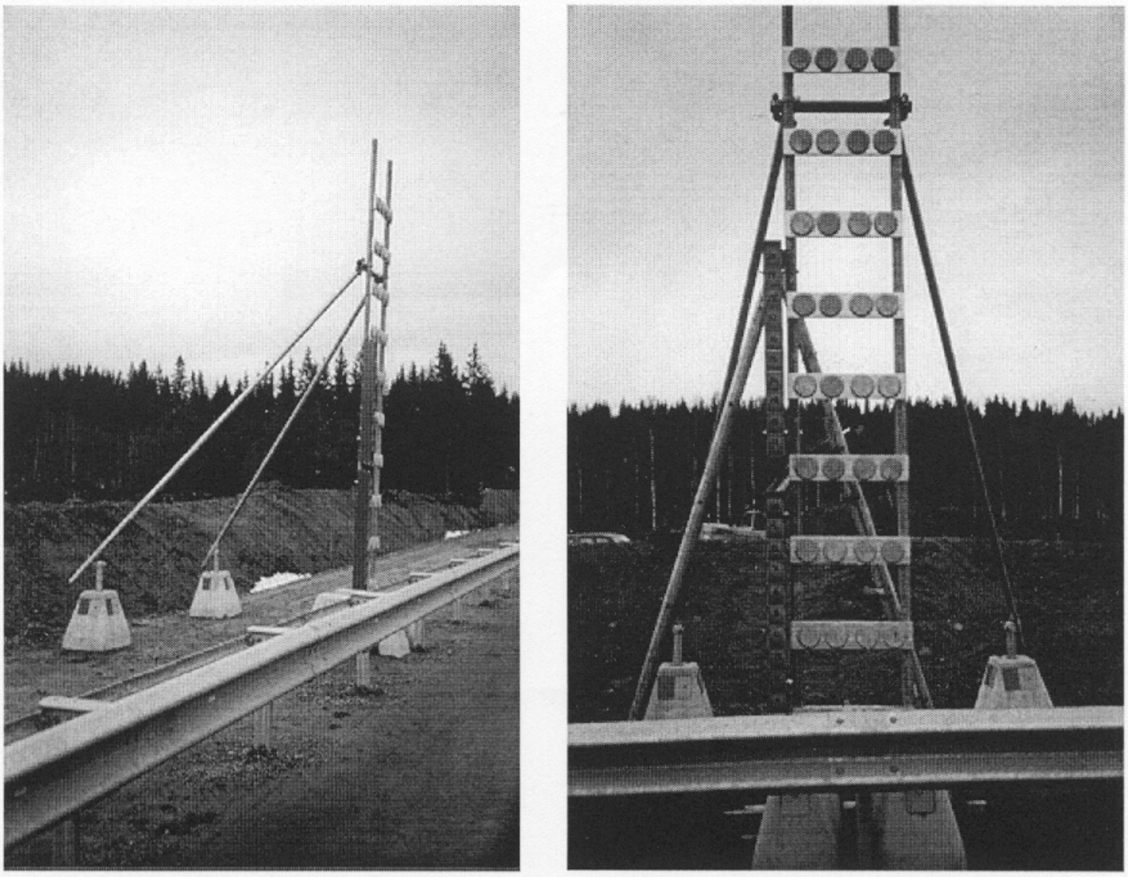


Figure 2.8: Location 1A

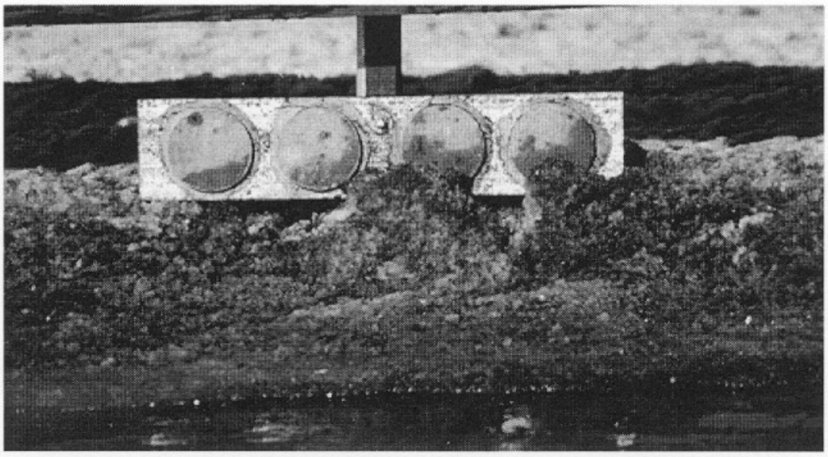


Figure 2.9: Location 1B. Specimens partly covered by saline snow.

Figure 2.10: Location 2A. Location 2B to the left.

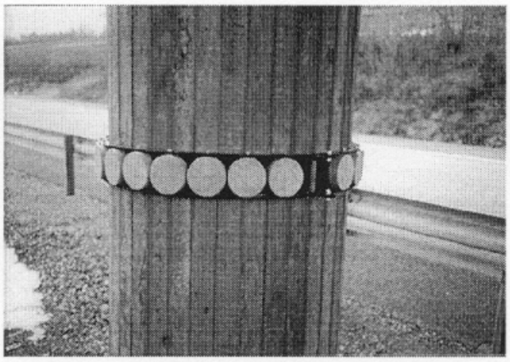


Figure 2.11: Location 2B.

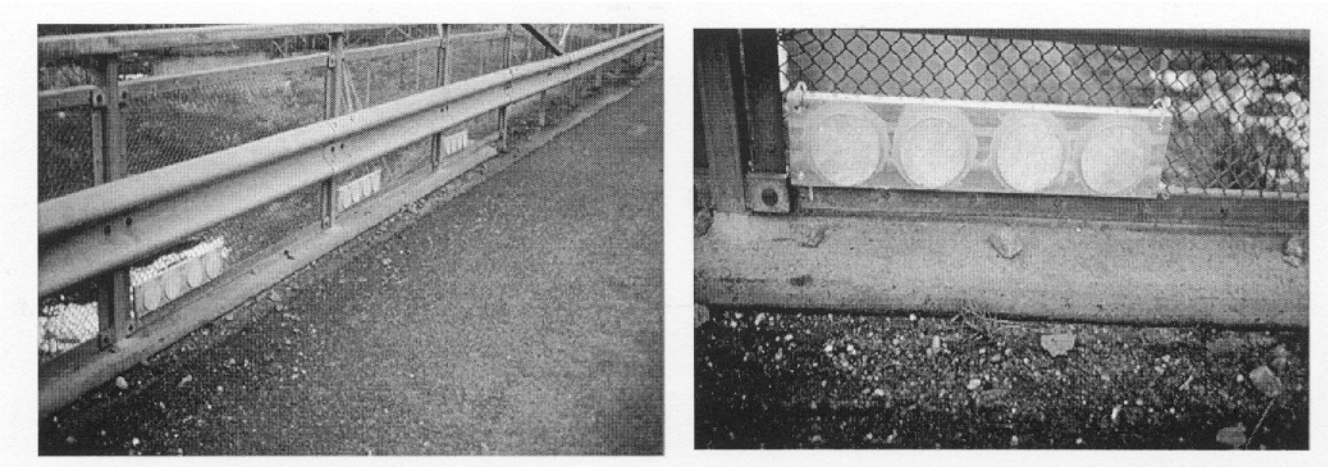


Figure 2.12: Location C.

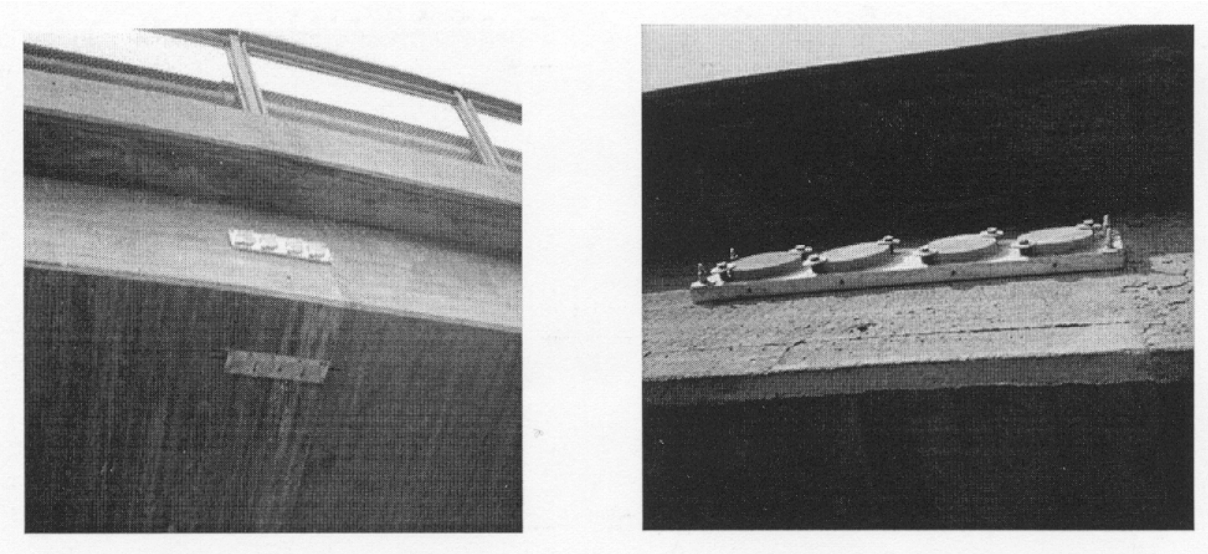


Figure 2.13: Location D.

3 METHOD FOR DETERMINATION OF THE CHLORIDE PROFILE

After a certain exposure time, a number of specimens from different locations were demounted, put in sealed plastic bags, and brought to the lab for determination of the chloride profile. The time, and the number of specimens tested at each time, is given in paragraph 4.

The chloride profile was determined on powder collected from the specimen from different layers below the exposed surface. The powder was obtained by gradual mechanical milling of the specimen on an area of about 65 cm^2 (total exposed surface was 79 cm^2); see Figure 3.1. After milling the powder was dried.

The thickness of each milled layer was about 1 mm. Powder milled from parts between examined layers was discarded.

The total amount of chloride ions (bound+free) in each powder sample was determined by the method Rapid Chloride Test (RCT); /2/. The dry powder was dissolved in a dissolving liquid, so that all chloride ions became free in the solution. The chloride concentration in this was analyzed by a chloride sensitive electrode. This was calibrated in calibration solutions with known chloride concentration.

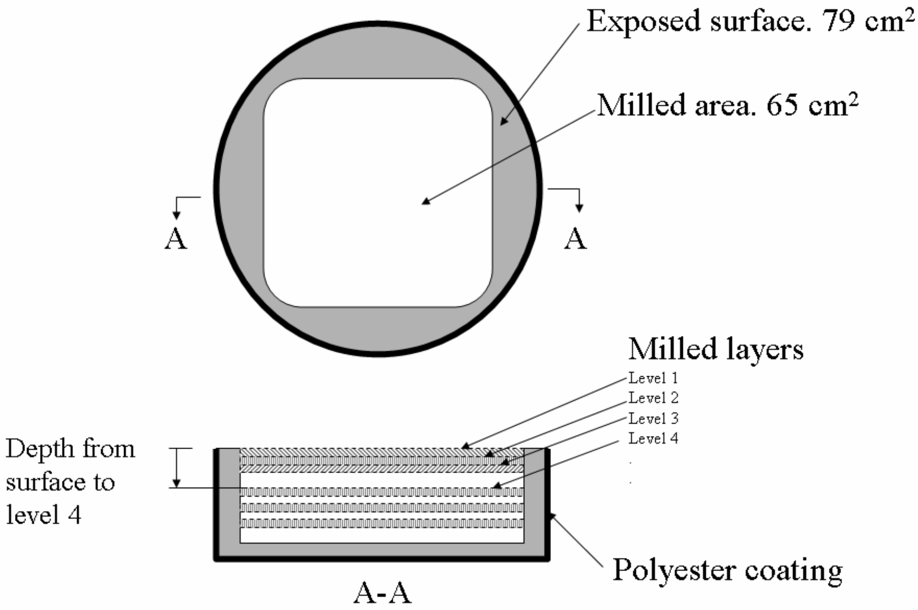


Figure 3.1: Milling of the specimen for determination of the chloride profile. The powder from each level in the specimen was collected and analyzed for its content of chloride.

The *chloride concentration* on a certain depth x expressed in terms of the *cement content* becomes:

$$c_{x,cement} = (2010/556)\cdot c_x = 3.6\cdot c_x \quad (3.1)$$

Where $c_{x,cement}$ is the chloride concentration on depth x related to the cement weight (kg/kg of cement), 556 is the cement content (kg/m^3) , 2010 is the density of concrete (kg/m^3), and c_x is the measured chloride concentration on depth x (kg/kg of concrete).

The *total amount* of chloride taken up within a certain depth from the surface is calculated in the following way; see Figure 3.2.

The total amount of chloride per m^2 of exposed surface in the layer with thickness Δx is:

$$\Delta Q_x = c_{x,mean} \cdot \Delta x \cdot \gamma = c_{x,mean} \cdot \Delta x \cdot 2010 \quad (3.2)$$

where ΔQ_x is the amount of chloride in the layer (kg/m^2), $c_{x,mean}$ is the mean chloride concentration in the interval (kg/kg of concrete), Δx is the thickness of the layer (m), and γ is the density of concrete (2010 kg/m^3).

$$c_{x,mean} = (c_i + c_{i+1})/2 \quad (3.3)$$

where c_i is the chloride concentration on level i (kg/kg).

The total amount of chloride in the outermost 20 mm (kg/kg of concrete) becomes:

$$Q_{20} = \Sigma ? Q_x \text{ from } x=0 \text{ to } x=0.02 \text{ m} \quad (3.4)$$

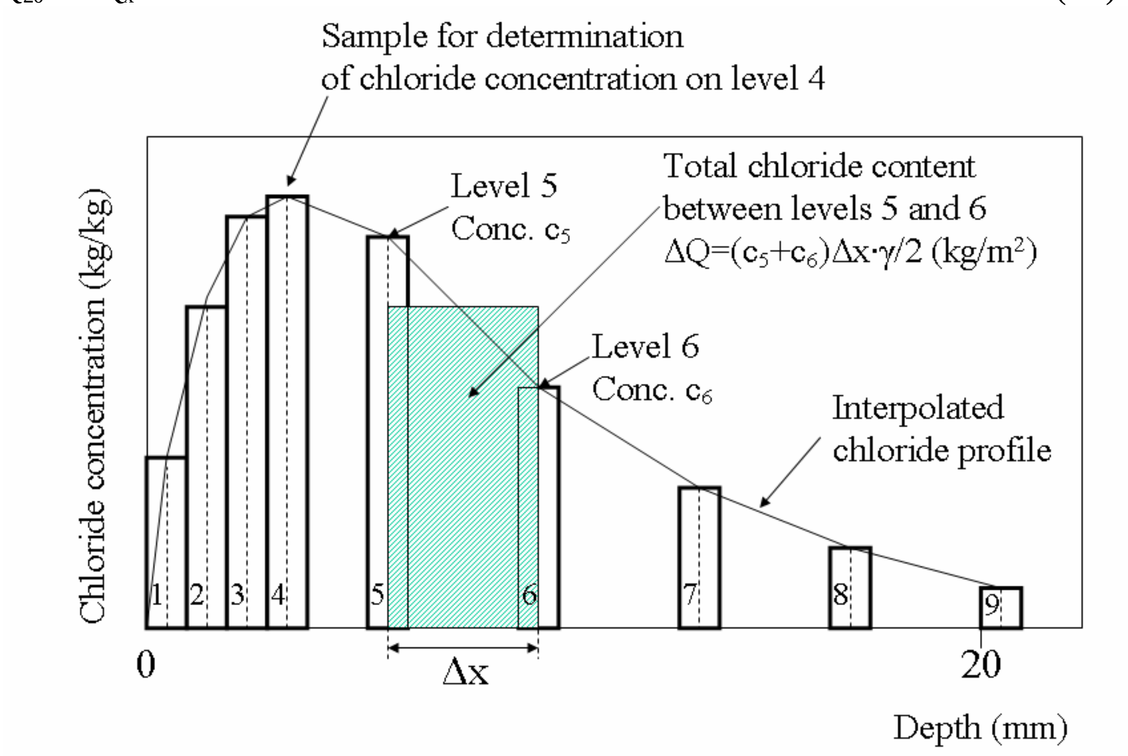


Figure 3.2: Calculation of the total chloride content in the layer with thickness ?x.

4 TIME SCHEDULE FOR EXPOSURE AND CHLORIDE MAPPING

The mapping of chloride was made at 4 occasions. A certain number of specimens was tested at each occasion. The time schedule for the tests is illustrated in Figure 4.1.

Occasion 1: April 1996, direct after the first winter exposure to chloride.

Number of tested specimens: 52
Location 1A: 1 specimen from each level. In total 10 specimens
Location 1B: 4 specimens from 5 holders (every four). In total 20 specimens
Location 2A: 1 specimen from each level. In total 10 specimens
Location 2B: Every other specimen directed towards the westbound roadway. In total 6 specimens
Location C: All specimens from one holder. In total 4 specimens
Location D: 1 specimen from each holder. In total 2 specimens.

Besides, 12 specimens were tested for the carbonation depth.

Occasion 2: October 1996, after the first summer "washing-out" of chloride.

Number of tested specimens: 54
Location 1A: 1 specimen from each level. In total 10 specimens
Location 1B: 4 specimens from 6 holders (every four). In total 24 specimens
Location 2A: 1 specimen from each level. In total 10 specimens
Location 2B: Remaining specimen directed towards the westbound roadway. In total 4 specimens
Location C: All specimens from one holder. In total 4 specimens
Location D: 1 specimen from each holder. In total 2 specimens.

Occasion 3: June 2000, after 5 winter exposures to chloride and after 3 months of the 5th "washing-out season".

Number of tested specimens: 49
Location 1A: 1 specimen from each level. In total 10 specimens
Location 1B: 4 specimens from 5 holders (every four). In total 20 specimens.
Location 2A: 1 specimen from each level. In total 10 specimens
Location 2B: 3 specimens directed towards the eastbound roadway.
Location C: All specimens from one holder. In total 4 specimens
Location D: 1 specimen from each holder. In total 2 specimens.

All "chloride specimens" were also examined for the carbonation depth.

Occasion 4: June 2003, after 8 winter exposures to chloride and after 3 months of the 8th "washing-out season".

Number of tested specimens: 31
Location 1A: 1 specimen from each level. In total 10 specimens
Location 1B: 1 specimen from 4 holders (every four). In total 4 specimens
Location 2A: 1 specimen from each level. In total 10 specimens
Location 2B: 5 specimens directed towards the eastbound roadway.
Location C: No specimen
Location D: 1 specimen from each holder. In total 2 specimens.

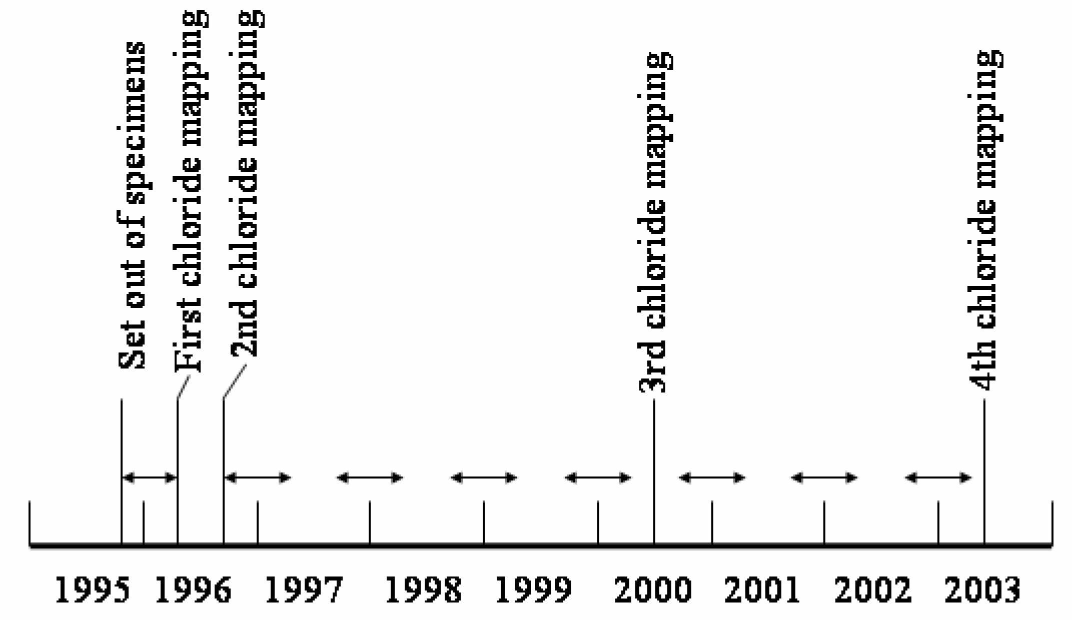


Figure 4.1: Time schedule for the exposure and chloride tests. The arrows indicate the winter seasons with spreading of de-icing salt.

5 RESULTS OF CHLORIDE MAPPING

5.1 Test data

Measurements of chloride distributions from the first three investigations in 1996 and 2000 have been published earlier; /3, 4/. The results are shown in APPENDIXES 1, 2 and 3. Measurements from the test in 2003 are shown in APPENDIX 4.

5.2 Location 1A: Unprotected from rain. Effect of the height above ground

The chloride distribution after the first winter is shown in Figure 5.1. The chloride uptake is very much decreased with increased height above ground. The peak chloride concentration on 4 m height is only about 20% of that on 0.5 m. This corresponds fairly well to the measurement of chloride collected in containers, as shown in Figure 2.3.

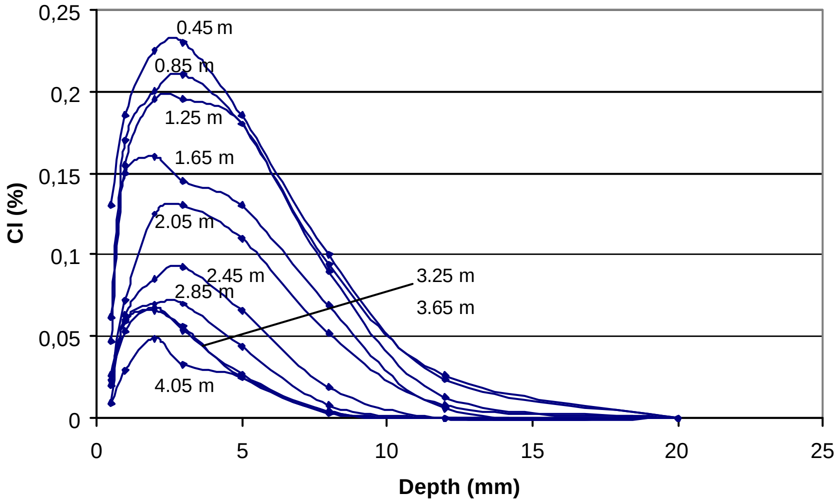


Figure 5.1: Location 1A. Chloride distribution as function of the height above ground immediately after the first winter (April 1996).

Chloride is evidently washed out from the concrete during the first summer as shown in Figure 5.2 according to which the peak concentration is reduced. But, at the same time the chloride front has transgressed further into the concrete.

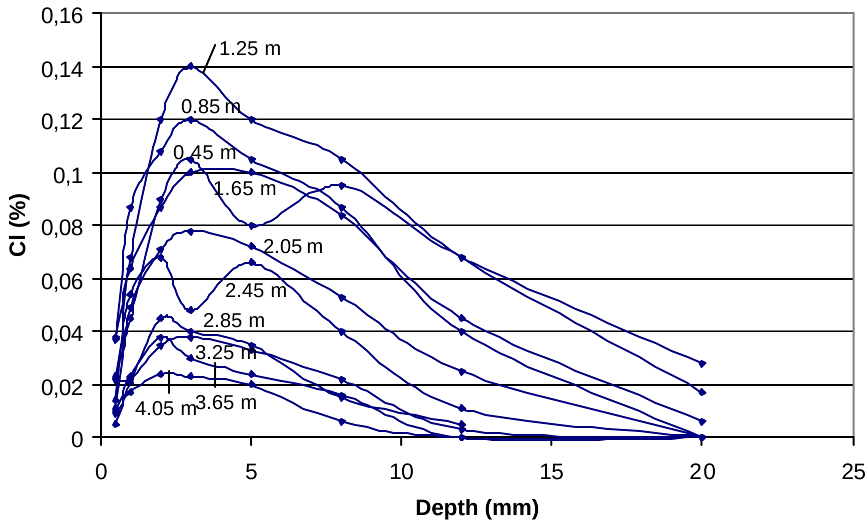


Figure 5.2: Location 1A. Chloride distribution as function of the height above ground after the first summer (October 1996).

Increased exposure time did not cause the peak concentration to increase, which is illustrated by Figure 5.3. One exception is the highest level above ground for which there is a certain increase compared with the first summer. The chloride profile becomes more flat with time, however, which shows that chloride is redistributed; it is washed out at the surface but proceeds inwards.

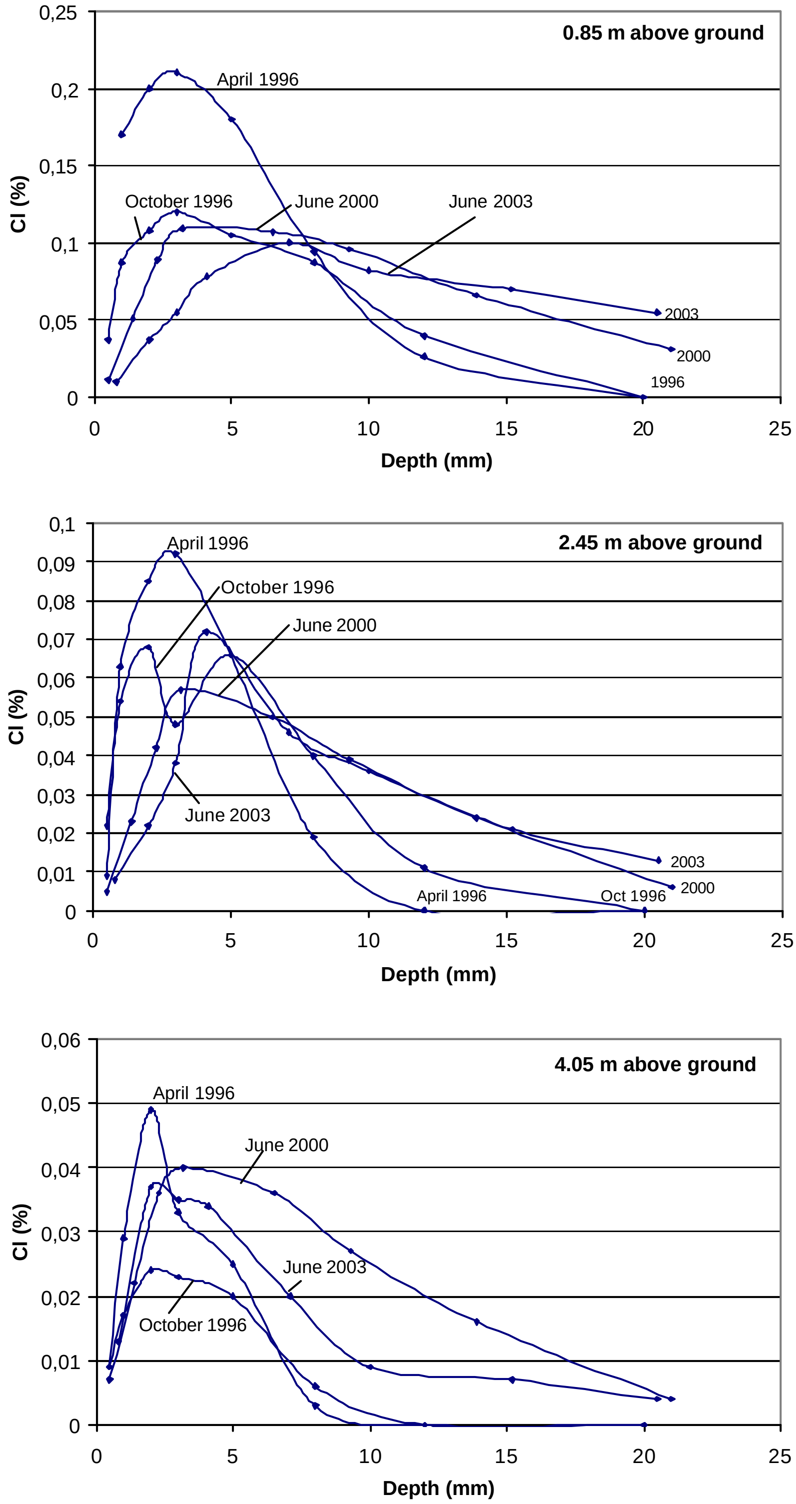


Figure 5.3: Location 1A. Chloride distribution on the levels 0.85, 2.45 and 4.05 meter above ground. Effect of exposure time.

The observations are summarized in Table 5.1. The following data are given in the table:

1. The peak value of the chloride concentration in weight-% of the concrete.
2. The depth from the surface on which the peak chloride content is measured (mm)
3. The total amount of chloride taken up in the outermost 20 mm of the concrete in kg per m^2 of exposed surface. 20 mm is selected since the chloride content is in most cases negligible on bigger depths. Furthermore, measurements are made down to this depth for almost all specimens.

The peak concentration in weight-% of the *cement* is obtained by multiplying the table values by the factor 3.6.

Table 5.1: Location 1A: Chloride conditions on different height above ground.

Height (m)	**After 1 winter April 1996**		**After 1 winter and 1 summer October 1996**		**After 5 winters June 2000**		**After 8 winters June 2003**	
	Peak Cl % (mm)	Total Cl kg/m^2	Peak Cl % (mm)	Total Cl kg/m^2	Peak Cl % (mm)	Total Cl kg/m^2	Peak Cl % (mm)	Total Cl kg/m^2
0.45	0.230 (3)	0.035	0.105 (3)	0.027	0.165? (14?)	0.041	0.118 (7)	0.029
0.85	0.210 (3)	0.033	0.120 (3)	0.024	0.109 (3)	0.030	0.100 (7)	0.028
1.25	0.195 (2)	0.030	0.140 (3)	0.031	0.095 (3)	0.025	0.143 (7)	0.038
1.65	0.160 (2)	0.023	0.100 (3)	0.023	0.086 (3)	0.025	0.106 (4)	0.024
2.05	0.130 (3)	0.020	0.078 (3)	0.015	0.096 (6)	0.024	0.060 (3)	0.016
2.45	0.092 (3)	0.010	0.068 (2)	0.011	0.057 (3)	0.013	0.072 (4)	0.013
2.85	0.070 (2)	0.008	0.045 (2)	0.006	0.055 (3)	0.012	0.026 (2)	0.005
3.25	0.068 (2)	0.006	0.038 (3)	0.006	0.044 (6)	0.010	0.034 (3)	0.007
3.65	0.066 (2)	0.006	0.038 (2)	0.004	0.037 (6)	0.009	0.035 (2)	0.005
4.05	0.049 (2)	0.004	0.024 (2)	0.003	0.040 (3)	0.009	0.037 (2)	0.006
Mean	**0.127**	**0.018**	**0.076**	**0.015**	**0.078**	**0.020**	**0.073**	**0.017**

The peak chloride concentration and the total absorbed chloride as function of time and height above ground are plotted in Figures 5.4 and 5.5.

The measurements show that the maximum (peak) chloride concentration is reached directly after the first winter. All measurements made some months after the winter give lower values of the peak concentration.

The total amount of chloride taken up within the outermost 20 mm is almost constant with time. There is a slight increase after 5 years (summer 2000) but this is reduced after the 8th winter (summer 2003).

Thus, the measurements indicate that most of the chloride taken up during winter is washed out during summer, except for the first winter and summer when there is a certain permanent chloride uptake, probably to a large extent chemically bound in the concrete.

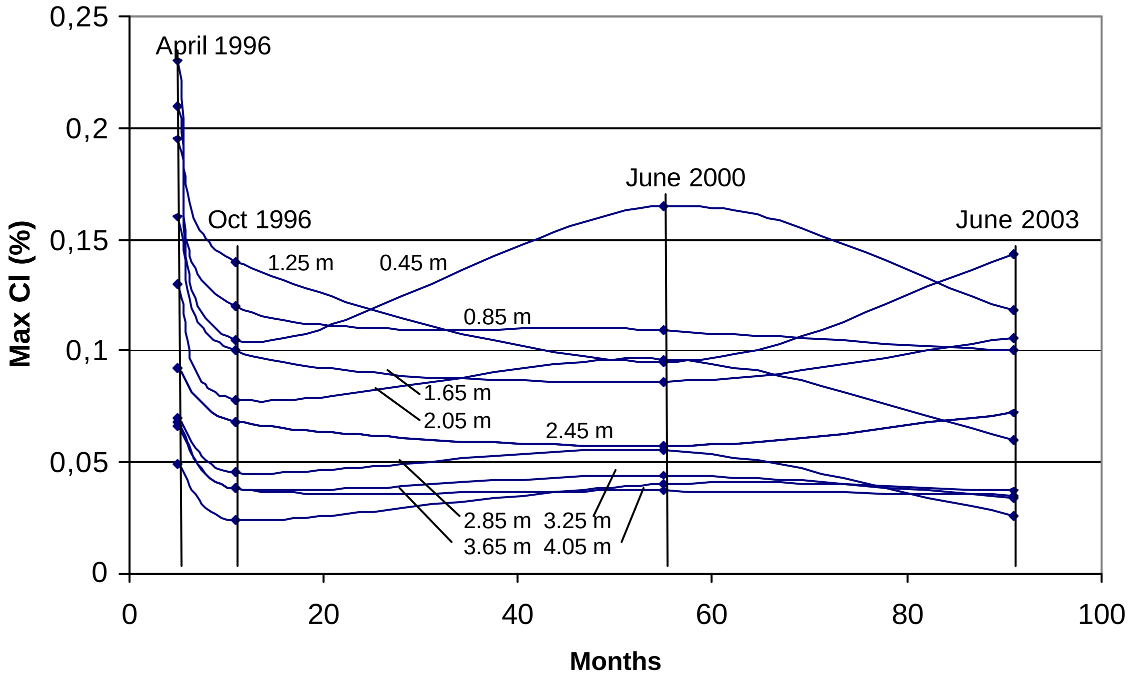


Figure 5.4: Location 1A. The maximum chloride concentration as function of time and height above ground. Data from Table 5.1

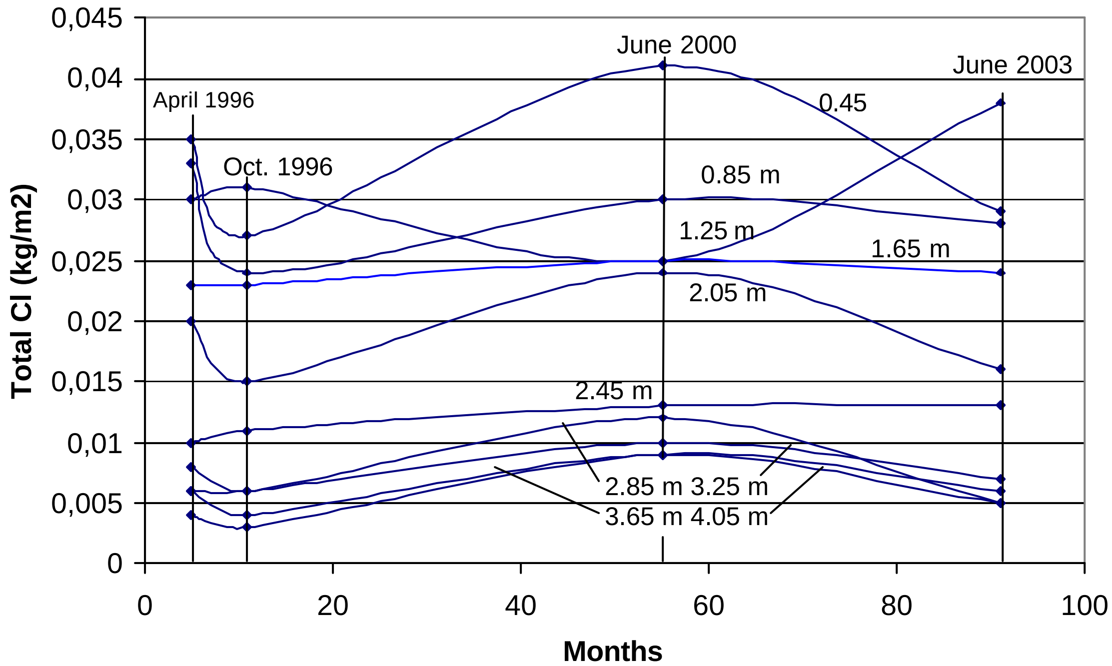


Figure 5.5: Location 5A. The total absorbed chloride in the outermost 20 mm of the specimens as function of time and height above ground. Data from Table 5.1

Comment concerning service life:
Measurements show that the threshold concentration for this type of concrete might be minimum 0.7 % of the cement weight /5/. This corresponds to about 0.2 % of the concrete weight. Thus, it is highly improbable that reinforcement corrosion could have been initiated in the actual type of concrete after 8 years of exposure to de-icing salt. The penetration of chloride and the peak concentrations are so low that it is also improbable that corrosion should be initiated even after 100 years in a concrete with normal concrete cover for this type of environment[1].

[1]) Minimum 45 mm according to the Swedish Standard SS 13 70 10.

5.3 Location 1B: Unprotected from rain. Chloride conditions along the road

The mean chloride distribution after the first winter (April 1996) is shown in Figure 5.8. The specimens are placed only 20 cm above ground which makes the peak concentration about the same as for the lowest specimen on location 1A; see Figure 5.1. The spread in the results is remarkably small.

A comparison of the distributions at different exposure times is made in Figure 5.7.

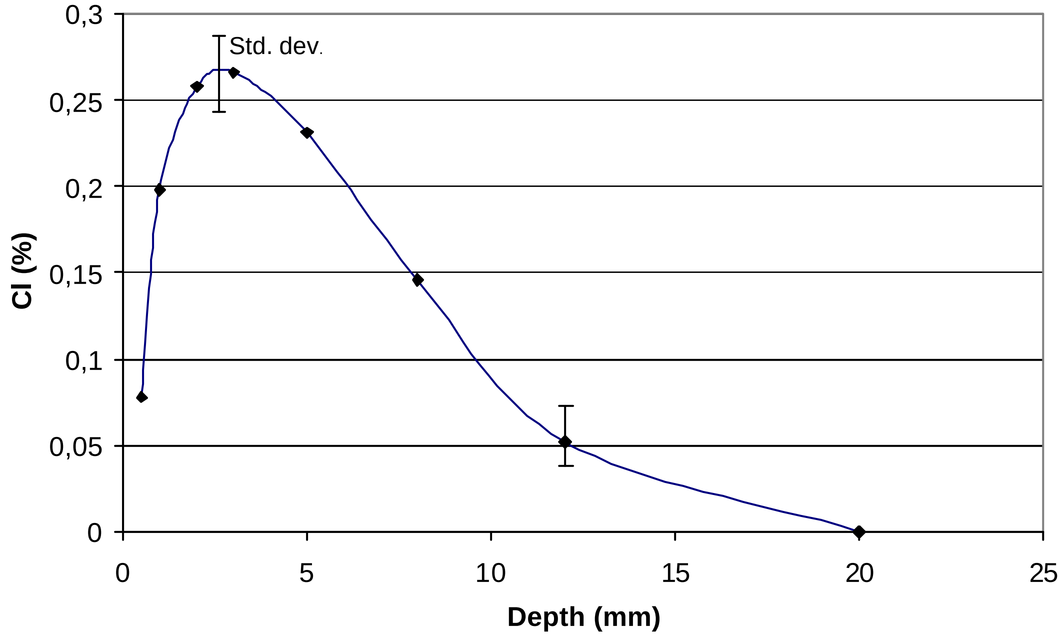


Figure 5.6: Location 1B. Chloride distribution along the road. Immediately after the first winter. Mean values

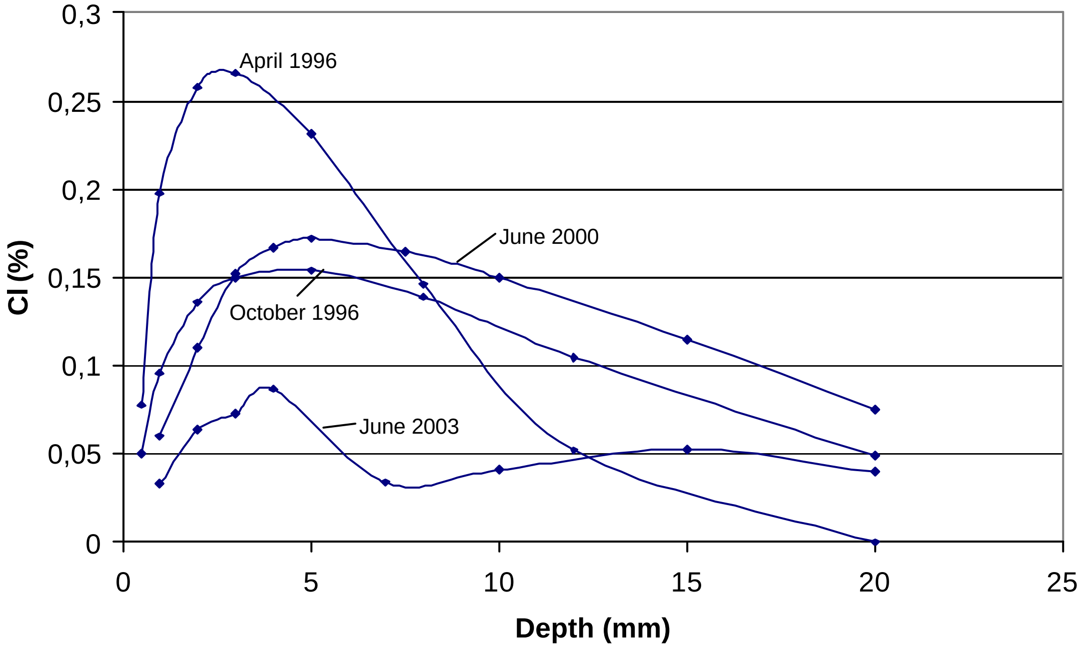


Figure 5.7: Location 1B. Chloride distribution along the road. Effect of the exposure time. Mean values.

The observations are summarized in Table 5.2. Explanation to the table is given in Table 5.1.

Table 5.2: Location 1B: Chloride condition along the road.

	After 1 winter April 1996		**After 1 winter and 1 summer October 1996**		**After 5 winters June 2000**		**After 8 winters June 2003**	
	Peak Cl % (mm)	Total Cl kg/m^2	Peak Cl % (mm)	Total Cl kg/m^2	Peak Cl % (mm)	Total Cl kg/m^2	Peak Cl % (mm)	Total Cl kg/m^2
Max. single value	0.345 (2)	0.055	0.200 (3)	0.057	0.200 (3)	0.060	0.115 (4)	0.021
Mean of all values	**0.266** (3)	**0.046**	**0.154** (5)	**0.043**	**0.146** (3)	**0.049**	**0.088** (4)	**0.020**
Std dev. of all values	0.024	0.006	0.021	0.006	0.023	0.009	0.021	0.002

The results are similar to those from location 1A; chloride taken up during winter is washed out during summer, making the total chloride taken up fairly constant. There is a deviation for 8 years exposure (June 20003) since both the peak concentration and the total chloride content is markedly lower than for June 2000 and October 1996. The reason is unclear. The number of specimens tested at June 2003 was only 4 compared to the 22 and 20 specimens tested at the other occasions. Therefore, the selection made might have been unrepresentative.

5.4 Location 2A: Protected from rain. Effect of height above ground

The chloride distribution after the first winter is shown in Figure 5.8. The results are qualitatively similar to those from location 1A at which the specimens are unprotected from rain. Chloride uptake is very much decreased with increased height above ground. The chloride uptake and the chloride concentration are, however, much lower than at location 1A, which might seem peculiar since the “salt load” on the road ought to be about the same. The most plausible reason is that the moisture level inside the concrete is lower. Therefore, the diffusivity of chloride is considerably smaller than in the unprotected concrete.

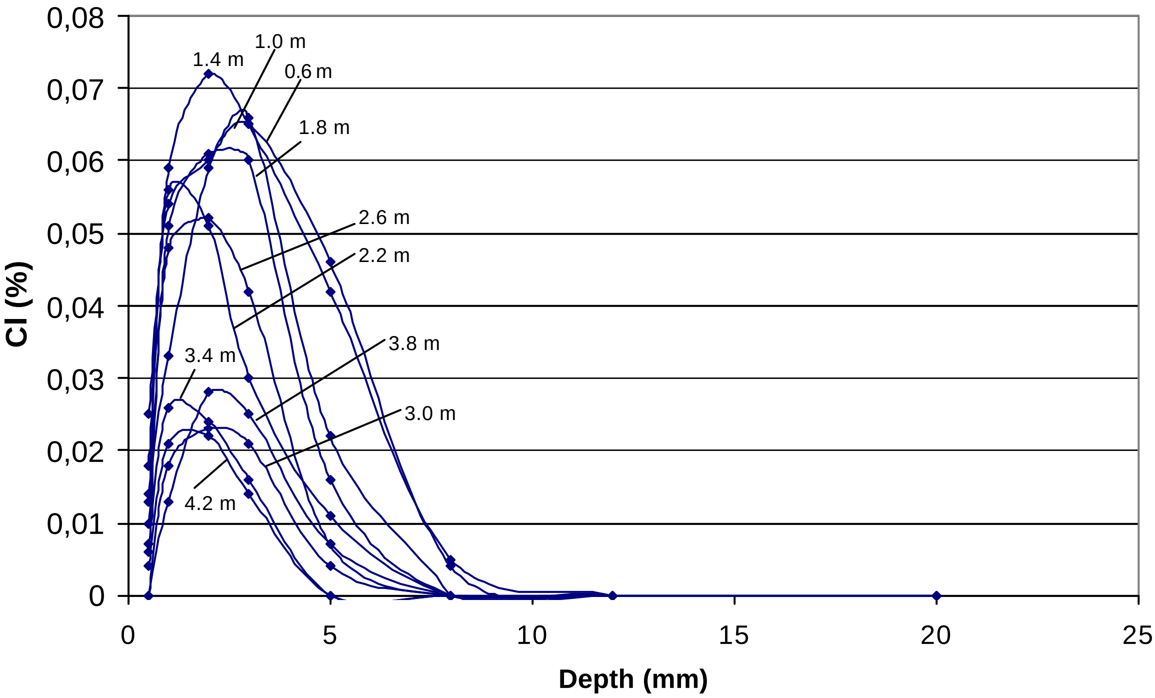
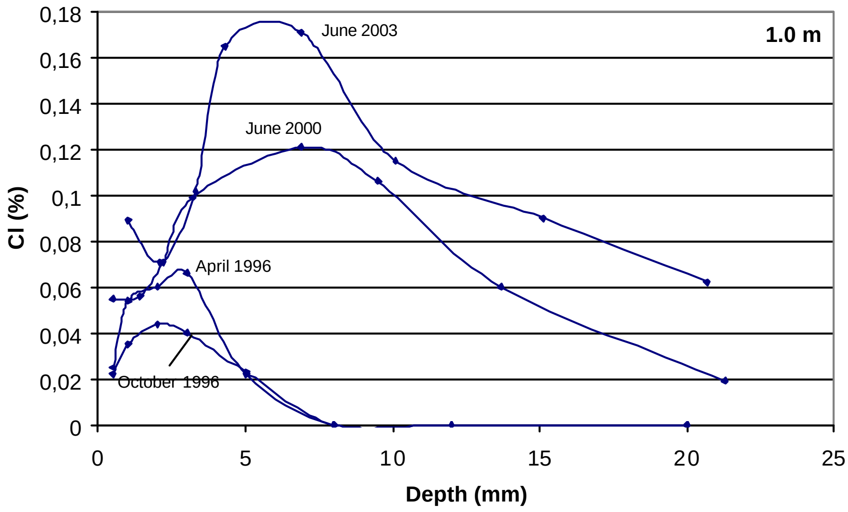
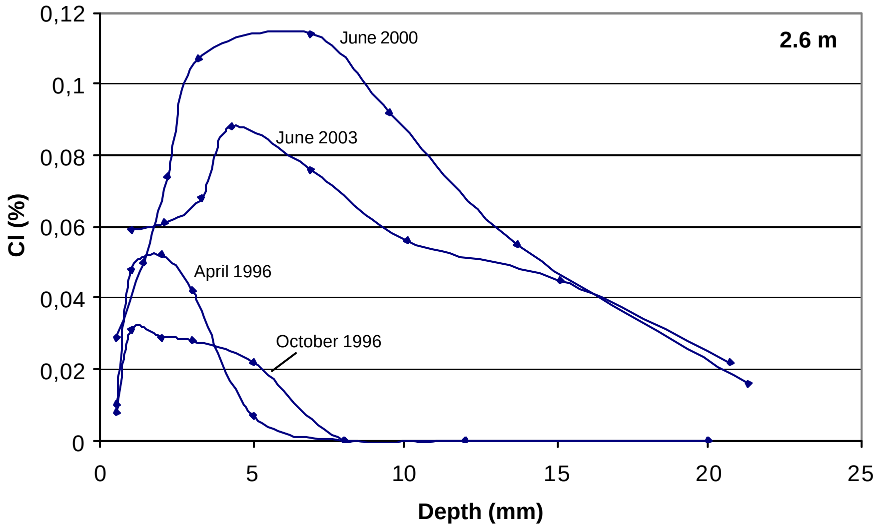


Figure 5.8: Location 2A. Chloride distribution as function of the height above ground, immediately after the first winter (April 1996).

A comparison between the chloride distributions after different exposure times is shown in Figure 5.9 for three levels above ground. The behaviour is quite different from location 1A, since the chloride concentration increases with time. The reason is that chloride is not washed out in the protected location 2A to the same extent as in the unprotected location 1A.

After 8 years (June 2003) the chloride concentration is, on all heights, markedly higher than for location 1A; c.f. Figure 5.3.





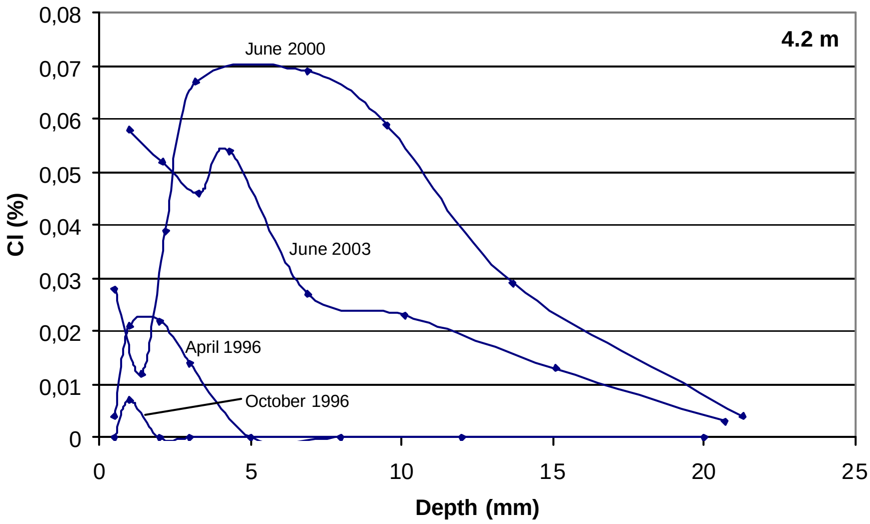


Figure 5.9: Location 2A. Chloride distribution on the levels 1.0, 2.6 and 4.2 meter above ground. Effect of exposure time.

The observations are summarized in Table 5.3. For explanation of the columns, see Table 5.1.

Table 5.3: Location 2A: Chloride conditions on different height above ground.

Height (m)	After 1 winter April 1996		After 1 winter and 1 summer October 1996		After 5 winters June 2000		After 8 winters June 2003	
	Peak Cl % (mm)	Total Cl kg/m^2	Peak Cl % (mm)	Total Cl kg/m^2	Peak Cl % (mm)	Total Cl kg/m^2	Peak Cl % (mm)	Total Cl kg/m^2
0.60	0.065 (3)	0.011	0.051 (3)	0.009	0.177 (7)	0.045	0.119 (4)	0.036
1.00	0.066 (3)	0.005	0.044 (2)	0.004	0.121 (7)	0.030	0.171 (7)	0.042
1.40	0.072 (2)	0.007	0.040 (5)	0.006	0.160 (7)	0.040	0.145 (10)	0.046
1.80	0.061 (2)	0.005	0.027 (3)	0.005	0.102 (7)	0.025	0.152 (7)	0.042
2.20	0.056 (1)	0.004	0.037 (2)	0.004	0.158 (7)	0.038	0.110 (7)	0.029
2.60	0.052 (2)	0.004	0.031 (1)	0.003	0.114 (7)	0.028	0.088 (4)	0.022
3.00	0.023 (2)	0.002	0.020 (2)	0.001	0.110 (7)	0.025	0.095 (4)	0.023
3.40	0.026 (1)	0.001	0.021 (2)	0.002	0.094 (7)	0.022	0.155 (7)	0.032
3.80	0.028 (2)	0.002	0.009 (3)	0.001	0.083 (3)	0.017	0.075 (7)	0.019
4.20	0.022 (2)	0.001	0.007 (1)	0	0.069 (7)	0.016	0.054 (4)	0.010
Mean	**0.047**	**0.004**	**0.029**	**0.004**	**0.119**	**0.029**	**0.116**	**0.030**

The maximum chloride concentration and the total absorbed chloride as function of time and height above ground are plotted in Figures 5.10 and 5.11.

The measurements show that the maximum (peak) chloride concentration is higher after 5 and 8 years than after the first winter. Also the total chloride content is gradually increased. There is a certain reduction in chloride concentration and content between June 2000 and June 2003 for some levels. The reason for this is unclear. Only one specimen is tested for each height. Thus, a certain variation in results can be expected due to spread in concrete properties and salt load.

Comment concerning service life:
As said in paragraph 5.2 the threshold chloride concentration for onset of corrosion is at least 0.2% of the concrete weight. Since the chloride concentration increases with time it cannot be excluded that this concentration is reached after some decades in rain protected locations.

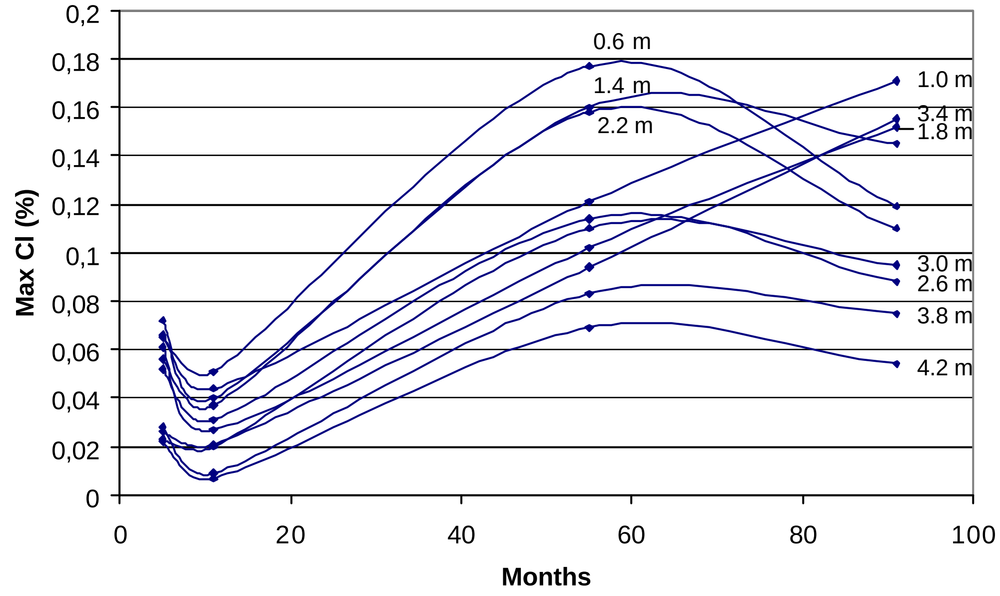


Figure 5.10: Location 2A.The maximum chloride concentration as function of time and height above ground. Data from Table 5.3.

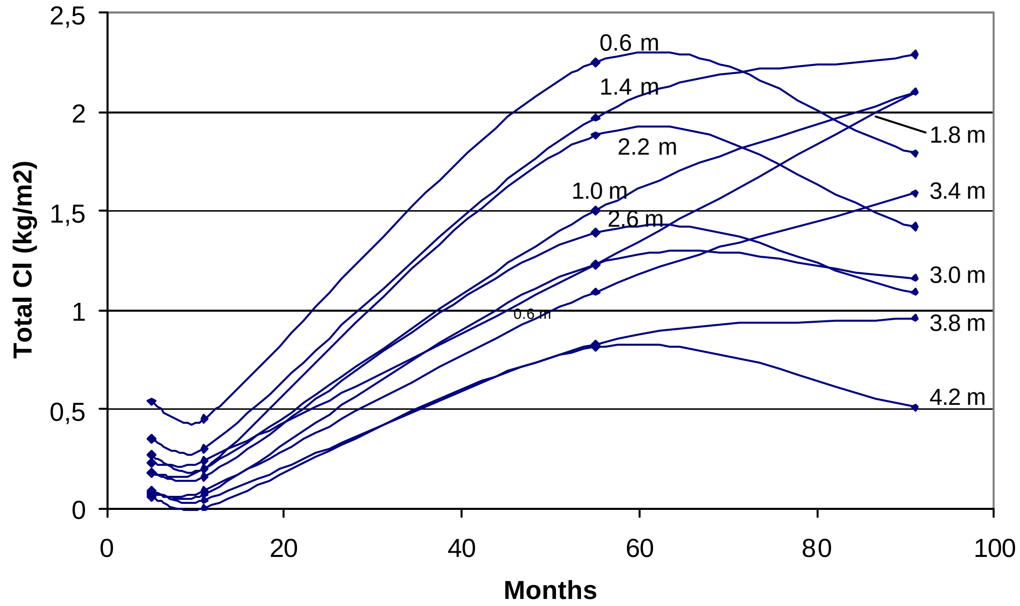


Figure 5.11: Location 2A. The total absorbed chloride in the outermost 20 mm of the specimens as function of time and height above ground. Data from Table 5.3.

5.5 Location 2B: Chloride conditions around a bridge column

The chloride distributions directly after the 1st winter (April 1996) and after the 8th winter followed by 3 months spring (June 2003) are shown in Figures 5.12 and 5.13. There is a clear effect of the direction of the exposed concrete surface to the direction of traffic. Specimens directed towards the traffic have higher chloride content than specimens directed from the traffic. The difference in chloride content is not necessarily an effect of the direction of traffic, however, since there is also a difference in quarter.

The chloride content is highest after the first winter. Thus, no chloride accumulation seems to occur

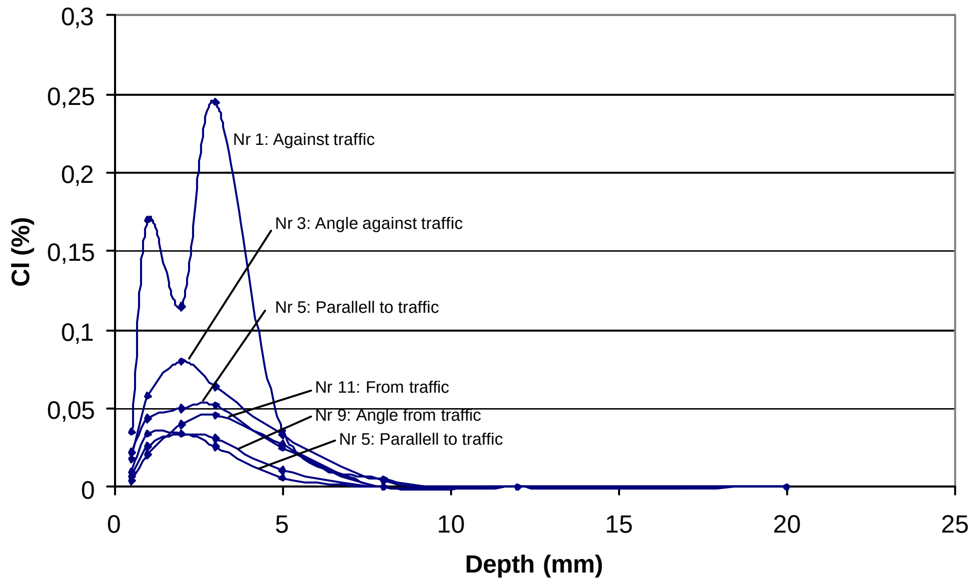


Figure 5.12:Location 2B. Chloride distribution around a bridge column. Westbound traffic. Immediately after the first winter (April 1996).

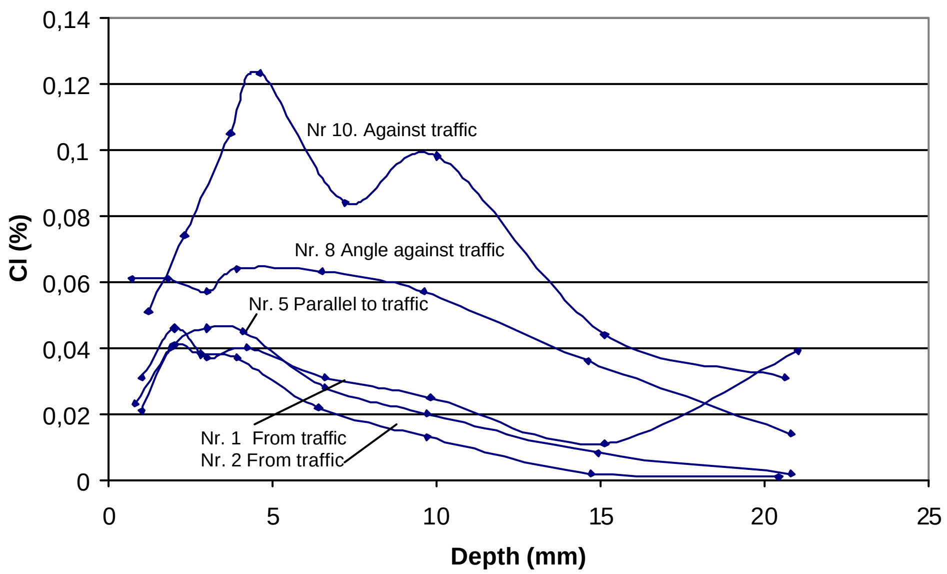


Figure 5.13: Location 2B. Chloride distribution around a bridge column. Eastbound traffic. After the 8th winter and 3 months summer (June 2003).

The observations are summarized in Table 5.4. For explanation of the columns, see Table 5.1.

Table 5.4: Location 2B: Chloride conditions around a bridge column.

Direction	**Spec. nr.** [1)]	**After 1 winter April 1996**		**After 1 winter and 1 summer October 1996**		**After 5 winters June 2000**		**After 8 winters June 2003**	
		Peak Cl %	Total Cl kg/m^2	Peak Cl %	Total Cl kg/m^2	Peak Cl %	Total Cl kg/m^2	Peak Cl %	Total Cl kg/m^2
Meeting traffic	**W1**	0.245[2)]	0.015						
	E11					0.067	0.015		
	E10							0.123	0.027
Angle against traffic	**W3**	0.080	0.007						
	W4			0.026	0.003				
	E8							0.064	0.019
Parallel to traffic	**W5**	0.052	0.005						
	W7	0.034	0.003						
	W6			0.026	0.002				
	E6					0.115	0.028		
	E5							0.046	0.008
Angle from traffic	**W9**	0.034	0.003						
	W8			0.044	0.004				
	E3					0.098	0.028		
From traffic	**W11**	0.046	0.004						
	W10			0.054	0.008				
	E1							0.046	0.011
	E2							0.040	0.006
Mean value		**0.082**	**0.006**	**0.038**	**0.004**	**0.093**	**0.024**	**0.064**	**0.014**

1) W1 is the specimen nr. 1 directed towards westbound traffic.
E1 ditto directed towards the eastbound traffic
2) Uncertain value, see Figure 5.12. Maybe a value of about 0.2% is more reasonable.

As for location 2A there is a certain increase in chloride content with time. The reason is probably that the column is protected from direct rain.

5.6 Location C: Unprotected foot and bicycle bridge along the highway

The chloride distribution directly after the first winter is shown in Figure 5.14.

In Figure 5.15 the mean distributions after different exposure times are shown. As for the other unprotected locations (1A and 1B) the peak concentration is not increased with time probably due to washing out of chloride during summer. On the other hand the chloride front is moving inwards, as it is also in locations 1A and 1B.

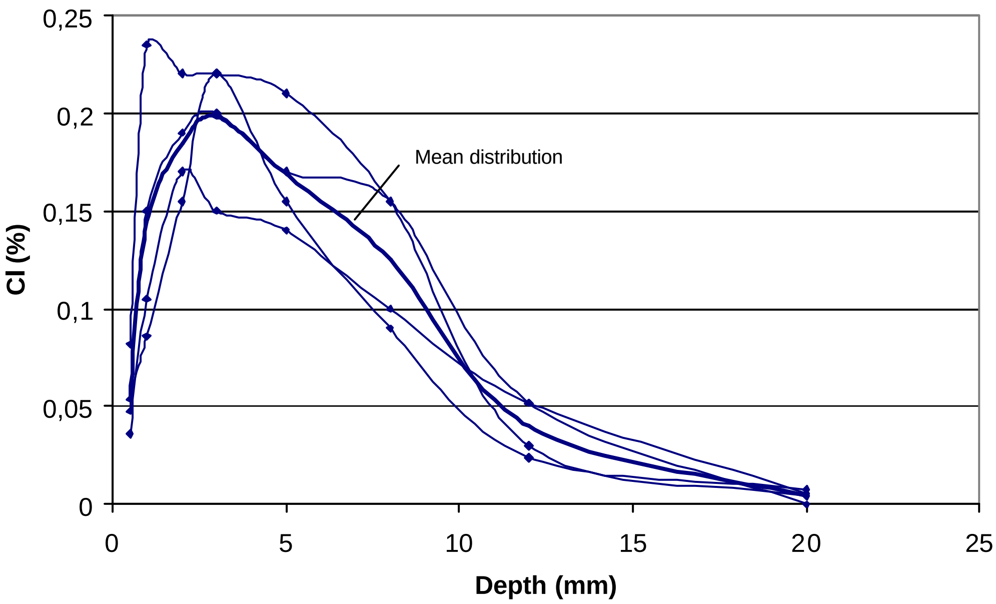


Figure 5.14: Location C. Chloride distribution immediately after the first winter (April 1996).

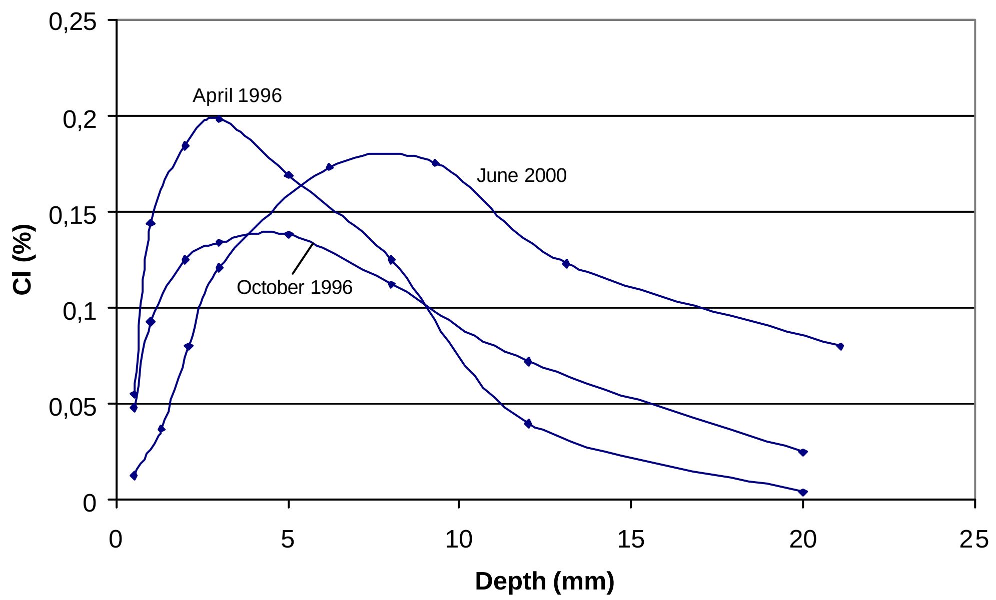


Figure 5.15: Location C. Mean chloride distributions at three occasions (the mean of 4 specimens at each occasion)

The observations are summarized in Table 5.4. For explanation of the columns, see Table 5.1.

Table 5.5: Location C: Chloride conditions. Mean values.

After 1 winter April 1996		**After 1 winter and 1 summer October 1996**		**After 5 winters June 2000**	
Peak Cl % (mm)	Total Cl kg/m^2	Peak Cl % (mm)	Total Cl kg/m^2	Peak Cl % (mm)	Total Cl kg/m^2
0.198 (3)	**0.035**	**0.138** (5)	**0.034**	**0.175** (9)	**0.050**

5.7 Location D: Edge beam of bridge crossing the highway

The chloride concentration is very low at all four measurement occasions. This can be explained by the high level above the salted roadway (4.6 m). The chloride level is about the same for the specimens mounted on the side of the edge beam as for the specimens mounted under this; see Figures 5.16 and 5.17.

For the protected specimens under the edge beam the chloride content increases with time. For the unprotected it decreases. This observation is in accordance with observations at the other locations.

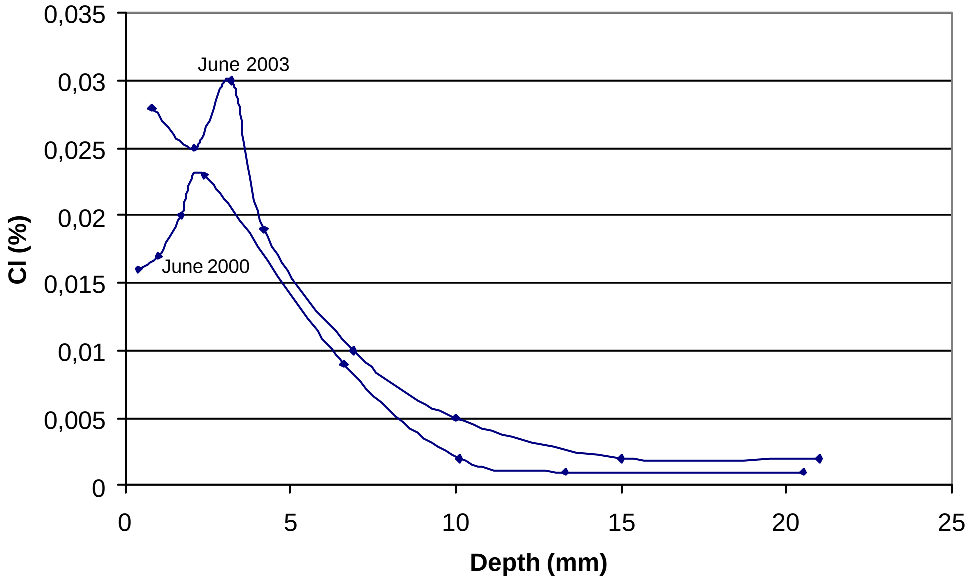


Figure 5.16: Location D. Specimens mounted under the edge beam. (see Figure 2.13)

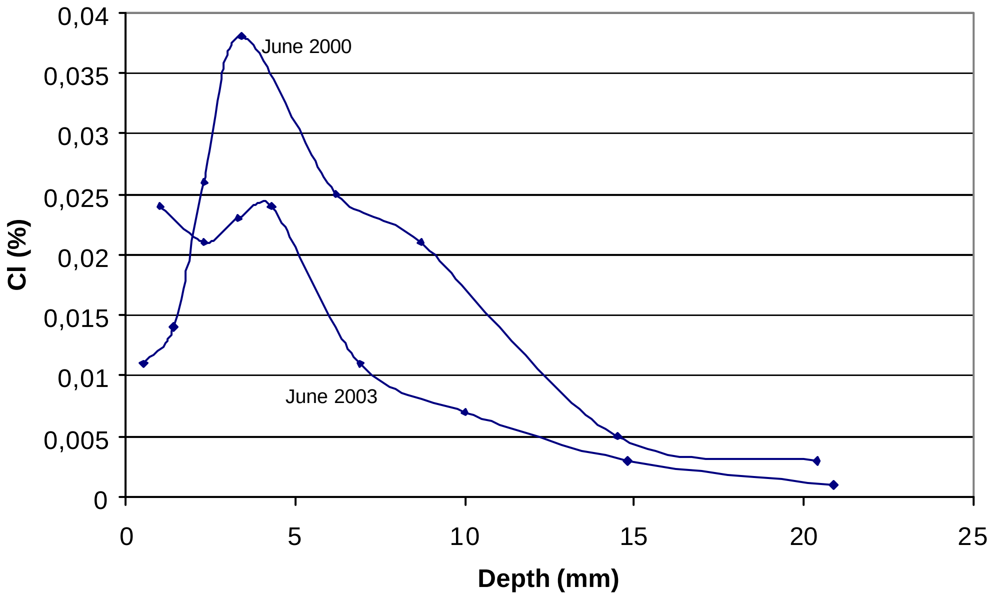


Figure 5.17: Location D. Specimens mounted at the side of the edge beam (see Figure 2.13).

5.8 Comparison between similar locations

Unprotected locations

Location C has similar conditions to location 1A height 45 cm, and location 1B. A comparison between these three locations is shown in Table 5.6. The chloride conditions agree fairly well.

Table 5.6: Comparison between locations 1A height 0.45 m, location 1B and location C. Mean values.

Location	**After 1 winter April 1996**		**After 1 winter and 1 summer October 1996**		**After 5 winters June 2000**	
	Peak Cl % (mm)	Total Cl kg/m^2	Peak Cl % (mm)	Total Cl kg/m^2	Peak Cl % (mm)	Total Cl kg/m^2
1A height 0.45 m	0.230	0.035	0.105	0.027	0.165	0.041
1B	0.266	0.045	0.154	0.043	0.146	0.049
C	0.198	0.035	0.138	0.034	0.175	0.050
Mean (std dev)	**0.231** (0.034)	**0.038** (0.006)	**0.132** (0.025)	**0.035** (0.008)	**0.162** (0.015)	**0.047** (0.005)

Protected locations

Location “D side” has similar conditions to location 1A height 4.05 m. Location “D under” is similar to location 2A height 4.2 m. A comparison between these four locations is shown in Table 5.7. The chloride conditions agree fairly well for the side of the edge beam. For the specimens mounted under the edge beam the chloride content is lower than for the highest specimen on location 2A. Probably the salt spray is lower on the bridge surface due to the more protected location.

Table 5.7: Comparison between locations 1A height 0.45 m, location 2A height 4.2 m and location D.

Location	**After 1 winter April 1996**		**After 1 winter and 1 summer October 1996**		**After 5 winters June 2000**		**After 8 winters June 2003**	
	Peak Cl % (mm)	Total Cl kg/m^2	Peak Cl % (mm)	Total Cl kg/m^2	Peak Cl % (mm)	Total Cl kg/m^2	Peak Cl % (mm)	Total Cl kg/m^2
1A height 4.05 m	0.049	0.004	0.024	0.003	0.040	0.009	0.035	0.006
D “side”	0.025	0.002	0.020	0.001	0.038	0.006	0.024	0.004
2A height 4.2 m	0.022	0.001	0.007	0	0.069	0.016	0.054	0.010
D “under”	0.008	0	0.006	0	0.023	0.003	0.030	0.004

6 DETERMINATION OF THE CARBONATION DEPTH

6.1 Carbonation depth after 1 winter and 1 summer

The carbonation depth was determined on 10 specimens that had been exposed at the following locations:

- 4 specimens in location 2B (the belt around the column)
- 8 specimens in location 1B (the railing along the road)

The measurements were made in June and October 1996.

The specimens were split and the carbonation depth determined by spraying the split surface by a 5% phenolphthalein solution in ethanol. The first spray was made on the dry surface. Parts coloured red are uncarbonated. The second spray was made on the same surface pre-moistened by pure water. OH-ions from possibly uncarbonated concrete beneath the surface can therefore diffuse to the surface and make this alkaline so it is coloured red at the test. Parts that are red after both sprays are judged uncarbonated.

The results are given in Table 6.1.

Table 6.1: Carbonation depth after 1 winter and 1 summer.

Location	**Specimen nr.**	**Time**	**Carbonation depth (mm)**
2B	1	June 1996	1 à 2
	2		1 à 2
	3	October 1996	2
	4		0 à 2
1B	1	June 1996	1 à 2
	2		0 à 1
	3		0 à 2
	4		0 à 2
	5	October 1996	1 à 3
	6		2 à 3
	7		0 à 3
	8		1 à 3

6.2 Carbonation depth after 5 winters

All specimens, previously used for determination of the chloride profile, were also used for determination of the carbonation depth. The remaining part of the specimens were split and the carbonation depth was determined on all fracture surfaces; Figure 6.1.

The measurements were made in June 2000. The same technique as described in 6.1 was used.

The results are shown in Table 6.2. The maximum value in the table is the biggest carbonation depth, normally occurring only in a local spot within one of the tested surfaces.

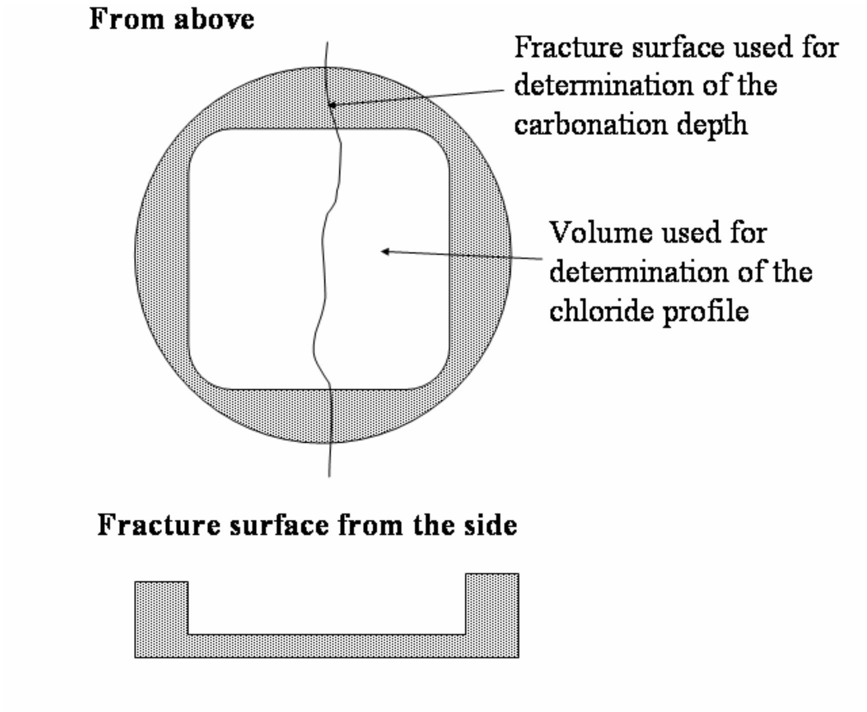


Figure 6.1: Splitting of specimens for determination of the carbonation depth.

Table 6.2: Carbonation depth after 5 winters..

Location	Number of specimens tested	Carbonation depth (mm)		
		Max	Mean	Std. dev.
1A	10	3.0	0.8	0.5
1B	20	6.5	0.9	0.3
2A	10	5.5	1.4	0.6
2B	3	1.5	0.8	0.4
C	4	7.5	0.9	0.2
D	2	4.0	1.3	0.3

7 CONCLUSIONS

The following conclusions can be drawn:

1. The chloride load is strongly reduced with increased height above the salted roadway. This is observed directly by measurements of the chloride content in water collected from different heights (Figure 2.3) and indirectly by measurements of the chloride profile in concrete specimens placed on different heights (Figures 5.1 and 5.8). After the first winter exposure the chloride uptake on 4.1 m height is only about 20% of that on 0.5 m height (figure 5.1).

2. When concrete is *unprotected from rain* (locations 1A, 1B and C) there is almost no chloride accumulation over time (Figure 5.3, 5.7, 5.14). The highest chloride concentration ("peak concentration") is reached already during the first winter. Exposure to rain during spring and summer evidently washes out chloride from the surface part reducing the peak concentration. On the other hand, the chloride "front" is gradually moving inwards.

3. When concrete is *protected from rain* (locations 2A and 2B) the chloride uptake during the first winter is considerably lower than in the unprotected locations (1A and 1B); compare Figures 5.1 and 5.8. On the lowest height above ground (0.45 to 0.60 m) the chloride peak is only 0.065% compared with 0.23%. On 2 m height it is only 0.056% compared with 0.13%.
   The salt load on the road is probably the same on all locations. Therefore, the reduced chloride uptake in the protected locations ought to depend on a lower diffusivity of chloride due to lower moisture content in the concrete. An estimation of the effect of the relative humidity in the concrete (RH) on the chloride diffusion coefficient is shown in Figure 7.1. It is based on the assumption that the chloride diffusivity is directly proportional to the amount of capillary water. The amount of capillary water as function of RH is given by the sorption isotherm. Data for this presented in /6/ are used.
   The calculations behind Figure 7.1 are performed in /7/.

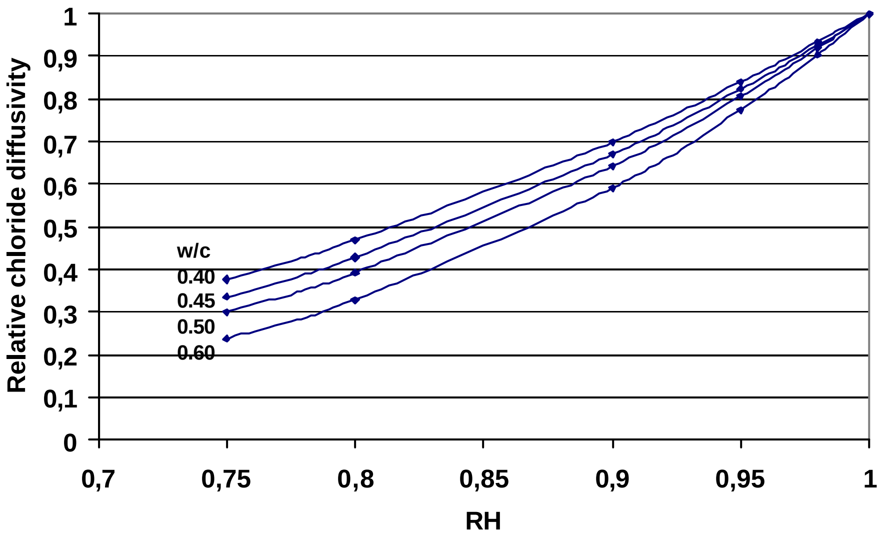


Figure 7.1: Calculated effect of the relative humidity in mature concrete (RH) on the chloride diffusivity; /7/.

4. In the *rain protected* locations (2A and 2B) the total chloride uptake increases with time (Figures 5.9 and 5.11, Tables 5.3 and 5.4). For the most chloride exposed location 2A also the peak concentration increases with time (Figure 5.9). The reason for this accumulation of chloride is probably that the washing out of chloride during the warm season is much smaller than it is at the unprotected locations.

   Contrary to the unprotected location, where the peak concentration lies fairly constant on about 3 mm from the surface (Table 5.1), the peak concentration transgresses inwards with time in the protected location and reaches about 7 mm after 5 winters (Table 5.3).

5. A probable lowest value of the threshold concentration for start of corrosion is about 0.7% of the cement content or 0.2% of the concrete weight; /5/. For the *unprotected* locations this value has not been reached after 8 years of exposure. The highest observed mean chloride concentration is certainly 0.27% (location 1B), but this is only reached on a depth of about 3 mm from the surface.

   In the protected locations there is a gradual increase in chloride concentration with time. The highest value observed is however only 0.18% and that is reached after 5 years on a depth from the surface of 7 mm. One cannot exclude completely, however, that reinforcement corrosion can be initiated within a period of 50 years or more in cases where the concrete cover is low.

6. The chloride profile drops drastically from the peak concentration towards the surface. The reason for this is not quite clear. One possible explanation is *carbonation*. It is known that the ability of cement paste to bind chloride chemically is very low in carbonated concrete. Furthermore, the porosity of carbonated OPC concrete is reduced in comparison with the uncarbonated concrete. According to /8/ the reduction in porosity for OPC concrete of w/c 0.45 is about 20%. Therefore, also the free chloride in the pore water is reduced in the carbonated zone. The agreement between the measured carbonation depth and the depth of the peak concentration is fairly good. The way of determination of carbonation does not necessarily give the correct answer since the carbonation front is not perfectly sharp and there might be some carbonation also inside the area coloured by the pH-inidictor.

   A slight reduction in the chloride content in the surface zone (1-3 mm) has been found also in concrete submerged for some time in pure NaCl-solution; /9/. The reduction is much smaller than in the actual investigation, however. Many of the specimens had no surface reduction at all. Some specimens with more marked reduction had been pre-cured for 7 to 14 days in lab air and were therefore carbonated in the outer "skin". Furthermore, the solution contained natural dissolved CO_2 which might have caused some surface carbonation.

   Considerable chloride drops in the surface zone has been observed in concrete exposed to sea water; e.g. /10/. The effect is often claimed to be an effect of chemical reaction between sea water and concrete creating a surface zone less capable of binding chloride and with lower porosity.

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/4/ Göran Fagerlund & Jenny Svärd: Kartering av kloridbelastning vid Riksväg 40. Resultat efter 5 vintersäsonger (*Mapping of the chloride load around a Swedish main road exposed to de-icing salts. Results after 5 winter seasons*). Div. Building Materials, Lund Institute of Technology, Report TVBM-7162, 2001. (In Swedish)

/5/ Swedish Concrete Association: Beständiga Betongkonstruktioner. Betongrapport nr 1, Utgåva 2. (*Durable Concrete Structures. Concrete Report Nr 1, Issue 2*). Stockholm 1998. (In Swedish)

/6/ Lars-Olof Nilsson: Fuktproblem vid betonggolv (*Moisture problems at concrete floors*). Div. Building Materials, Lund Institute of Technology, Report TVBM-3002,1977. (in Swedish)

/7/ Göran Fagerlund: Livslängdsberäkningar för betongkonstruktioner. (*Calculations of the service life of concrete structures*). Overview with applications. Div. Building Materials, Lund Institute of Technology, Report TVBM-3070, 1996. (in Swedish)

/8/ Peter Utgenannt: The influence of ageing on the salt-frost resistance of concrete. Div. Building Materials, Lund Institute of Technology, Report TVBM-1021, 2004.

/9/ Mårten Janz & Björn Johannesson: En studie av kloridinträngning i betong - med försök till livslängdsberäkning (*A study of chloride penetration in concrete - with an attempt to service life calculations*). Div. Building Materials, Lund Institute of Technology, Report TVBM-5026, 1993. (in Swedish)

/10/ Paul Sandberg: Chloride initiated reinforcement corrosion in marine concrete. Div. Building Materials, Lund Institute of Technology, Report TVBM-1015, 1998.

APPENDIX 1

Chloride profiles in April 1996 directly after 1 winter season

Location 1A:
Different height above the road surface. Unprotected from rain

Level	Depth mm	Chloride content %						
		Height m						
		0.45	**0.85**	**1.25**	**1.65**	**2.05**	**2.45**	**2.85**
1	0.5	0.130	0.062	0.047	0.062	0.026	0.009	0.023
2	1	0.185	0.170	0.155	0.150	0.072	0.063	0.060
3	2	0.225	0.200	0.195	0.160	0.125	0.085	0.070
4	3	0.230	0.210	0.195	0.145	0.130	0.092	0.070
5	5	0.185	0.180	0.18	0.130	0.110	0.066	0.044
6	8	0,100	0.094	0.090	0.069	0.052	0.019	0.008
7	12	0.024	0.026	0.013	0.006	0.008	0	0
8	20	0	0	0	0	0	0	0
Total chloride content in the outermost 20 mm (%·mm)[1)]		**1.76**	**1.62**	**1.48**	**1.14**	**0.97**	**0.51**	**0.38**

Level	Depth mm	Chloride content %		
		Height m		
		3.25	**3.65**	**4.05**
1	0.5	0.020	0.020	0.009
2	1	0.053	0.059	0.029
3	2	0.068	0.066	0.049
4	3	0.054	0.056	0.033
5	5	0.027	0.025	0.025
6	8	0.004	0.004	0.003
7	12	0	0	0
8	20	0	0	0
Total chloride content in the outermost 20 mm (%·mm)[1)]		**0.28**	**0.29**	**0.20**

1) Total chloride is the area under the chloride profile expressed in terms of the units used in the table, i.e. *%·mm*, where % is the chloride concentration in % of the concrete weight, and mm is the depth from the surface.

The chloride content expressed in terms of *kg/m^2 exposed surface* is obtained by multiplying the figures in the table with the factor $\gamma\cdot 10^{-5}$ where γ=2010 kg/m^3 is the density of the concrete; see Equation (3.2).

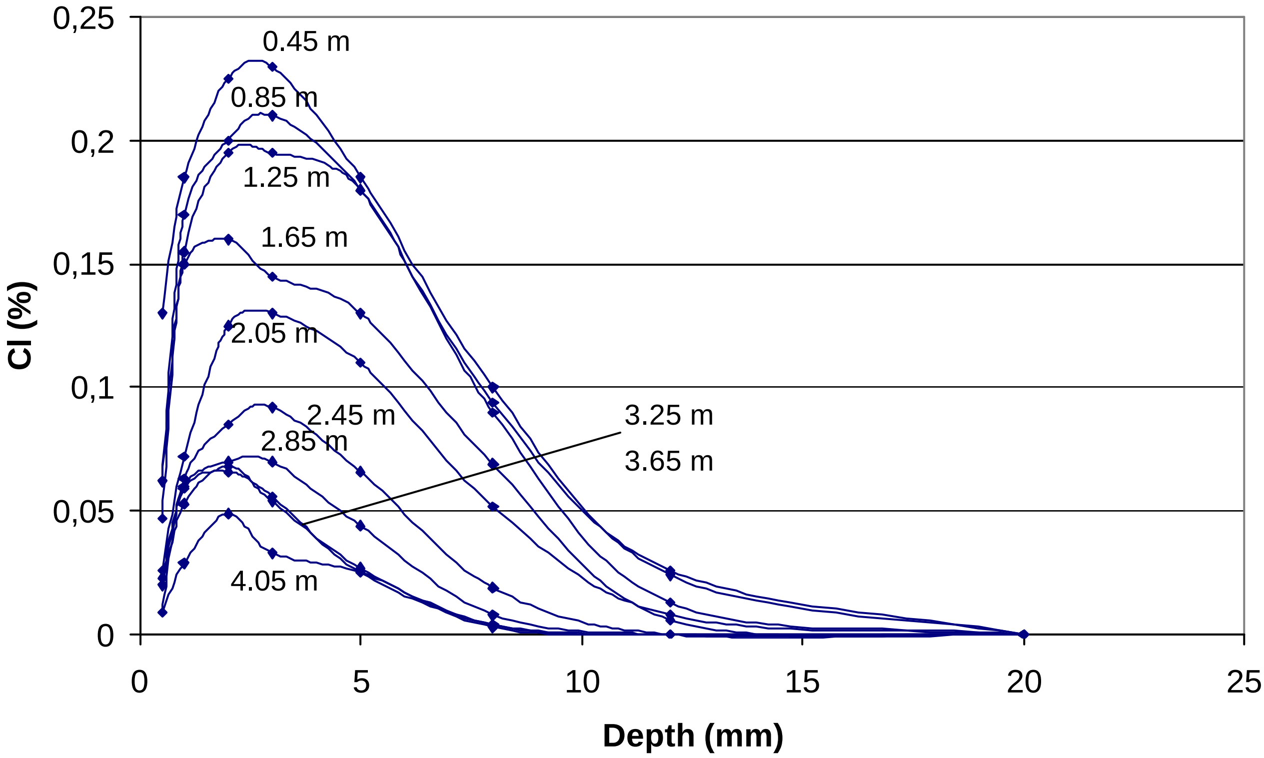

Figure A1.1: Location 1A. Chloride distribution after 1 winter.

Location 1B:

Along the road. Unprotected from rain

Level	Depth mm	Chloride content, %											
		Holder nr/specimen nr											
		1/1	**1/2**	**1/3**	**1/4**	**5/1**	**5/2**	**5/3**	**5/4**	**9/1**	**9/2**	**9/3**	**9/4**
1	0.5	0.049	0.043	0.078	0.082	0.091	0.047	0.078	0.110	0.070	0.060	0.084	0.090
2	1	0.190	0.195	0.210	0.170	0.200	0.115	0.190	0.245	0.195	0.180	0.215	0.215
3	2	0.285	0.250	0.345	0.250	0.240	0.185	0.330	0.295	0.240	0.245	0.250	0.250
4	3	0.280	0.255	0.305	0.290	0.250	0.225	0.275	0.285	0.250	0.275	0.255	0.260
5	5	0.265	0.230	0.245	0.250	0.226	0.215	0.200	0.240	0.215	0.270	0.215	0.215
6	8	0.225	0.155	0.160	0.140	0.130	0.110	0.064	0.155	0.140	0.195	0.150	0.140
7	12	0.069	0.040	0.060	0.043	0.054	0.030	0.005	0.049	0.038	0.080	0.062	0.055
8	20	0	0	0	0	0	0	0.004	0.005	0	0.005	0	0.004
Total chloride content in the outermost 20 mm (% ·mm) 1)		**2.75**	**2.17**	**2.55**	**2.24**	**2.18**	**1.57**	**1.71**	**2.45**	**2.07**	**2.70**	**2.29**	**2.24**

Level	Depth mm	Chloride content, %								
		Holder nr/specimen nr								
		13/1	**13/2**	**13/3**	**13/4**	**17/1**	**17/2**	**17/3**	**17/4**	**All specimens mean value (std dev)**
1	0.5	0.067	0.080	0.082	0.084	0.084	0.090	0.100	0.093	**0.078 (0.018)**
2	1	0.150	0.190	0.190	0.150	0.235	0.200	0.225	0.300	**0.198 (0.039)**
3	2	0.250	0.255	0.265	0.265	0.265	0.225	0.245	0.225	**0.258 (0.030)**
4	3	0.275	0.300	0.275	0.300	0.255	0.250	0.235	0.225	**0.266 (0.024)**
5	5	0.240	0.240	0.220	0.270	0.240	0.215	0.200	0.205	**0.231 (0.022)**
6	8	0.140	0.140	0.125	0.140	0.165	0.150	0.170	0.130	**0.146 (0.032)**
7	12	0.045	0.063	0.024	0.060	0.082	0.053	0.073	0.061	**0.052 (0.019)**
8	20	0	0	0.008	0	0.010	0	0	0.005	**0**
Total chloride content in the outermost 20 mm (% ·mm)		**2.19**	**2.38**	**2.05**	**2.41**	**2.57**	**2.20**	**2.37**	**2.21**	**2.27 (0.29)**

1) Total chloride is the area under the chloride profile expressed in terms of the units used in the table, i.e. *%·mm*, where % is the chloride concentration in % of the concrete weight, and mm is the depth from the surface. The chloride content expressed in terms of *kg/m² exposed surface* is obtained by multiplying the figures in the table with the factor $\gamma \cdot 10^{-5}$ where γ=2010 kg/m³ is the density of the concrete; see Equation (3.2).

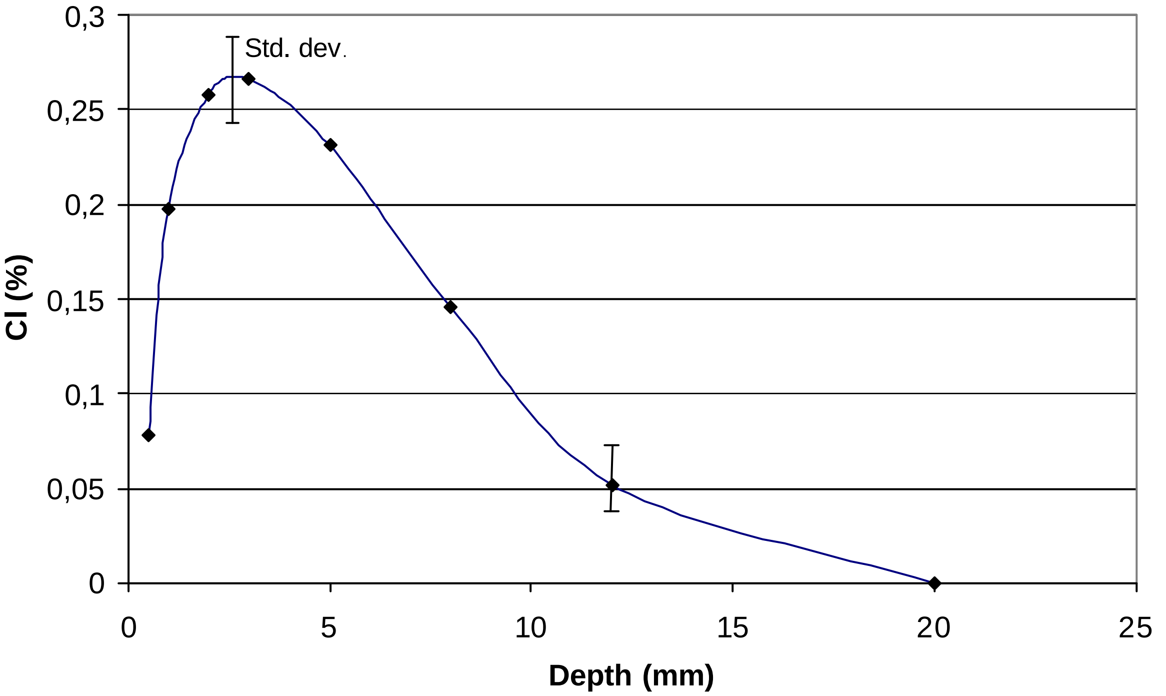

Figure A1.2: Location 1B. Mean value of the chloride distribution after 1 winter.

Location 2A:

Different height above the road surface. Protected from rain

Level	Depth mm	chloride content %						
		height m						
		0.6	**1.0**	**1.4**	**1.8**	**2.2**	**2.6**	**3.0**
1	0.5	0.014	0.025	0.013	0.006	0.018	0.010	0
2	1	0.033	0.054	0.059	0.051	0.056	0.048	0.018
3	2	0.059	0.060	0.072	0.061	0.051	0.052	0.023
4	3	0.065	0.066	0.065	0,060	0.030	0.042	0.021
5	5	0.046	0.022	0.042	0.016	0.011	0.007	0.004
6	8	0.004	0	0.005	0	0	0	0
7	12	0	0	0	0	0	0	0
8	20	0	0	0	0	0	0	0
total chloride content in outermost 20 mm (%·mm) 1)		**0.54**	**0.27**	**0.35**	**0.23**	**0.18**	**0.18**	**0.08**

Level	Depth mm	chloride content %		
		height m		
		3.4	**3.8**	**4.2**
1	0.5	0.007	0	0.004
2	1	0.026	0.013	0.021
3	2	0.024	0.028	0.022
4	3	0.016	0.025	0.014
5	5	0	0.007	0
6	8	0	0	0
7	12	0	0	0
8	20	0	0	0
total chloride content in outermost 20 mm (%·mm)		**0.07**	**0.09**	**0.06**

1) Total chloride is the area under the chloride profile expressed in terms of the units used in the table, i.e. *%·mm*, where % is the chloride concentration in % of the concrete weight, and mm is the depth from the surface.

The chloride content expressed in terms of *kg/m^2 exposed surface* is obtained by multiplying the figures in the table with the factor $\gamma \cdot 10^{-5}$ where γ=2010 kg/m^3 is the density of the concrete; see Equation (3.2).

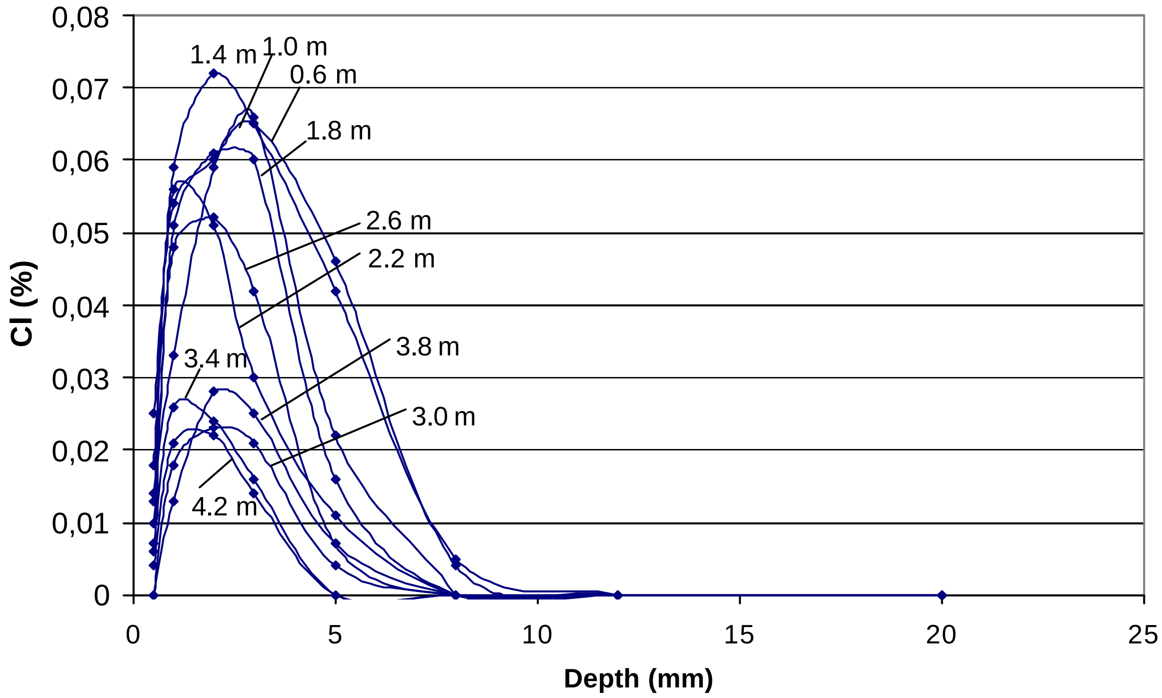

Figure A1.3: Location 2A. Chloride distribution after 1 winter.

Location 2B:

Chloride content around a column founded on the reserve strip between roadways.

Specimens towards westbound traffic

Level	Depth mm	Chloride content %						
		Specimen nr						
		1 meeting traffic	3 angle against traffic	5 parallel to traffic	7 parallel to traffic	9 angle from traffic	11 directed from traffic	All specimens mean value (std dev)
1	0.5	0.035	0.018	0.022	0.010	0.007	0.004	**0.016 (0.011)**
2	1	0.170	0.058	0.044	0.034	0.026	0.021	**0.063 (0.053)**
3	2	0.115	0.080	0.050	0.034	0.034	0.040	**0.059 (0.032)**
4	3	0.245	0.064	0.052	0.031	0.026	0.046	**0.077 (0.083)**
5	5	0.036	0.033	0.025	0.011	0.006	0.027	**0.023 (0.012)**
6	8	0.005	0.004	0	0	0	0	**0**
7	12	0	0	0	0	0	0	**0**
8	20	0	0	0	0	0	0	**0**
Total chloride content in outermost 20 mm [1)] (%·mm)		**0.74**	**0.33**	**0.24**	**0.14**	**0.13**	**0.20**	**0.30 (0.23)**

1) Total chloride is the area under the chloride profile expressed in terms of the units used in the table, i.e. *%·mm*, where % is the chloride concentration in % of the concrete weight, and mm is the depth from the surface.

The chloride content expressed in terms of *kg/m² exposed surface* is obtained by multiplying the figures in the table with the factor $\gamma \cdot 10^{-5}$ where γ=2010 kg/m³ is the density of the concrete; see Equation (3.2).

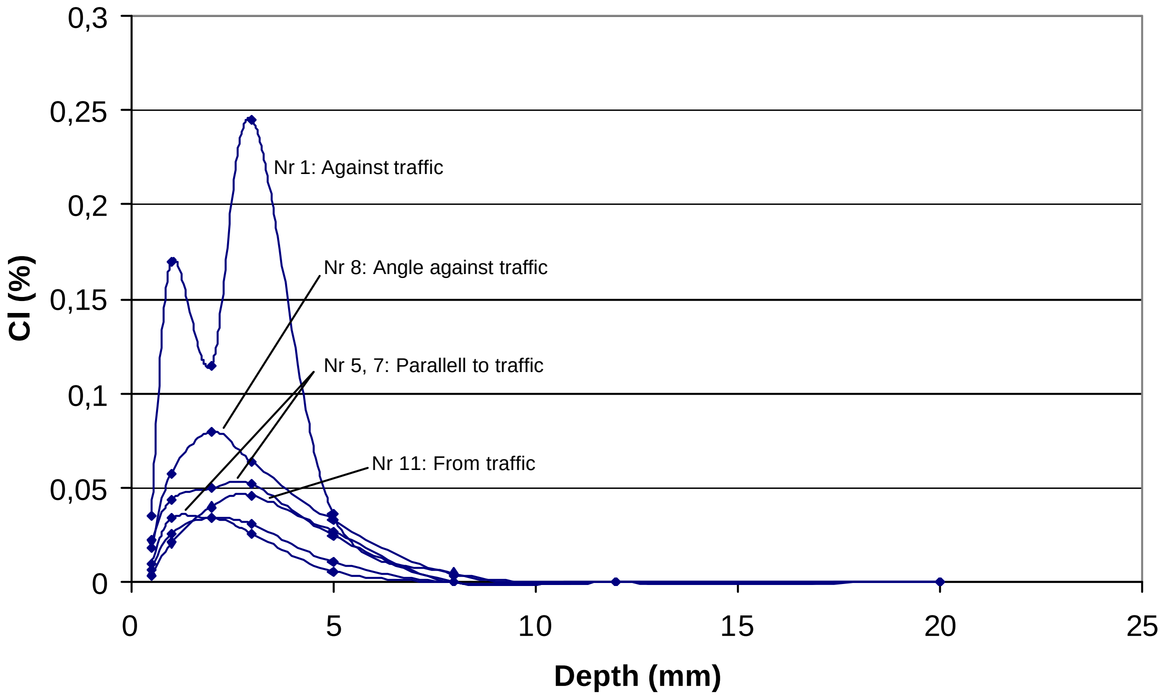

Figure A1.4: Location 2B. Chloride distribution after 1 winter.

Location C:
Foot and bicycle bridge at the highway

Level	Depth mm	Chloride content %				
		holder nr/specimen nr				
		32/1	**32/2**	**32/3**	**32/4**	**All specimens mean value (std dev)**
1	0.5	0.036	0.054	0.082	0.048	**0.055 (0.019)**
2	1	0.105	0.086	0.235	0.150	**0.144 (0.066)**
3	2	0.170	0.155	0.220	0.190	**0,184 (0.028)**
4	3	0.150	0.220	0.220	0.200	**0.198 (0.033)**
5	5	0.140	0.155	0.210	0.170	**0.169 (0.030)**
6	8	0.100	0.090	0.155	0.155	**0.125 (0.035)**
7	12	0.052	0.024	0.030	0.052	**0.040 (0.015)**
8	20	0.006	0.008	0.004	0	**0.004 (0.003)**
Total chloride content in outermost 20 mm (%·mm) 1)		**1.54**	**1.47**	**2.05**	**1.92**	**1.75 (0.28)**

1) Total chloride is the area under the chloride profile expressed in terms of the units used in the table, i.e. *%·mm*, where % is the chloride concentration in % of the concrete weight, and mm is the depth from the surface.

The chloride content expressed in terms of *kg/m² exposed surface* is obtained by multiplying the figures in the table with the factor $\gamma \cdot 10^{-5}$ where γ=2010 kg/m³ is the density of the concrete; see Equation (3.2).

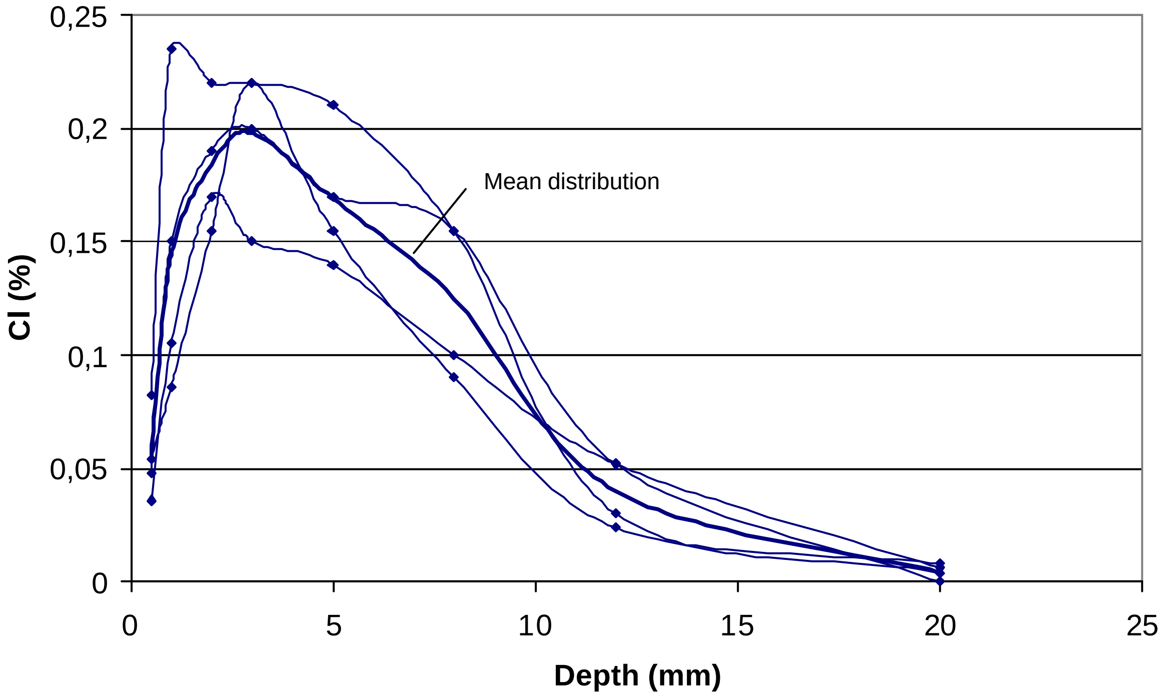

Figure A1.5: Location C. Chloride distribution after 1 winter.

Location D:
Edge beam of viaduct crossing the highway

Level	Depth mm	Chloride content %	
		holder nr/specimen nr	
		41/1 Under the edge beam	**42/1 At the side of the edge beam**
1	0.5	0	0.005
2	1	0.008	0.020
3	2	0.005	0.025
4	3	0	0.019
5	5	0	0.006
6	8	0	0
7	12	0	0
8	20	0	0
Total chloride content in outermost 20 mm (%·mm) 1)		**0.01**	**0.09**

1) Total chloride is the area under the chloride profile expressed in terms of the units used in the table, i.e. *%·mm*, where % is the chloride concentration in % of the concrete weight, and mm is the depth from the surface.

The chloride content expressed in terms of *kg/m^2 exposed surface* is obtained by multiplying the figures in the table with the factor $\gamma \cdot 10^{-5}$ where γ=2010 kg/m^3 is the density of the concrete; see Equation (3.2).

APPENDIX 2

Chloride profiles in October 1996 after 1 winter season and 1 summer season

Location 1A:
Different height above the road surface. Unprotected from rain

Level	Depth mm	Chloride content %						
		Height m						
		0.45	**0.85**	**1.25**	**1.65**	**2.05**	**2.45**	**2.85**
1	0.5	0.023	0.037	0.014	0.038	0.011	0.022	0.005
2	1	0.045	0.087	0.068	0.064	0.049	0.054	0.021
3	2	0.090	0.108	0.120	0.087	0.071	0.068	0.045
4	3	0.105	0.120	0.140	0.100	0.078	0.048	0.040
5	5	0.080	0.105	0.120	0.100	0.072	0.066	0.035
6	8	0.095	0.087	0.105	0.084	0.053	0.040	0.015
7	12	0.068	0.040	0.068	0.045	0.025	0.011	0.005
8	20	0.028	0	0.017	0.006	0	0	0
Total chloride content in outermost 20 mm (%·mm)		**1.35**	**1.19**	**1.54**	**1.13**	**0.75**	**0.57**	**0.29**

Level	Depth mm	Chloride content %		
		Height m		
		3.25	**3.65**	**4.05**
1	0.5	0.022	0.010	0.009
2	1	0.022	0.023	0.017
3	2	0.035	0.038	0.024
4	3	0.038	0.030	0.023
5	5	0.033	0.024	0.020
6	8	0.022	0.016	0.006
7	12	0.003	0	0
8	20	0	0	0
Total chloride content in outermost 20 mm(%·mm) [1)]		**0.28**	**0.22**	**0.15**

1) Total chloride is the area under the chloride profile expressed in terms of the units used in the table, i.e. *%·mm*, where % is the chloride concentration in % of the concrete weight, and mm is the depth from the surface.

The chloride content expressed in terms of *kg/m^2 exposed surface* is obtained by multiplying the figures in the table with the factor $\gamma \cdot 10^{-5}$ where γ=2010 kg/m^3 is the density of the concrete; see Equation (3.2).

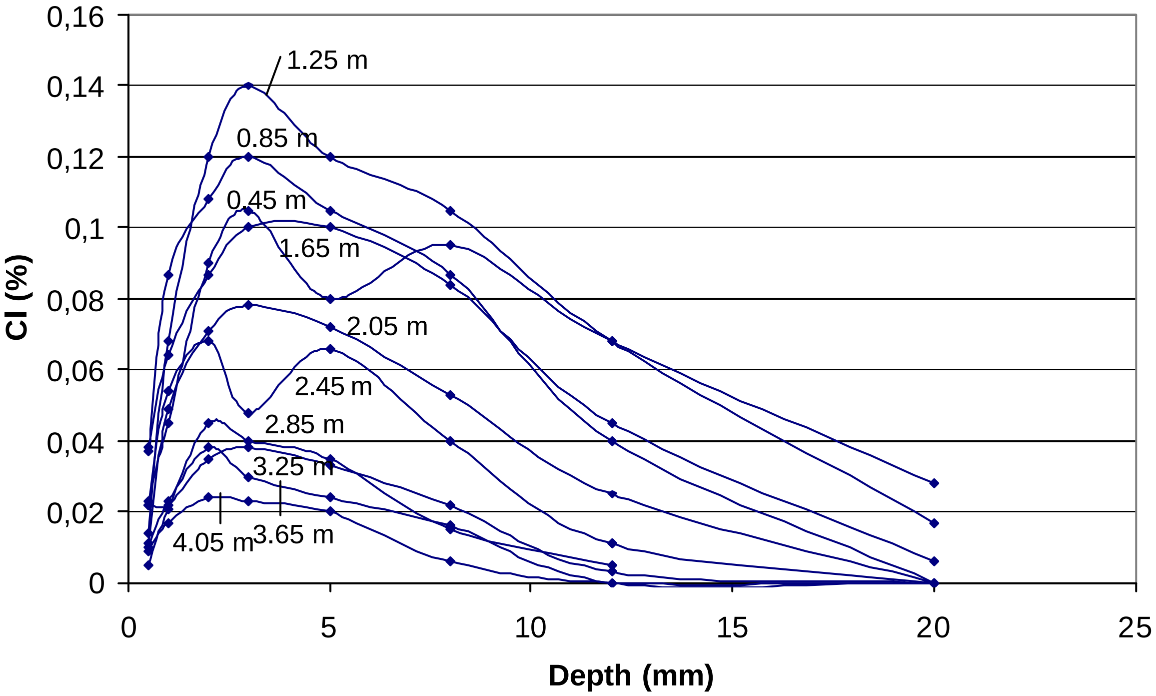

Figure A2.1: Location 1A. Chloride distribution after 1 winter and 1 summer.

Location 1B:

Along the road. Unprotected from rain

Level	Depth mm	Chloride content, %											
		Holder nr/specimen nr											
		2/1	**2/2**	**2/3**	**2/4**	**6/1**	**6/2**	**6/3**	**6/4**	**10/1**	**10/2**	**10/3**	**10/4**
1	0.5	0.040	0.039	0.054	0.037	0.066	0.060	0.055	0.055	0,064	0.045	0.035	0.045
2	1	0.080	0.077	0.098	0.080	0.115	0.110	0.105	0.090	0.100	0.105	0.061	0.081
3	2	0.135	0.120	0.135	0.110	0.140	0.130	0.125	0.135	0.155	0.135	0.105	0.126
4	3	0.160	0.150	0.160	0.130	0.100	0.160	0.125	0.155	0.120	0.130	0.150	0.140
5	5	0.135	0.150	0.140	0.140	0.140	0.155	0.110	0.155	0.145	0.170	0.160	0.150
6	8	0.135	0.140	0.135	0.135	0.140	0.133	0.115	0.136	0.135	0.130	0.125	0.142
7	12	0.115	0.098	0.068	0.130	0.110	0.098	0.068	0.09	0.080	0.120	0.098	0.105
8	20	0	0.047	0.027	0.067	0.040	0.038	0.025	0.045	0.040	0.072	0.045	0.050
Total chloride content in outermost 20 mm (% ·mm) 1)		**1.97**	**2.07**	**1.83**	**2,26**	**2.09**	**2.09**	**1.62**	**2.06**	**1.91**	**2.33**	**2.01**	**1.93**

Level	Average mm	Chloride content, %										
		Holder nr/specimen nr										
		14/1	**14/2**	**14/3**	**18/2**	**18/3**	**18/4**	**22/1**	**22/2**	**22/3**	**22/4**	**Mean value (std dev)**
1	0.5	0.054	0.054	0.051	0.045	0.054	0,054	0.060	0.055	0.055	0.024	**0.050 (0.010)**
2	1	0.122	0.100	0.110	0.091	0.100	0.110	0.105	0.098	0.099	0.082	**0.096 (0.015)**
3	2	0.180	0.135	0.145	0.135	0.130	0.145	0.155	0.130	0.150	0.125	**0.136 (0.016)**
4	3	0.200	0.160	0.165	0.160	0.140	0.160	0.175	0.155	0.155	0.160	**0.150 (0.021)**
5	5	0.200	0.160	0.165	0.180	0.130	0.160	0.175	0.155	0.150	0.155	**0.154 (0.021)**
6	8	0.180	0.140	0.160	0.140	0.112	0.135	0.150	0.150	0.155	0.145	**0.139(0.014)**
7	12	0.135	0.105	0.112	0.112	0.073	0.091	0.135	0.125	0.135	0.105	**0.105 (0.021)**
8	20	0.070	0.044	0.054	0.067	0.015	0.028	0.074	0.090	0.077	0.060	**0.049 (0.022)**
Total chloride content in outermost 20 mm (% ·mm)		**2.83**	**2.19**	**2.37**	**2.36**	**1.67**	**2.04**	**2.61**	**2.50**	**2.53**	**2.21**	**2.16 (0.30)**

1) Total chloride is the area under the chloride profile expressed in terms of the units used in the table, i.e. *%·mm*, where % is the chloride concentration in % of the concrete weight, and mm is the depth from the surface. The chloride content expressed in terms of *kg/m² exposed surface* is obtained by multiplying the figures in the table with the factor $\gamma \cdot 10^{-5}$ where γ=2010 kg/m³ is the density of the concrete; see Equation (3.2).

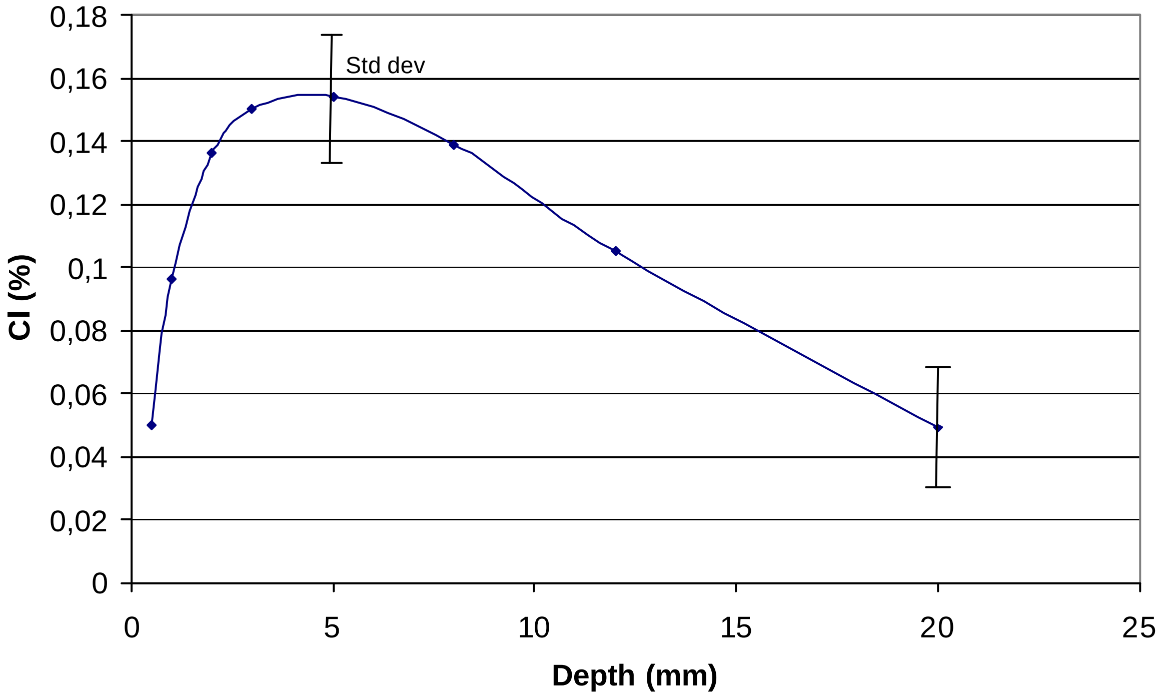

Figure A2.2: Location 1B. Mean chloride distribution after 1 winter and 1 summer.

Location 2A:
Different height above the road surface. Protected from rain

Level	Depth mm	chloride content %						
		height m						
		0.6	**1.0**	**1.4**	**1.8**	**2.2**	**2.6**	**3.0**
1	0.5	0.005	0.022	0.017	0.006	0.006	0.008	0.005
2	1	0.022	0.035	0.033	0.017	0.017	0.031	0.016
3	2	0.038	0.044	0.039	0.026	0.037	0.029	0.020
4	3	0.051	0.040	0.039	0.027	0.032	0.028	0.015
5	5	0.050	0.023	0.040	0.025	0.027	0.022	0.006
6	8	0.037	0	0.017	0.019	0.007	0	0
7	12	0.010	0	0	0.005	0	0	0
8	20	0	0	0	0	0	0	0
total chloride content in outermost 20 mm (%·mm) 1)		**0.45**	**0.20**	**0.30**	**0.24**	**0.20**	**0.16**	**0.07**

Level	Depth mm	chloride content %		
		height m		
		3.4	**3.8**	**4.2**
1	0.5	0	0	0
2	1	0.012	0.008	0.007
3	2	0.021	0.006	0
4	3	0.021	0-009	0
5	5	0.011	0.006	0
6	8	0	0	0
7	12	0	0	0
8	20	0	0	0
total chloride content in outermost 20 mm (%·mm)		**0.09**	**0.04**	**0**

1) Total chloride is the area under the chloride profile expressed in terms of the units used in the table, i.e. *%·mm*, where % is the chloride concentration in % of the concrete weight, and mm is the depth from the surface.

The chloride content expressed in terms of *kg/m^2 exposed surface* is obtained by multiplying the figures in the table with the factor $\gamma \cdot 10^{-5}$ where γ=2010 kg/m^3 is the density of the concrete; see Equation (3.2).

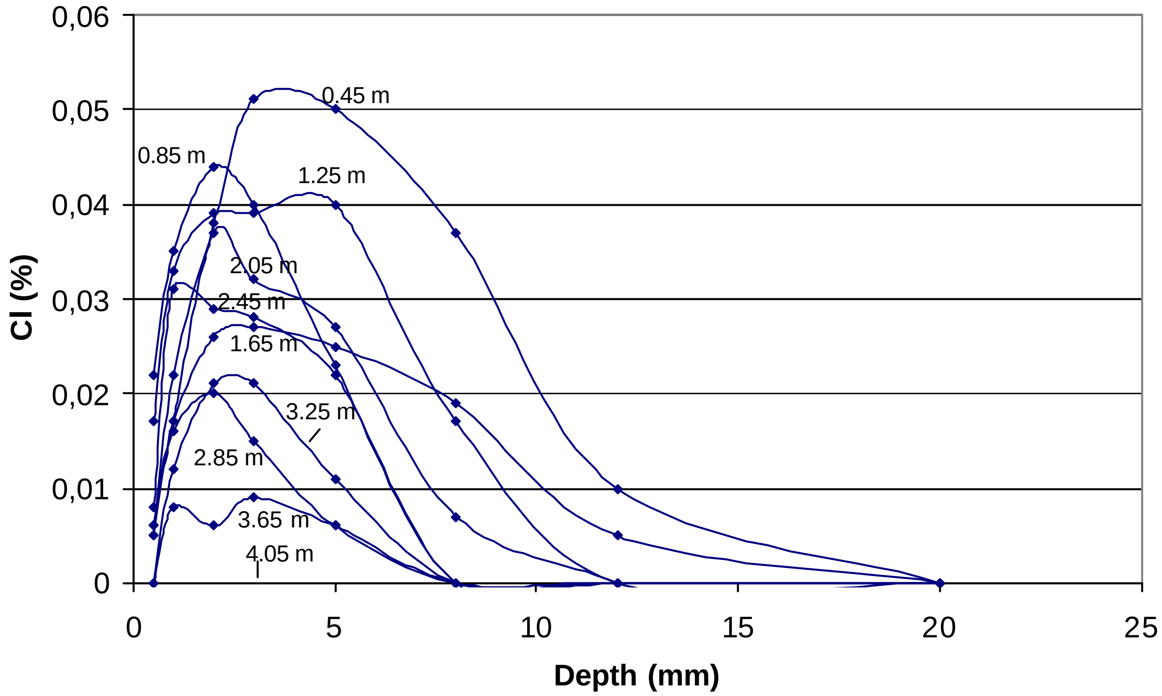

Figure A2.3: Location 2A. Chloride distribution after 1 winter and 1 summer.

Location 2B:

Chloride content around a column founded on the reserve strip between roadways.
Specimens towards westbound traffic

Level	Depth mm	Chloride content %				
		Specimen nr				
		4 angle towards traffic — less rain protected	**6 parallel to traffic**	**8 angle from traffic**	**10 directed from traffic** — more rain protected	**All specimens mean value (std dev)**
1	0.5	0.006	0.009	0.019	0.011	**0.011 (0.005)**
2	1	0.020	0.022	0.037	0.038	**0.029 (0.009)**
3	2	0.026	0.026	0.044	0.040	**0.034 (0.009)**
4	3	0.026	0.022	0.032	0.054	**0.034 (0.014)**
5	5	0.023	0.011	0.028	0.050	**0.028 (0.016)**
6	8	0.006	0	0	0.028	**0.008 (0.013)**
7	12	0	0	0	0	**0**
8	20	0	0	0	0	**0**
Total chloride content in outermost 20 mm (%·mm) 1)		**0.16**	**0.11**	**0.20**	**0.38**	**0.21 (0.12)**

1) Total chloride is the area under the chloride profile expressed in terms of the units used in the table, i.e. *%·mm*, where % is the chloride concentration in % of the concrete weight, and mm is the depth from the surface.

The chloride content expressed in terms of *kg/m^2 exposed surface* is obtained by multiplying the figures in the table with the factor $\gamma \cdot 10^{-5}$ where γ=2010 kg/m^3 is the density of the concrete; see Equation (3.2).

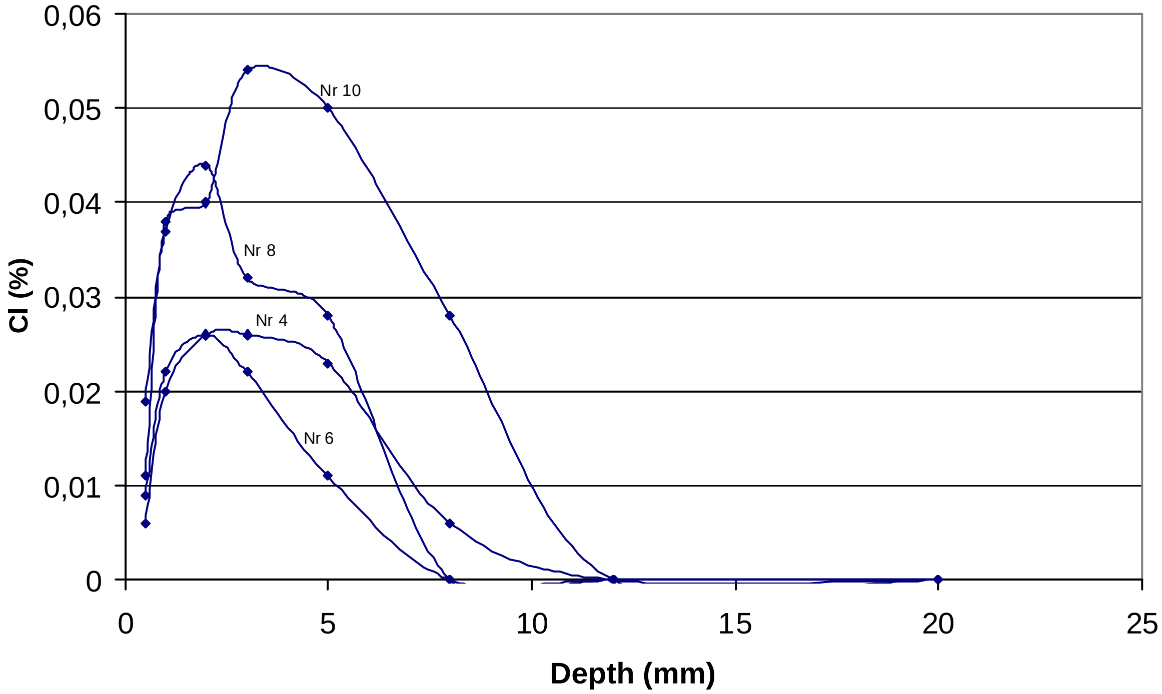

Figure A2.4: Location 2B. Chloride distribution after 1 winter and 1 summer.

Location C:
Foot and bicycle bridge at the highway

Level	Depth mm	Chloride content %				
		holder nr/specimen nr				
		31/1	31/2	31/3	31/4	All specimens mean value (std dev)
1	0.5	0.054	0.044	0.035	0.057	**0.048 (0.010)**
2	1	0.093	0.093	0.084	0.100	**0.093 (0.007)**
3	2	0.110	0.130	0.130	0.130	**0.125 (0.010)**
4	3	0.130	0.150	0.120	0.135	**0.134 (0.013)**
5	5	0.145	0.130	0.140	0.135	**0.138 (0.006)**
6	8	0.125	0.112	0.112	0.100	**0.112 (0.010)**
7	12	0.077	0.091	0.073	0.045	**0.072 (0.019)**
8	20	0.009	0.054	0.024	0.014	**0.025 (0.020)**
Total chloride content in outermost 20 mm (%·mm) 1)		**1.71**	**1.94**	**1.68**	**1.46**	**1.70 (0.20)**

1) Total chloride is the area under the chloride profile expressed in terms of the units used in the table, i.e. *%·mm*, where % is the chloride concentration in % of the concrete weight, and mm is the depth from the surface.

The chloride content expressed in terms of *kg/m² exposed surface* is obtained by multiplying the figures in the table with the factor $\gamma \cdot 10^{-5}$ where γ=2010 kg/m³ is the density of the concrete; see Equation (3.2).

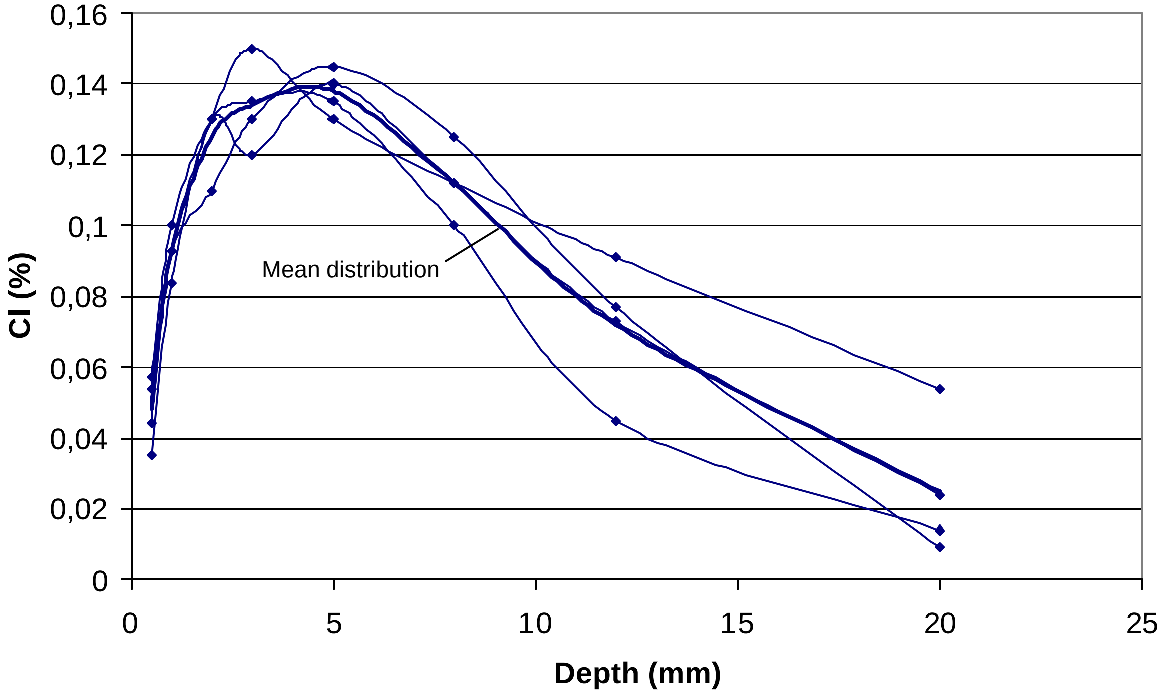

Figure A2.5: Location C. Chloride distribution after 1 winter and 1 summer.

Location D:

Edge beam of viaduct crossing the highway

Level	Depth mm	Chloride content %	
		holder nr/specimen nr	
		41/2 Under the edge beam	42/2 At the side of the edge beam
1	0.5	0	0
2	1	0.006	0.017
3	2	0	0.020
4	3	0	0.009
5	5	0	0.006
6	8	0	0
7	12	0	0
8	20	0	0
Total chloride content in outermost 20 mm (%·mm) 1)		**0.005**	**0.06**

1) Total chloride is the area under the chloride profile expressed in terms of the units used in the table, i.e. *%·mm*, where % is the chloride concentration in % of the concrete weight, and mm is the depth from the surface.

The chloride content expressed in terms of kg/m^2 *exposed surface* is obtained by multiplying the figures in the table with the factor $\gamma \cdot 10^{-5}$ where γ=2010 kg/m^3 is the density of the concrete; see Equation (3.2).

APPENDIX 3

Chloride profiles in June 2000 after 5 winter seasons

Location 1A:

Different height above the road surface. Unprotected from rain

Level	Average depth of level mm	Chloride content %						
		Height m						
		0.45	0.85	1.25	1.65	2.05	2.45	2.85
1	0.5	0.008	0.011	0.022	0.006	0.003	0.005	0.004
2	1.4	0.030	0.051	0.055	0.032	0.016	0.023	0.021
3	2.3	0.061	0.089	0.085	0.066	0.053	0.042	0.038
4	3.2	0.096	0.109	0.095	0.086	0.080	0.057	0.055
5	6.5	0.113	0.107	0.094	0.079	0.096	0.050	0.045
6	9.3	0.109	0.096	0.074	0.080	0.064	0.039	0.040
7	13.9	0.165	0.066	0.050	0.067	0.058	0.024	0.023
8	21.0	0.039	0.031	0.017	0.029	0.032	0.006	0.009
Total chloride content in outermost 20 mm (%·mm) [1)]		**2.04**	**1.49**	**1.22**	**1.26**	**1.17**	**0.62**	**0.61**

Level	Average depth of level mm	Chloride content %		
		Height m		
		3.25	3.65	4.05
1	0.5	0.009	0.003	0.007
2	1.4	0.014	0.011	0.022
3	2.3	0.031	0.024	0.036
4	3.2	0.043	0.033	0.040
5	6.5	0.044	0.037	0.036
6	9.3	0.031	0.029	0.027
7	13.9	0.021	0.019	0.016
8	21.0	0.004	0.004	0.004
Total chloride content in outermost 20 mm (%·mm)		**0.51**	**0.44**	**0.45**

1) Total chloride is the area under the chloride profile expressed in terms of the units used in the table, i.e. *%·mm*, where % is the chloride concentration in % of the concrete weight, and mm is the depth from the surface.

The chloride content expressed in terms of *kg/m^2 exposed surface* is obtained by multiplying the figures in the table with the factor $\gamma \cdot 10^{-5}$ where γ=2010 kg/m^3 is the density of the concrete; see Equation (3.2).

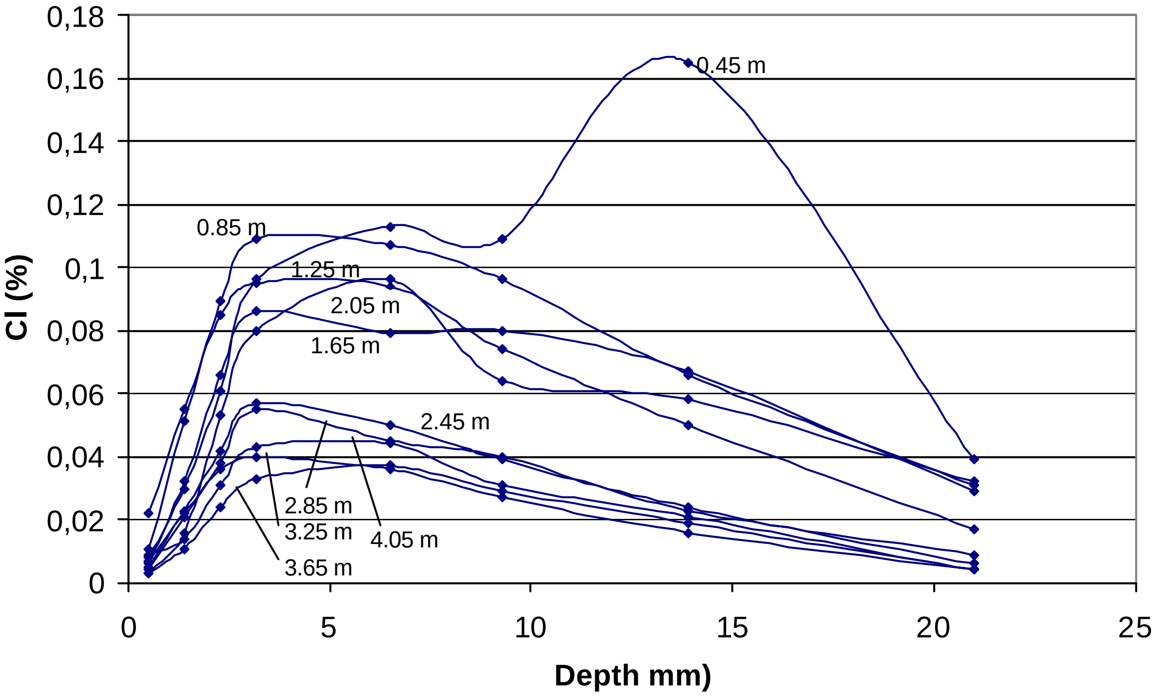

Figure A3.1: Location 1A. Chloride distribution after 5 winters.

Location 1B:
Along the road. Unprotected from rain

Holder nr 3

Specimen nr 1			Specimen nr 2		
Level	**Depth of level mm**	**Cl %**	**Level**	**Depth of level mm**	**Cl %**
1	0.3	0.013	1	0.5	0.013
2	0.9	0.059	2	1.2	0.059
3	1.9	0.125	3	1.8	0.125
4	2.7	0.150	4	2.3	0.150
5	5.4	0.142	5	3.0	0.142
6	8.8	0.127	6	3.8	0.127
7	12.3	0.110	7	7.8	0.110
8	20.2	0.059	8	11.5	0.059
9	21.6	0.050	9	19.5	0.050
Total chloride content in outermost 20 mm (%mm) 1)		**2.16**	**Total chloride content in outermost 20 mm (%mm)**		**2.28**

Specimen nr 3			Specimen nr 4		
Level	**Depth of level mm**	**Cl %**	**Level**	**Depth of level mm**	**Cl %**
1	0.4	0.011	1	1.2	0.085
2	1.1	0.038	2	3.0	0.170
3	2.0	0.049	3	3.5	0.140
4	2.8	0.085	4	4.0	0.145
5	3.6	0.086	5	4.6	0.160
6	4.5	0.085	6	5.1	0.137
7	7.1	0.090	7	5.8	0.165
8	11.2	0.079	8	6.5	0.135
9	11.9	0.066	9	8.4	0.130
10	16.0	0.060	10	11.3	0.078
11	20.3	0.040	11	15.8	0.069
			12	20.4	0.043
Total chloride content in outermost 20 mm (%mm)		**1.34**	**Total chloride content in outermost 20 mm (%mm)**		**1.56**

1) Total chloride is the area under the chloride profile expressed in terms of the units used in the table, i.e. *%·mm*, where % is the chloride concentration in % of the concrete weight, and mm is the depth from the surface.

The chloride content expressed in terms of *kg/m² exposed surface* is obtained by multiplying the figures in the table with the factor $\gamma \cdot 10^{-5}$ where γ=2010 kg/m³ is the density of the concrete; see Equation (3.2).

Holder nr 7

Specimen nr1			Specimen nr 2		
Level	Depth of level mm	Cl %	Level	Depth of level mm	Cl %
1	0.5	0.018	1	0.4	0.009
2	1.4	0.078	2	1.2	0.043
3	2.3	0.138	3	1.9	0.103
4	3.2	0.170	4	2.7	0.145
5	4.8	0.190	5	5.4	0.165
6	8.4	0.170	6	9.0	0.172
7	13.4	0.155	7	12.3	0.130
8	24.7	0.078	8	22.3	0.082
Total chloride content in outermost 20 mm (%mm)		**2.80**	**Total chloride content in outermost 20 mm (%mm)**		**2.30**

Specimen nr 3			Specimen nr 4		
Level	Depth of level mm	Cl %	Level	Depth of level mm	Cl %
1	0.4	0.011	1	0.4	0.015
2	0.9	0.038	2	1.2	0.062
3	1.6	0.088	3	2.3	0.134
4	2.3	0.128	4	3.2	0.170
5	3.1	0.144	5	6.5	0.200
6	5.5	0.155	6	9.4	0.160
7	8.7	0.146	7	12.4	0.155
8	12.6	0.120	8	20.1	0.105
9	23.9	0.05			
Total chloride content in outermost 20 mm (%mm)		**2.23**	**Total chloride content in outermost 20 mm (%mm)**		**2.81**

Holder nr 11

Specimen nr1			Specimen nr 2		
Level	**Depth of level mm**	**Cl %**	**Level**	**Depth of level mm**	**Cl %**
1	0.7	0.019	1	0.5	0.014
2	2.4	0.120	2	1.2	0.039
3	3.1	0.165	3	1.9	0.103
4	6.3	0.190	4	2.7	0.154
5	8.5	0.188	5	5.7	0.188
6	12.2	0.162	6	9.4	0.171
7	16.0	0.150	7	11.4	0.175
8	20.7	0.104	8	20.5	0.088
Total chloride content in outermost 20 mm (%mm)		**3.00**	**Total chloride content in outermost 20 mm (%mm)**		**2.83**

Specimen nr 3			Specimen nr 4		
Level	**Depth of level mm**	**Cl %**	**Level**	**Depth of level mm**	**Cl %**
1	0.4	0.009	1	0.5	0.020
2	1.2	0.030	2	1.5	0.078
3	1.9	0.085	3	2.5	0.128
4	2.7	0.145	4	3.5	0.155
5	5.4	0.186	5	7.2	0.161
6	8.5	0.168	6	9.0	0.155
7	12.3	0.148	7	12.4	0.138
8	20.7	0.100	8	21.1	0.080
Total chloride content in outermost 20 mm (%mm)		**2.70**	**Total chloride content in outermost 20 mm (%mm)**		**2.49**

Holder nr 15

Specimen nr1			Specimen nr 2		
Level	Depth of level mm	Cl %	Level	Depth of level mm	Cl %
1	0.5	0.012	1	0.6	0.014
2	1.3	0.056	2	1.6	0.066
3	2.1	0.122	3	2.6	0.128
4	3.1	0.167	4	3.5	0.168
5	5.8	0.190	5	6.1	0.168
6	9.4	0.155	6	8.9	0.170
7	12.5	0.143	7	13.0	0.135
8	20.4	0.096	8	24.4	0.064
Total chloride content in outermost 20 mm (%mm)		**2.71**	**Total chloride content in outermost 20 mm (%mm)**		**2.51**

Specimen nr 3			Specimen nr 4		
Level	Depth of level mm	Cl %	Level	Depth of level mm	Cl %
1	0.4	0.010	1	0.5	0.009
2	1.3	0.062	2	1.3	0.038
3	2.2	0.118	3	2.0	0.087
4	2.8	0.142	4	2.7	0.145
5	5.7	0.155	5	5.7	0.190
6	10.5	0.130	6	8.5	0.175
7	14.5	0.108	7	12.2	0.148
			8	21.8	0.092
Total chloride content in outermost 20 mm (%mm)		**1)**	**Total chloride content in outermost 20 mm (%mm)**		**2.51**

1) Not calculated since the measurements ended at a depth < 20 mm.

Holder nr 19

Specimen nr1			Specimen nr 2		
Level	**Depth of level mm**	**Cl %**	**Level**	**Depth of level mm**	**Cl %**
1	0.5	0.023	1	0.5	0.019
2	1.7	0.081	2	1.5	0.079
3	2.6	0.133	3	2.4	0.123
4	3.3	0.163	4	3.2	0.142
5	5.3	0.186	5	6.0	0.154
6	9.2	0.178	6	9.7	0.129
7	12.9	0.144	7	13.7	0.115
8	20.9	0.096	8	23.0	0.059
Total chloride content in outermost 20 mm (%mm)		**2.81**	**Total chloride content in outermost 20 mm (%mm)**		**2.22**

Specimen nr 3			Specimen nr 4		
Level	**Depth of level mm**	**Cl %**	**Level**	**Depth of level mm**	**Cl %**
1	0.8	0.036	1	0.5	0.014
2	2.0	0.100	2	1.2	0.039
3	3.0	0.132	3	1.9	0.068
4	3.8	0.156	4	2.7	0.103
5	6.2	0.145	5	6.4	0.153
6	9.5	0.130	6	9.6	0.123
7	13.8	0.112	7	12.8	0.110
8	22.8	0.063	8	20.6	0.071
Total chloride content in outermost 20 mm (%mm)		**2.20**	**Total chloride content in outermost 20 mm (%mm)**		**2.13**

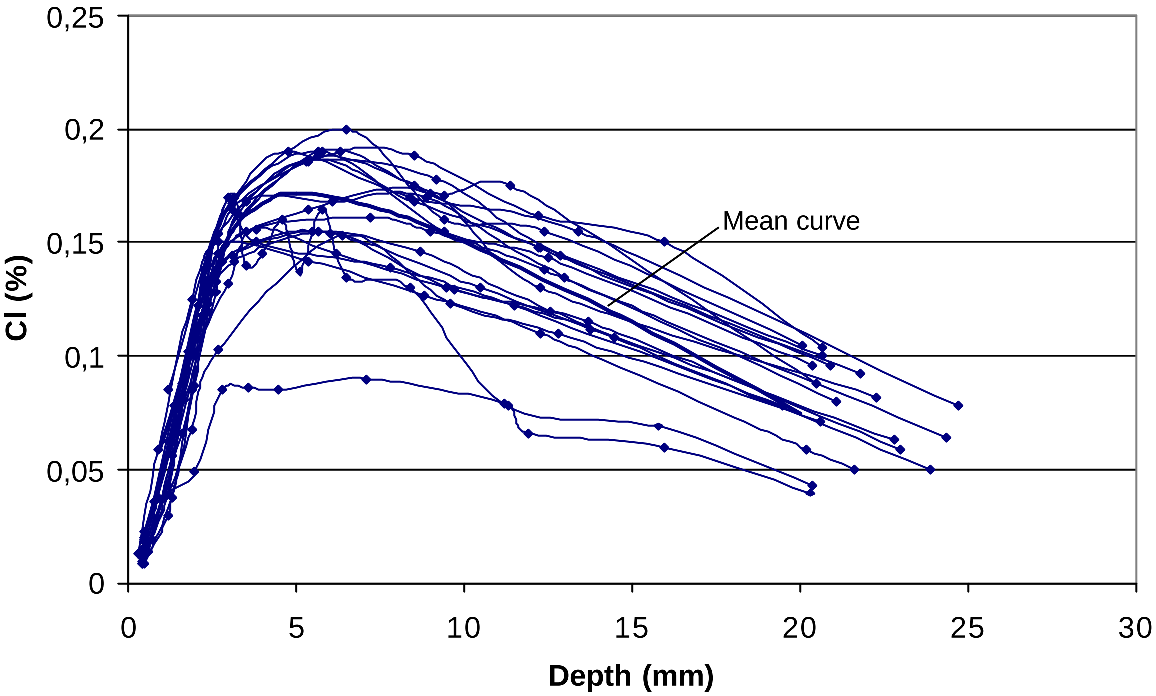

Figure A3.2: Location 1B. Chloride distribution after 5 winters.

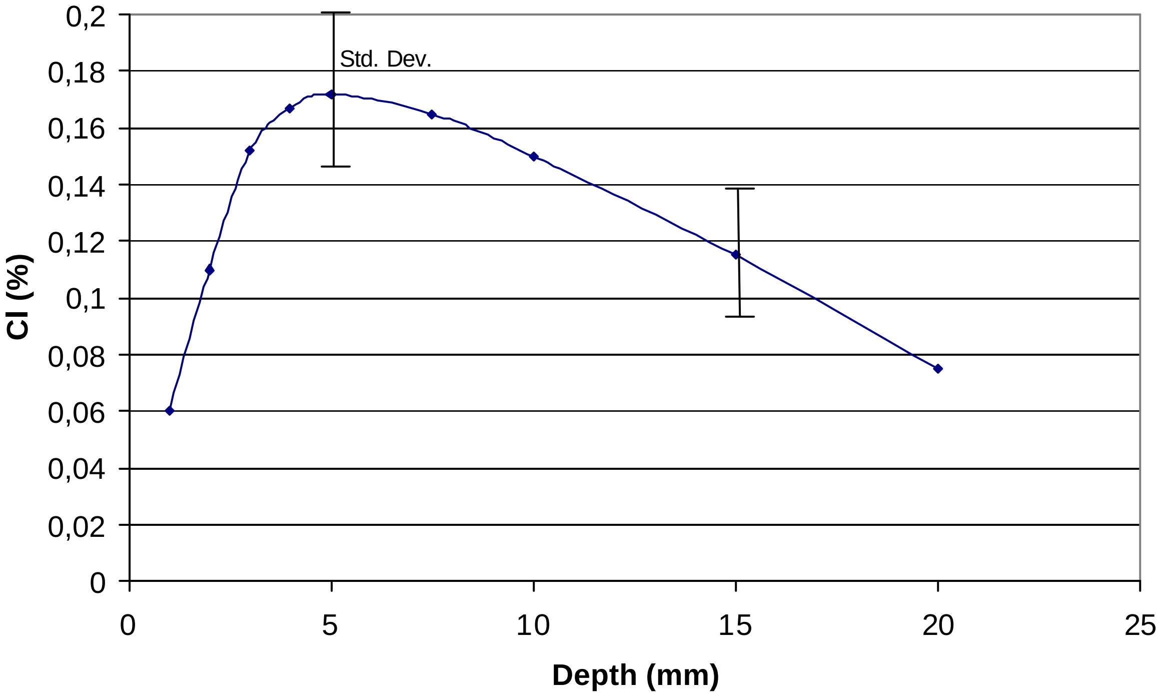

Figure A3.3: Location 1B. Chloride distribution after 5 winters. Mean value and standard deviation.

Location 2A:

Different height above the road surface. Protected from rain

Level	Average depth of level mm	Chloride content %						
		Height m						
		0.6	**1.0**	**1.4**	**1.8**	**2.2**	**2.6**	**3.0**
1	0.5	0.037	0.055	0.040	0.055	0.039	0.029	0.023
2	1.4	0.058	0.056	0.049	0.058	0.041	0.050	0.026
3	2.2	0.053	0.071	0.063	0.068	0.079	0.074	0.057
4	3.2	0.071	0.099	0.110	0.099	0.135	0.107	0.104
5	6.9	0.177	0.121	0.160	0.102	0.158	0.114	0.110
6	9.5	0.155	0.106	0.102	0.077	0.118	0.092	0.084
7	13.7	0.131	0.060	0.076	0.048	0.088	0.055	0.044
8	21.3	0.061	0.019	0.034	0.004	0.022	0.016	0.010
Total chloride content in outermost 20 mm (%·mm) 1)		**2.25**	**1.50**	**1.97**	**1.23**	**1.88**	**1.39**	**1.23**

Level	Average depth of level mm	Chloride content %		
		Height m		
		3.4	**3.8**	**4.2**
1	0.5	0.027	0.042	0.028
2	1.4	0.039	0.060	0.012
3	2.2	0.063	0.079	0.039
4	3.2	0.088	0.083	0.067
5	6.9	0.094	0.069	0.069
6	9.5	0.071	0.043	0.059
7	13.7	0.039	0.021	0.029
8	21.3	0.010	0.003	0.004
Total chloride content in outermost 20 mm (%·mm)		**1.09**	**0.83**	**0.81**

1) Total chloride is the area under the chloride profile expressed in terms of the units used in the table, i.e. *%·mm*, where % is the chloride concentration in % of the concrete weight, and mm is the depth from the surface.

The chloride content expressed in terms of *kg/m² exposed surface* is obtained by multiplying the figures in the table with the factor $\gamma \cdot 10^{-5}$ where γ=2010 kg/m³ is the density of the concrete; see Equation (3.2).

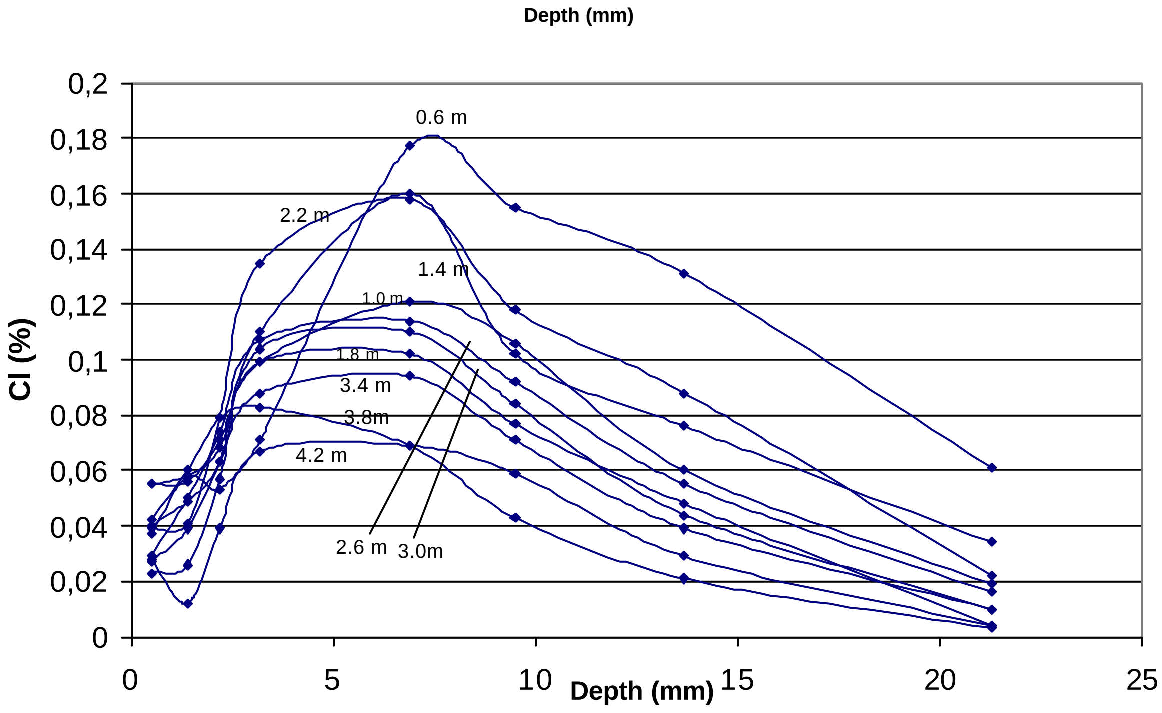

Figure A3.4: Location 2A. Chloride distribution after 5 winters

Location 2B:

Chloride content around a column founded on the reserve strip between roadways.
Specimens towards eastbound traffic

Specimen nr 3 angle from traffic		Specimen nr 6 parallel to traffic		Specimen nr 11 meeting traffic	
Depth mm	**Cl %**	**Depth mm**	**Cl %**	**Depth mm**	**Cl %**
0.5	0.013	0.5	0.039	0.4	0.006
1.4	0.035	1.3	0.044	1.1	0.027
2.3	0.066	1.9	0.049	2.0	0.050
3.4	0.098	2.5	0.070	2.9	0.067
7.6	0.089	6.4	0.115	6.1	0.064
8.8	0.084	9.8	0.096	9.1	0.047
14.1	0.048	13.1	0.066	12.9	0.032
21.2	0.01	20.4	0.014	20.8	0.006
Total chloride content in outermost 20 mm (%·mm) 1)	**1.18**		**1.37**		**0.76**

1) Total chloride is the area under the chloride profile expressed in terms of the units used in the table, i.e. *%·mm*, where % is the chloride concentration in % of the concrete weight, and mm is the depth from the surface.

The chloride content expressed in terms of *kg/m^2 exposed surface* is obtained by multiplying the figures in the table with the factor $\gamma \cdot 10^{-5}$ where γ=2010 kg/m^3 is the density of the concrete; see Equation (3.2).

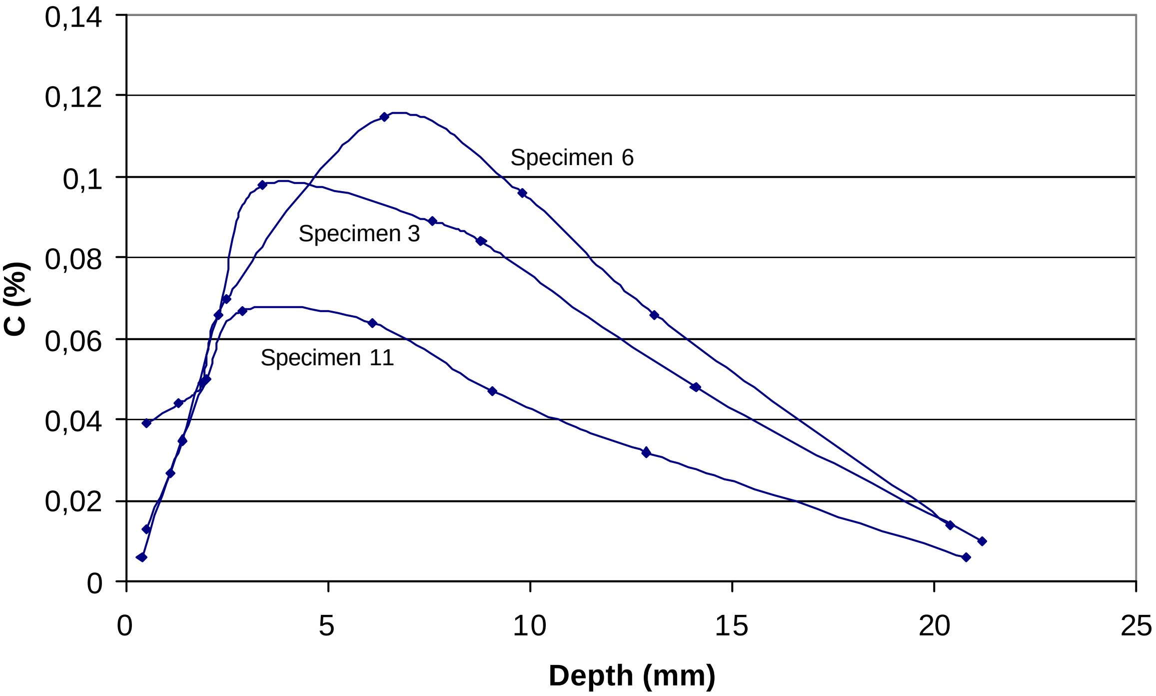

Figure A3.5: Location 2B. Chloride distribution after 5 winters

Location C:
Foot and bicycle bridge at the highway

Holder nr 33

Specimen nr 1		**Specimen nr 2**		**Specimen nr 3**		**Specimen nr 4**		**All specimens Mean value (std dev)**
Depth mm	**Cl %**	**Depth mm**	**Cl %**	**Depth mm**	**Cl %**	**Depth mm**	**Cl %**	
0.4	0.015	0.5	0.016	0.5	0.013	0.5	0.009	0.013 (0.003)
1.3	0.039	1.4	0.030	1.5	0.045	1.3	0.032	0.037 (0.007)
2.2	0.084	2.0	0.057	2.4	0.105	2.1	0.074	0.080 (0.020)
3.1	0.130	2.7	0.092	4.4	0.150	3.0	0.113	0.121 (0.025)
5.8	0.150	5.4	0.223	6.5	0.178	6.2	0.140	0.173 (0.037)
8.7	0.175	9.2	0.190	9.5	0.205	9.3	0.130	0.175 (0.032)
14.2	0.120	14.5	0.130	14.5	0.134	13.1	0.108	0.123 (0.012)
20.5	0.072	20.3	0.113	21.0	0.062	21.1	0.072	0.080 (0.023)
Total chloride content in outermost 20 mm(%·mm) 1)	**2.40**		**2.83**		**2.66**		**2.04**	**2.48 (0.34)**

1) Total chloride is the area under the chloride profile expressed in terms of the units used in the table, i.e. *%·mm*, where % is the chloride concentration in % of the concrete weight, and mm is the depth from the surface.

The chloride content in expressed in terms of kg/m^2 *exposed surface* is obtained by multiplying the figures in the table with the factor $\gamma\cdot 10^{-5}$ where γ=2010 kg/m^3 is the density of the concrete; see Equation (3.2).

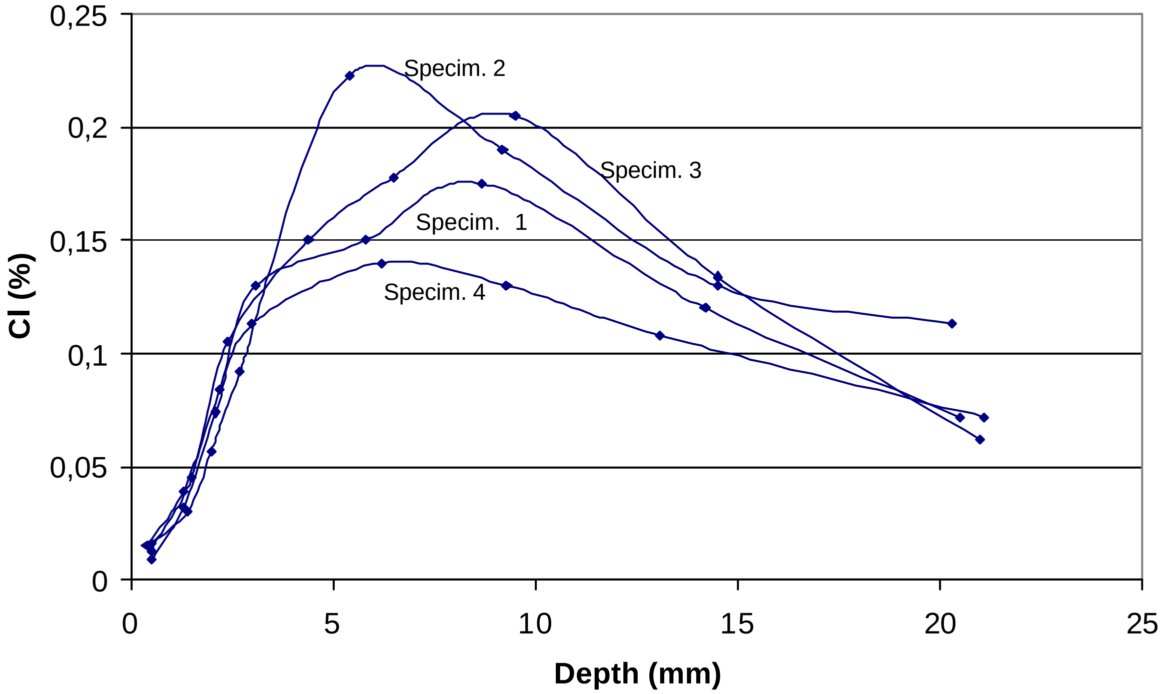

Figure A3.6: Location C. Chloride distribution after 5 winters

Location D:
Edge beam of viaduct crossing the highway

Holder nr/specimen nr		Holder nr/specimen nr	
41/3 Under the edge beam		42/3 at the side of the edge beam	
Depth mm	**Cl %**	**Depth mm**	**Cl %**
0.4	0.016	0.5	0.011
1.0	0.017	1.4	0.014
1.7	0.020	2.3	0.026
2.4	0.023	3.4	0.038
6.6	0.009	6.2	0.025
10.1	0.002	8.7	0.021
13.3	0.001	14.5	0.005
20.5	0.001	20.4	0.003
Total chloride content in outermost 20 mm (%·mm) 1)	**0.14**		**0.31**

1) Total chloride is the area under the chloride profile expressed in terms of the units used in the table, i.e. *%·mm*, where % is the chloride concentration in % of the concrete weight, and mm is the depth from the surface.

The chloride content expressed in terms of *kg/m² exposed surface* is obtained by multiplying the figures in the table with the factor $\gamma \cdot 10^{-5}$ where γ=2010 kg/m^3 is the density of the concrete; see Equation (3.2).

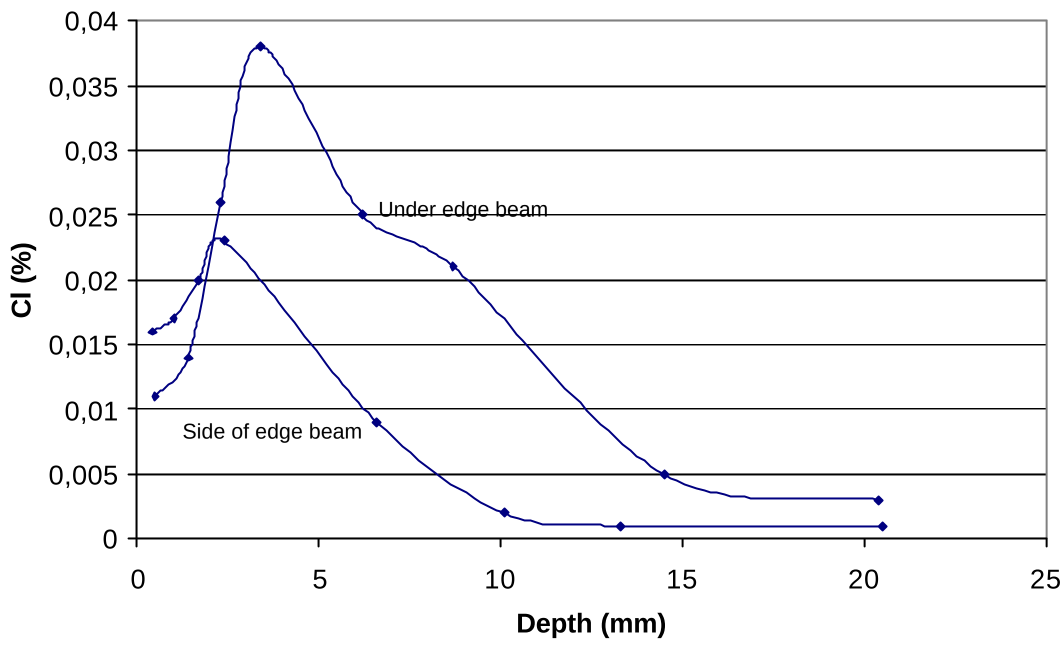

Figure A3.7: Location D. Chloride distribution after 5 winters

APPENDIX 4

Chloride profiles in June 2003 after 8 winter seasons

Location 1A:

Different height above the road surface. Unprotected from rain

Level	Average depth of level mm	Chloride content %						
		Height m						
		0.45	**0.85**	**1.25**	**1.65**	**2.05**	**2.45**	**2.85**
1	0.8	0.028	0.010	0.018	0.017	0.025	0.008	0.017
2	2.0	0.054	0.037	0.040	0.049	0.045	0.022	0.026
3	3.0	0.079	0.055	0.110	0.079	0.060	0.038	0.025
4	4.1	0.070	0.078	0.138	0.106	0.044	0.072	0.019
5	7.1	0.118	0.100	0.143	0.057	0.049	0.046	0.021
6	10.0	0.076	0.082	0.113	0.050	0.048	0.036	0.011
7	15.2	0.066	0.070	0.079	0.067	0.032	0.021	0.008
8	20.5	0.064	0.055	0.062	0.038	0.023	0.013	0.003
Total chloride content in outermost 20 mm (%·mm) [1)]		**1.45**	**1.38**	**1.88**	**1.17**	**0.78**	**0.64**	**0.26**

0.079

Level	Average depth of level mm	Chloride content %		
		Height m		
		3.25	**3.65**	**4.05**
1	0.8	0.015	0.011	0.013
2	2.0	0.032	0.035	0.037
3	3.0	0.034	0.022	0.035
4	4.1	0.030	0.026	0.034
5	7.1	0.024	0.010	0.020
6	10.0	0.013	0.005	0.009
7	15.2	0.016	0.012	0.007
8	20.5	0.006	0.004	0.004
Total chloride content in outermost 20 mm (%·mm)		**0.36**	**0.24**	**0.30**

1) Total chloride is the area under the chloride profile expressed in terms of the units used in the table, i.e. *%·mm*, where % is the chloride concentration in % of the concrete weight, and mm is the depth from the surface.

The chloride content in expressed in terms of *kg/m^2 exposed surface* is obtained by multiplying the figures in the table with the factor $\gamma \cdot 10^{-5}$ where γ=2010 kg/m^3 is the density of the concrete; see Equation (3.2).

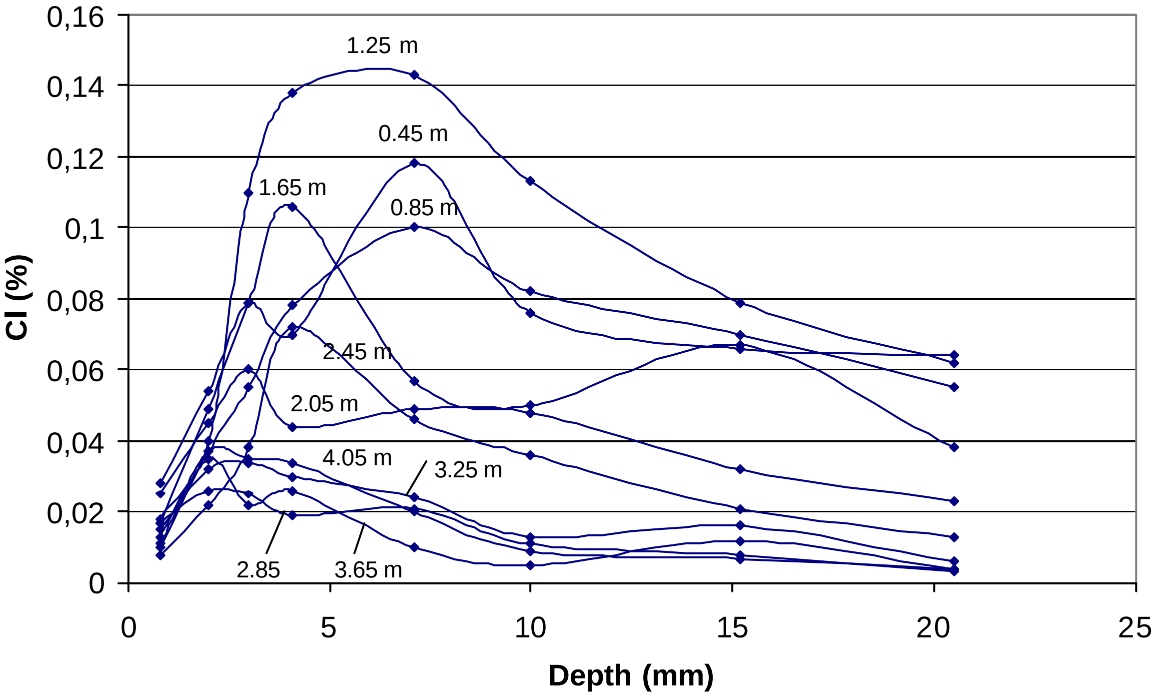

Figure A4.1: Location 1A. Chloride distribution after 8 winters.

Location 1B:
Along the road. Unprotected from rain

Holder nr 4

Specimen nr 3		
Level	**Depth of level mm**	**Cl %**
1	1.0	0.024
2	2.0	0.049
3	3.3	0.070
4	4.3	0.115
5	6.8	0.033
6	9.9	0.027
7	15.0	0.061
8	20.2	0.050
Total chloride content in outermost 20 mm (%mm) [1)]		**1.00**

1) Total chloride is the area under the chloride profile expressed in terms of the units used in the table, i.e. *%·mm*, where % is the chloride concentration in % of the concrete weight, and mm is the depth from the surface.

The chloride content expressed in terms of *kg/m^2 exposed surface* is obtained by multiplying the figures in the table with the factor $\gamma \cdot 10^{-5}$ where γ=2010 kg/m^3 is the density of the concrete; see Equation (3.2).

Holder nr 12

Specimen nr 3		
Level	**Depth of level mm**	**Cl %**
1	1.1	0.032
2	2.1	0.074
3	3.3	0.077
4	4.4	0.088
5	7.0	0.029
6	10.1	0.050
7	15.0	0.055
8	20.9	0.046
Total chloride content in outermost 20 mm (%mm)		**1.04**

Holder nr 16

Specimen nr 4		
Level	**Depth of level mm**	**Cl %**
1	1.0	0.051
2	2.1	0.083
3	3.2	0.088
4	4.3	0.087
5	6.6	0.039
6	9.5	0.051
7	14.7	0.051
8	20.6	0.029
Total chloride content in outermost 20 mm (%mm)		**1.04**

Holder nr 20

Specimen nr1		
Level	**Depth of level mm**	**Cl %**
1	0.8	0.027
2	1.8	0.055
3	2.9	0.065
4	3.9	0.062
5	6.6	0.034
6	9.6	0.033
7	14.6	0.043
8	20.5	0.029
Total chloride content in outermost 20 mm (%mm)		**0.81**

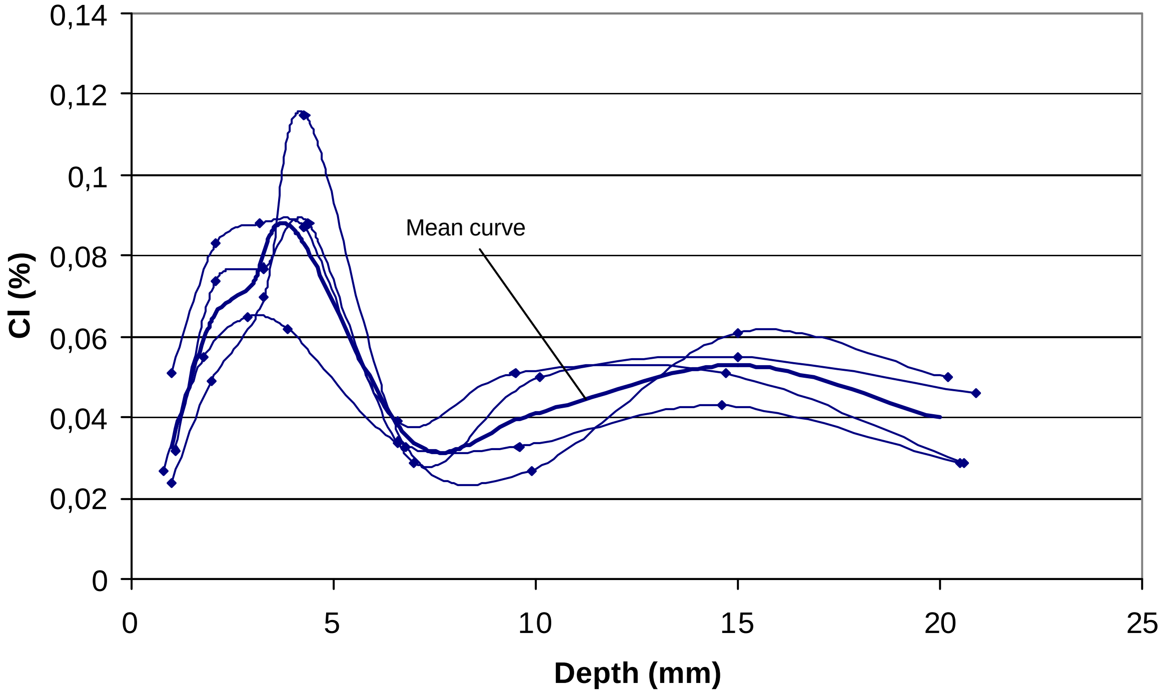

Figure A4.2: Location 1B. Chloride distribution after 8 winters.

Location 2A:

Different height above the road surface. Protected from rain

Level	Average depth of level mm	Chloride content %						
		Height m						
		0.6	1.0	1.4	1.8	2.2	2.6	3.0
1	1.0	0.084	0.089	0.120	0.097	0.062	0.059	0.044
2	2.1	0.082	0.071	0.098	0.065	0.080	0.061	0.057
3	3.3	0.075	0.102	0.103	0.103	0.080	0.068	0.079
4	4.3	0.119	0.165	0.124	0.134	0.102	0.088	0.095
5	6.9	0.084	0.171	0.142	0.152	0.110	0.076	0.080
6	10.1	0.102	0.115	0.145	0.115	0.080	0.056	0.067
7	15.1	0.094	0.090	0.112	0.103	0.057	0.045	0.046
8	20.7	0.073	0.062	0.066	0.059	0.024	0.022	0.022
Total chloride content in outermost 20 mm (%·mm) 1)		**1.79**	**2.10**	**2.29**	**2.10**	**1.42**	**1.09**	**1.16**

Level	Average depth of level mm	Chloride content %		
		Height m		
		3.4	3.8	4.2
1	1.0	0.034	0.035	0.058
2	2.1	0.049	0.044	0.052
3	3.3	0.077	0.068	0.046
4	4.3	0.088	0.064	0.054
5	6.9	0.155	0.075	0.027
6	10.1	0.080	0.051	0.023
7	15.1	0.084	0.041	0.013
8	20.7	0.026	0.020	0.003
Total chloride content in outermost 20 mm (%·mm) 1)		**1.58**	**0.96**	**0.51**

1) Total chloride is the area under the chloride profile expressed in terms of the units used in the table, i.e. *%·mm*, where % is the chloride concentration in % of the concrete weight, and mm is the depth from the surface.

The chloride content expressed in terms of *kg/m^2 exposed surface* is obtained by multiplying the figures in the table with the factor $\gamma \cdot 10^{-5}$ where γ=2010 kg/m^3 is the density of the concrete; see Equation (3.2).

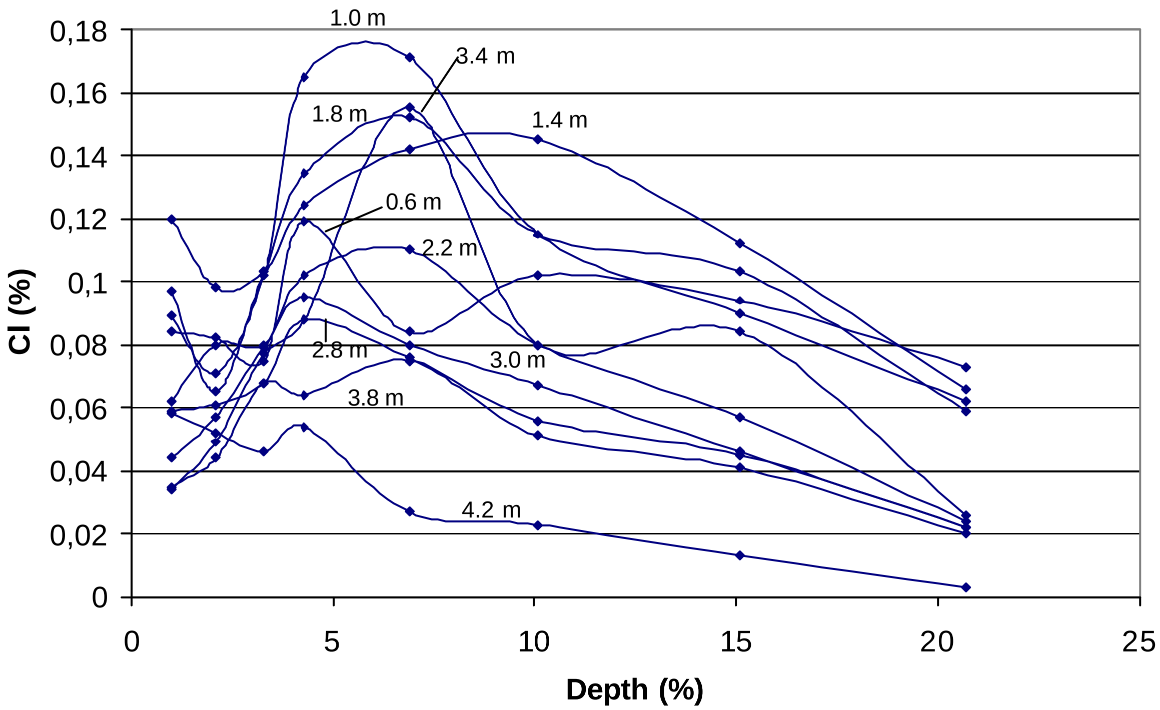

Figure A4.3: Location 2A. Chloride distribution after 8 winters.

Location 2B:

Chloride content around a column founded on the reserve strip between roadways.
Specimens towards eastbound traffic

Specimen nr 1 directed from traffic		**Specimen nr 2 from traffic**		**Specimen nr 5 parallel to traffic**		**Specimen nr 8 angle towards traffic**		**Specimen nr 10 meeting traffic**	
Depth mm	**Cl %**	**Depth mm**	**Cl %**	**Depth mm**	**Cl %**	**Depth mm**	**Cl %**	**Depth mm**	**Cl %**
1.0	0.031	1.0	0.021	0.8	0.023	0.7	0.061	1.2	0.051
2.0	0.046	1.9	0.040	2.0	0.041	1.8	0.061	2.3	0.074
3.0	0.037	2.8	0.038	3.0	0.046	3.0	0.057	3.7	0.105
4.2	0.040	3.9	0.037	4.1	0.045	3.9	0.064	4.6	0.123
6.6	0.031	6.4	0.022	6.6	0.028	6.5	0.063	7.2	0.084
9.8	0.025	9.7	0.013	9.7	0.020	9.6	0.057	10.0	0.098
15.1	0.011	14.7	0.002	14.9	0.008	14.6	0.036	15.1	0.044
21.0	0.039	20.4	0.001	20.8	0.002	20.8	0.014	20.6	0.031
Total chloride content in outermost 20 mm[1)] (%·mm)	**0.53**		**0.29**		**0.41**		**0.93**		**1.35**

1) Total chloride is the area under the chloride profile expressed in terms of the units used in the table, i.e. *%·mm*, where % is the chloride concentration in % of the concrete weight, and mm is the depth from the surface.

The chloride content expressed in terms of *kg/m² exposed surface* is obtained by multiplying the figures in the table with the factor $\gamma \cdot 10^{-5}$ where $\gamma = 2010$ kg/m³ is the density of the concrete; see Equation (3.2).

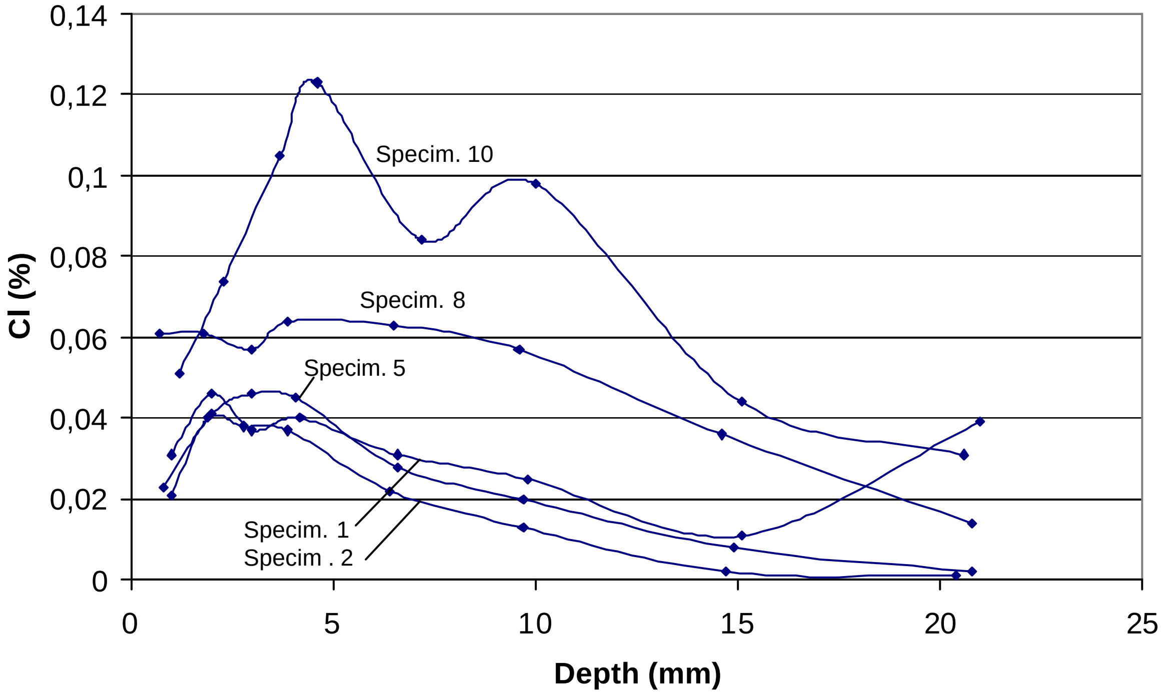

Figure A4.4: Location 2B. Chloride distribution after 8 winters.

Location D:
Edge beam of viaduct crossing the highway

Holder nr/specimen nr		Holder nr/specimen nr	
41/4 **Under the edge beam**		**42/4** **At the side of the edge beam**	
Depth mm	**Cl %**	**Depth mm**	**Cl %**
0.8	0.028	1.0	0.024
2.1	0.025	2.3	0.021
3.2	0.030	3.3	0.023
4.2	0.019	4.3	0.024
6.9	0.010	6.9	0.011
10.0	0.005	10.0	0.007
15.0	0.002	14.8	0.003
21.0	0.002	20.9	0.001
Total chloride content in outermost 20 mm[1)] (%·mm)	**0.19**		**0.19**

1) Total chloride is the area under the chloride profile expressed in terms of the units used in the table, i.e. *%·mm*, where % is the chloride concentration in % of the concrete weight, and mm is the depth from the surface.

The chloride contentexpressed in terms of *kg/m² exposed surface* is obtained by multiplying the figures in the table with the factor $\gamma \cdot 10^{-5}$ where γ=2010 kg/m³ is the density of the concrete; see Equation (3.2).

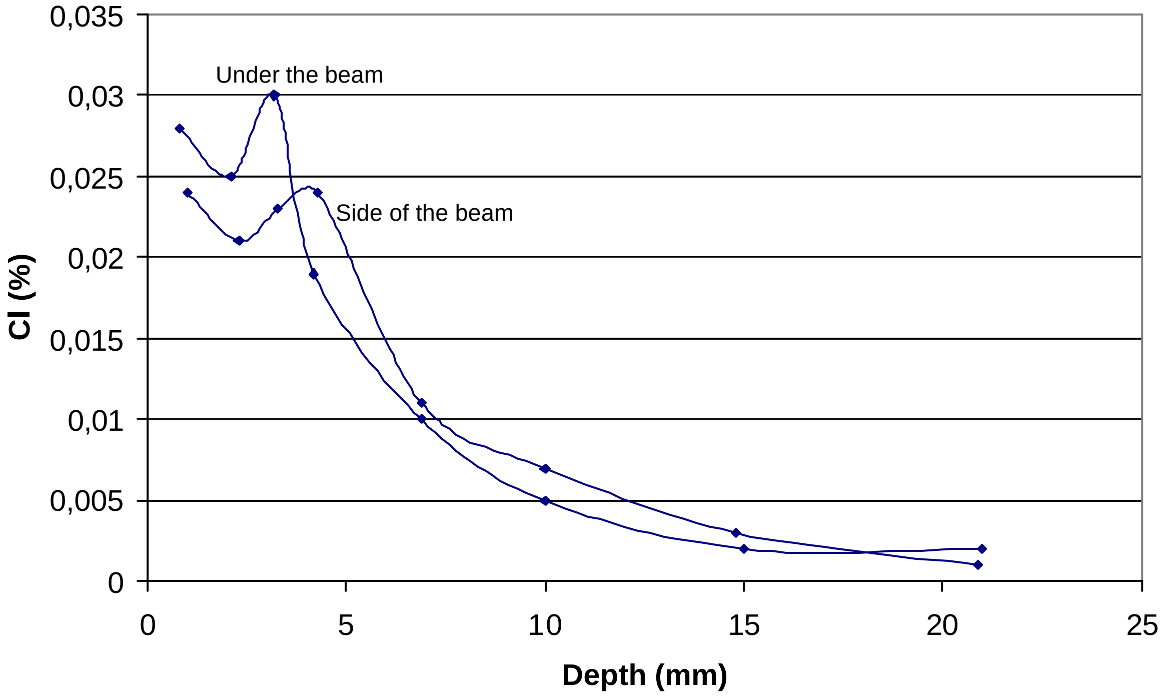

Figure A4.5: Location D. Chloride distribution after 8 winters.