CHLORIDE EXPOSURE ON GIMSØYSTRAUMEN BRIDGE - RESULTS FROM EXTENDED CONDITION SURVEY

Finn Fluge, Norwegian Road Research Laboratory, PB 8142 Dep, N-0033 Oslo.
Aage Blankvoll, Nordland County Roads Office, Nordstrandv. 41, N-8002 Bodø.

ABSTRACT

An extended condition survey was performed at Gimsøystraumen bridge in 1992. Included in the extended condition survey was more than 4500 chloride analyses. Additional chloride measurements were performed in connection with trial repairs in 1993 and 1994. In the extended condition survey chlorides were analysed using the Rapid Chloride Test (RCT) as a "field-method", while chlorides were analysed by the use of more sophisticated laboratory methods in 1993 and 1994. The results from the RCT measurements were consistent with the results from the laboratory analyses.

A limited part of the results from these investigations, have been used for calculation of diffusion coefficients (D) and chloride exposure coefficients (C_s). The calculated diffusion coefficient (D) varies from 22 - 48 mm^2/year. The average is 35 mm^2/year with a standard deviation of 7,5 mm^2/year. This indicates relatively uniform concrete quality in the structure. The height above the sea level is of major importance for the environmental "chloride load" exposed to the superstructure. The "chloride load" is a lot heavier on the lee side than on the windward side. This effect is of most importance for the parts of the superstructure closest to the sea level. The recorded "chloride load" is consistent with the damage recorded at the superstructure of the bridge.

The accuracy of the RCT-method is considered as good enough for chloride analyses in condition surveys. The use of 10 mm steps for powder sampling does not detect high concentrations of chlorides in thin layers of the concrete. The analysed chloride value closest to the surface must be treated with care in assessments after condition surveys. In calculations of D and C_s the value closest to the surface should be left out.

Keywords: Concrete Bridge, Marine Environment, Chlorides

1. INTRODUCTION

Durability of concrete bridges has been focused in all of the Nordic countries the last decade. To solve problems related to durability and repair of concrete bridges, Norway has used a practical approach. This means, that several condition surveys including visual inspection, chloride measurements, potential mapping and laboratory analyses have been performed. The same way, a lot of different techniques for maintenance and repair have been tried out since 1988. The other Nordic countries have chosen another approach and attached importance to theoretical studies and laboratory analyses rather than gaining experience from field studies.

In the very beginning of the OFU Bridge Repair Project, an extended condition survey was performed. The extent of this condition survey, is maybe the largest performed ever on one bridge. More than 4500 chloride analyses were performed. In addition, the condition survey consisted of visual inspection, potential mapping, measurements of concrete cover and rebar inspection.

The work presented in this report is a part of investigations in progress.

2. GIMSØYSTRAUMEN BRIDGE

Gimsøystraumen bridge is located 30 km west of Svolvær on the E 10 road in the Nordland County. The bridge was constructed between 1979 - 1981. The bridge is a link between two of the Lofoten Islands, Austvågøy and Gimsøy. The longitudinal bridge axis is roughly east-west. The climate is severe with strong winds and salt spray from the sea. The bridge length is 840 m divided into 9 sections, see fig. 1. The environmental effects vary greatly along the bridge as the bridge deck level varies from 4 m to 36 m above sea level.

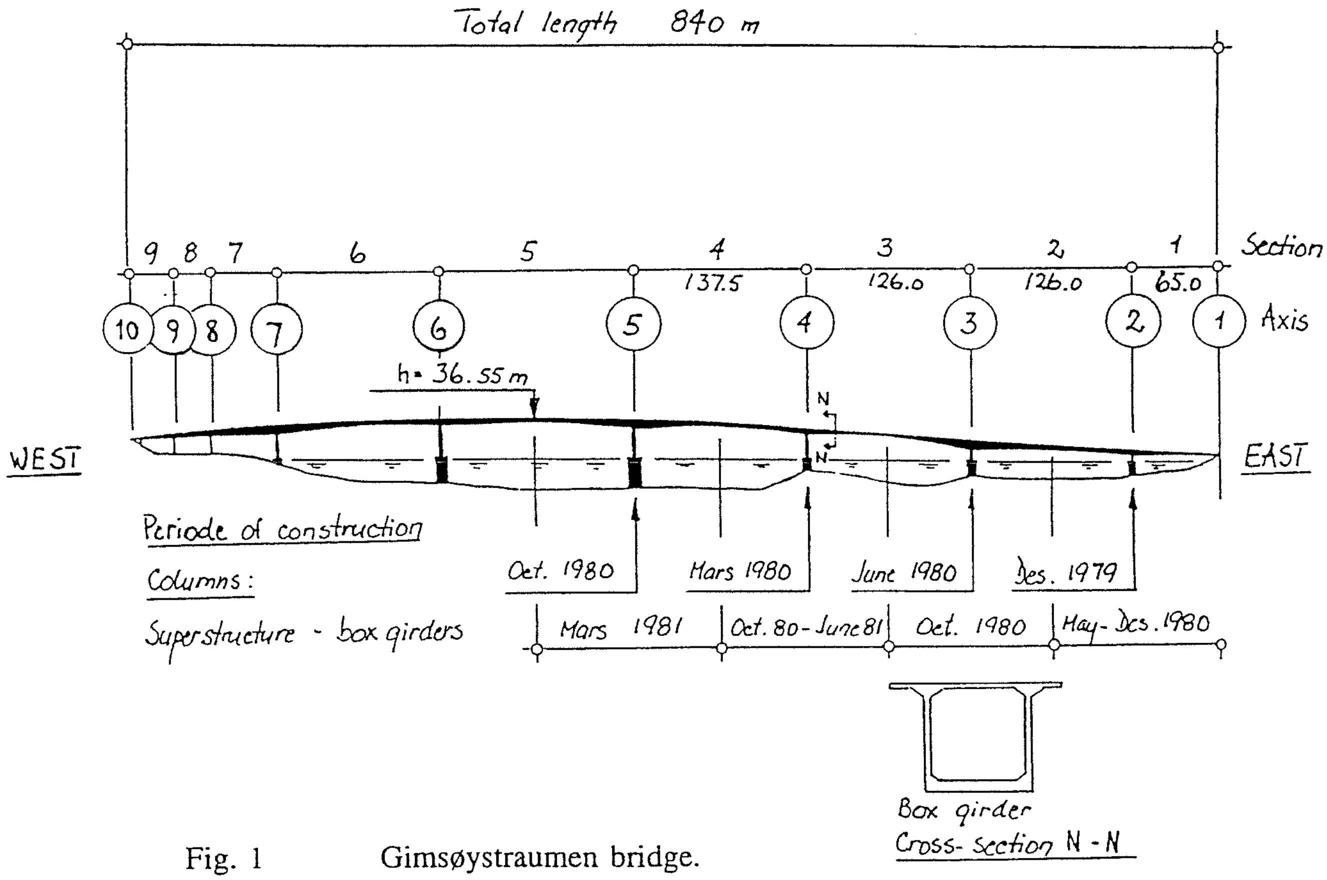

Fig. 1 Gimsøystraumen bridge.

The bridge is a post-tensioned, free cantilevered, box construction. The box height varies from 2,2 m to 7,4 m. The designed concrete strength for substructures was C 35 with 50 mm cover of rebars. For the bridge deck the corresponding values were C 40 and 30 mm. Fixing bars were allowed in the cover zone in horizontal construction elements. The designed quality of reinforcement bars was Ks 50 and Ks 40 for stirrups.

3. EXPERIMENTAL METHODS

The extended condition survey was performed during the autumn of 1992 by Ringtek (ref. 1). From the superstructure of the bridge 11 chloride profiles were measured for every six meters in longitudinal direction of section 1, 2, 3 and 4. This is illustrated in fig. 2. Section 1, 2, 3 and 4 are all together 454,5 m. A total of 752 chloride profiles was analysed from this area of the bridge.

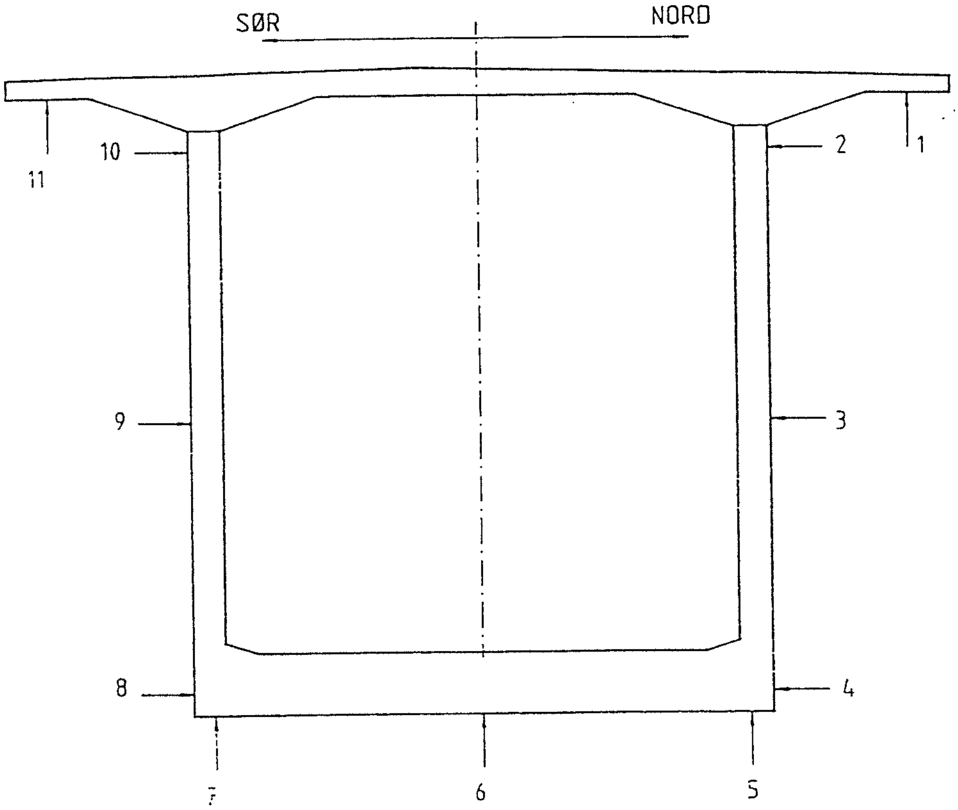

Fig. 2 Measuring points at the box girder in the Ringtek survey.

From the columns in the same area, this means the columns in axis 2, 3, 4 and 5, ten chloride profiles were measured for every four meters. A total of 160 chloride profiles was measured for the columns. The results from the columns are not included in this report.

For the superstructure, concrete powder was drilled out with a 18 mm bit for the depths 0 - 10 mm, 10 - 20 mm, 20 - 30 mm, 30 - 50 mm and 50 - 75 mm. For each location 4 holes were drilled out for powder sampling. Hence, one sample is the average of powder from 4 holes. Chlorides were analysed using the RCT-method. The chloride content is presented as % by weight of cement. In the calculation from % by weight of concrete a factor of 6,4 is used. This means that 375 kg of cement was specified in the concrete mix.

Within the "OFU Bridge Repair Project" additional investigations including chloride measurements are performed during 1993 and 1994. This is reported in ref. 2, 3 and 4.

Rescon performed in 1993 a total of 40 control measurements analysing exactly the same powder Ringtek had analysed in 1992 (ref. 2). The powder had been kept in plastic bags (not PVC) for 10 months. For the control measurements chlorides were analysed using titration after NS 3671.

As a part of investigations before the trial repair in 1993, chloride profiles were determined from three concrete cores drilled out (ref. 3). In connection with the trial repair in 1994, two additional cores were drilled out in section no. 2 (ref. 4). In these investigations concrete powder was grained off the cores in short steps and chlorides were analysed with the potentiometric titration method. Both in 1993 and in 1994 the chloride analyses were performed by Norut Technology.

4. RESULTS AND DISCUSSION

The results from the Ringtek survey in 1992 show very high content of chlorides in some areas of the superstructure. The most exposed areas of the superstructure are close to the sea level on the north side of the box girder. In the discussion, we have chosen the results from 3 cross sections (A, B and C), see fig. 3. The cross sections (A and B) in section no. 2 (between the axis 2 and 3) are inside the testing areas investigated as a part of the Trial Repair in 1993.

The carbonation of concrete might influence the chloride profiles. Carbonation depth of 2 mm is measured by the use of phenolphthalein (ref. 2). Carbonation depth of 1,5 - 6 mm is measured after analyses of thin sections. These analyses were performed by Byggforsk and also reported in ref. 2. The possible influence of carbonation on chloride profiles is not discussed in this report.

4.1 Results from the Ringtek survey in 1992

The highest content of chlorides measured at cross section no. A is 2,43 % by weight of cement. This value is measured on the lowest part of the box girder on the northern side, rcorded at the depth 10 - 20 mm. The highest value on the southern side of the box girder is 0,45 % at the depth 0 - 10 mm. The bridge deck level at cross section no. A is 11,9 m above sea level.

For cross section no. B, the highest value is 1,54 %. This value is recorded both on the north side of the box girder (0 - 10 mm) and on the underside of the box girder (10 - 20 mm). On the south side the highest value is 0,69 % (0 - 10 mm). The bridge deck level for cross section no. B is at 17,6 m.

Cross section no. C is 33,4 m above sea level. The highest chloride content is 0,77 % (0 - 10 mm) on the north side and 0,33 % (0 - 10 mm) on the south side of the box girder.

Detailed results are presented in appendix no. 1.

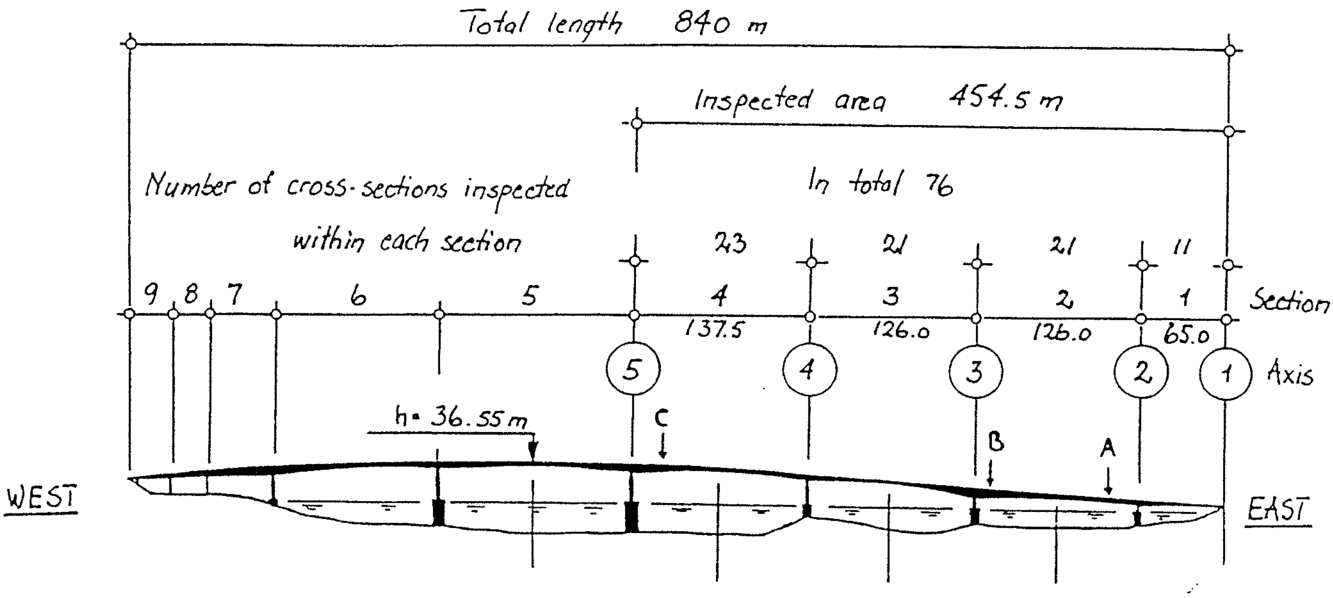

Fig. 3 Location of the cross sections A, B and C.

4.2 Results from Norut analyses in 1993 and 1994

The chloride content is analysed in shorter steps in the Norut analyses than in the Ringtek survey. The average chloride content is calculated for the same steps used by Ringtek. This means 0 - 10 mm, 10 - 20 mm, 20 - 30 mm, 30 - 50 mm and 50 - 75 mm.

Using these steps, the highest chloride content at cross section no. A is recorded at the depth 10 - 20 mm. The recorded value at the analyses in 1993 was 2, 91 % by weight of cement and 2, 34 % at the analyses in 1994. Both chloride profiles were taken from the north side of the box girder. These values are corresponding with the values from the Ringtek survey. The closest chloride profile from the Ringtek survey recorded 2,30 % at this depth. However, it should be noticed that one of the values in the Norut analyses at the depth 8 - 10 mm, showed a chloride content of 3,45 % by weight of cement.

At cross section no. B, chloride profiles from both the north and the south side of the box girder were analysed in 1993, while one profile from the north side was analysed in 1994. Using the steps from the Ringtek survey again, the highest value on the north side is 1,66 % at the depth 0 - 10 mm. Using the finer steps in the Norut analyses in 1994, the highest value is 2, 60 % at the depth 2 - 4 mm. The highest value on the south side is 0,72 % (0 - 10 mm). Using the finer steps in the Norut analyses in 1993, the highest value is 0,98 % at the depth 0 - 5 mm. Also these values are corresponding with the values from the Ringtek survey.

Detailed results from the analyses in 1993 are presented in appendix no. 2, while the detailed results from Norut in 1994 are listed in appendix no.3.

4.3 Calculation of D and C_s

The results from cross sections A, B and C are used for calculation of diffusion coefficients (D) and chloride exposure coefficients (C_s). The calculations are performed using a computer program developed by Selmer.

The calculations of D and C_s are based upon Ficks second law of diffusion. The calculations have taken into account that different parts of the superstructure are build in different time periods and that test material sampling is performed at different points of time. The background chloride concentration used is 0,01 % by weight of cement. Another assumption made, is that the value closest to the surface is left out in the calculations of D and Cs, see fig. 4. Results from the calculations are presented in table 1.

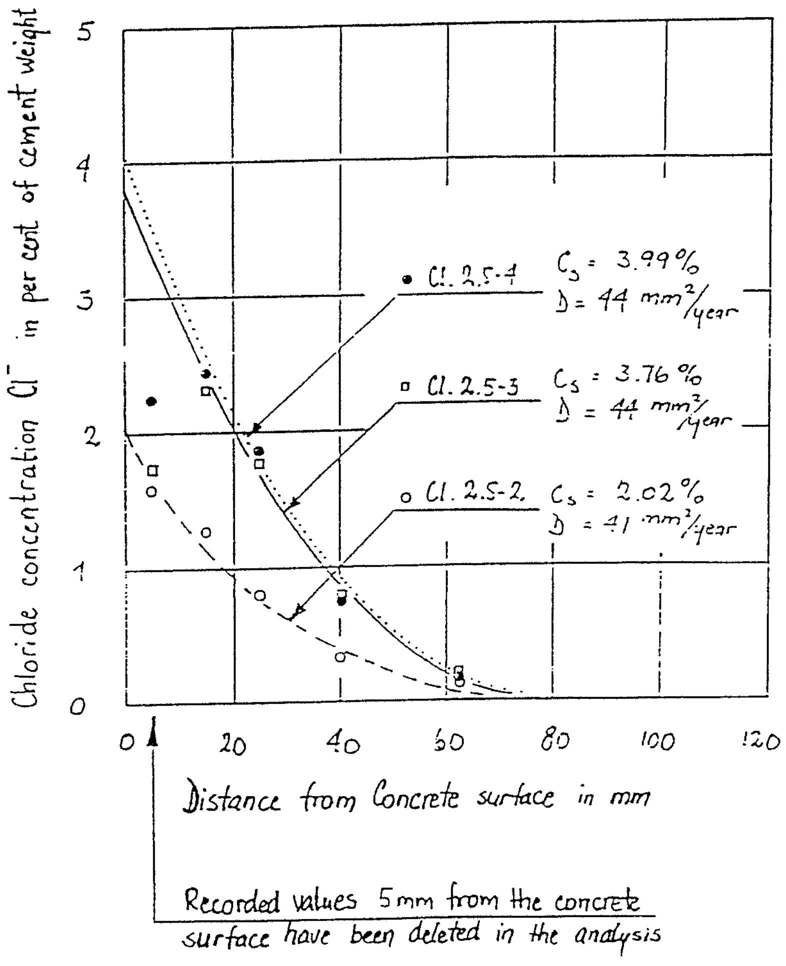

Fig. 4 Chloride profile and calculation of D and C_s.

The calculated diffusion coefficient (D) varies from 22 - 48 mm^2/year. The average is 35 mm^2/year with a standard deviation of 7,5 mm^2/year. This indicates relatively uniform concrete quality in the structure.

The calculated chloride exposure coefficients (C_s) give quantitative numbers to the chloride exposure on the superstructure in the cross sections A, B and C.

Table 1 Diffusion coefficients (D) and chloride exposure coefficients (C_s).

Location	Measuring point (fig.2)	Ringtek 1992		Norut 1993	Norut 1994
		C_s (%)	D (mm²/year)	C_s / D	C_s / D
Cross section A (2.5) 24 m west of axis no. 2	2.5 - 2	2,02	41		
	2.5 - 3	3,76	44	3,83 / 37	3,55 / 48
	2.5 - 4	3,99	44		
	2.5 - 5	2,61	46		
	2.5 - 6	2,61	37		
	2.5 - 7	2,34	26		
	2.5 - 8	0,53	40		
	2.5 - 9	0,36	45		
	2.5 - 10	0,51	45		
Cross section B (2.20) 114 m west of axis no. 2	2.20 - 2	2,18	38		
	2.20 - 3	2,38	37	2,18 / 25	1,75 / 35
	2.20 - 4	1,96	28		
	2.20 - 5	2,50	28		
	2.20 - 6	2,00	25		
	2.20 - 7	0,30	26		
	2.20 - 8	0,68	27		
	2.20 - 9	0,78	31	0,91 / 22	
	2.20 - 10	0,60	42		
Cross section C (4.20) 114 m west of axis no. 4	4.20 - 2	0,89	40		
	4.20 - 3	0,62	29		
	4.20 - 4	0,61	28		
	4.20 - 5	0,64	26		
	4.20 - 6	0,61	34		
	4.20 - 7	0.31	32		
	4.20 - 8	0,30	40		
	4.20 - 9	0,35	33		
	4.20 - 10	0,26	39		

4.4 Discussion about chloride exposure on the superstructure

The chloride exposure coefficients (C_s) are assumed to represent the "chloride load" on the superstructure. This is presented graphically for the cross sections A, B and C in fig. 5, 6 and 7.

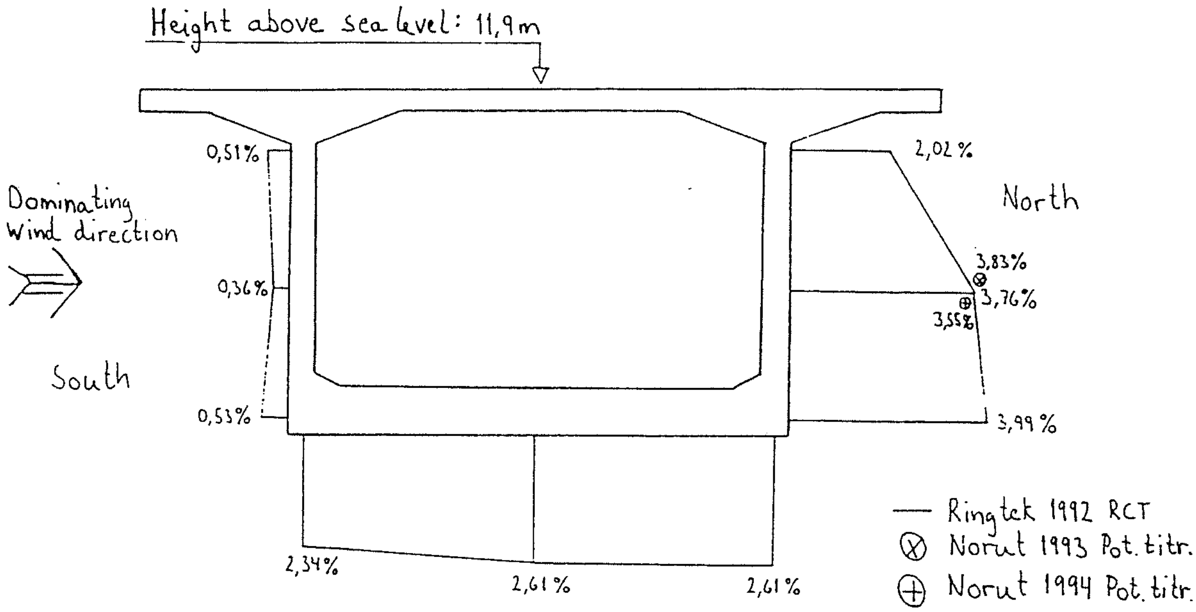

Fig. 5 Chloride load (C_s) on the superstructure at cross section A, 24 m west of axis no. 2. Recorded values in % by weight of cement.

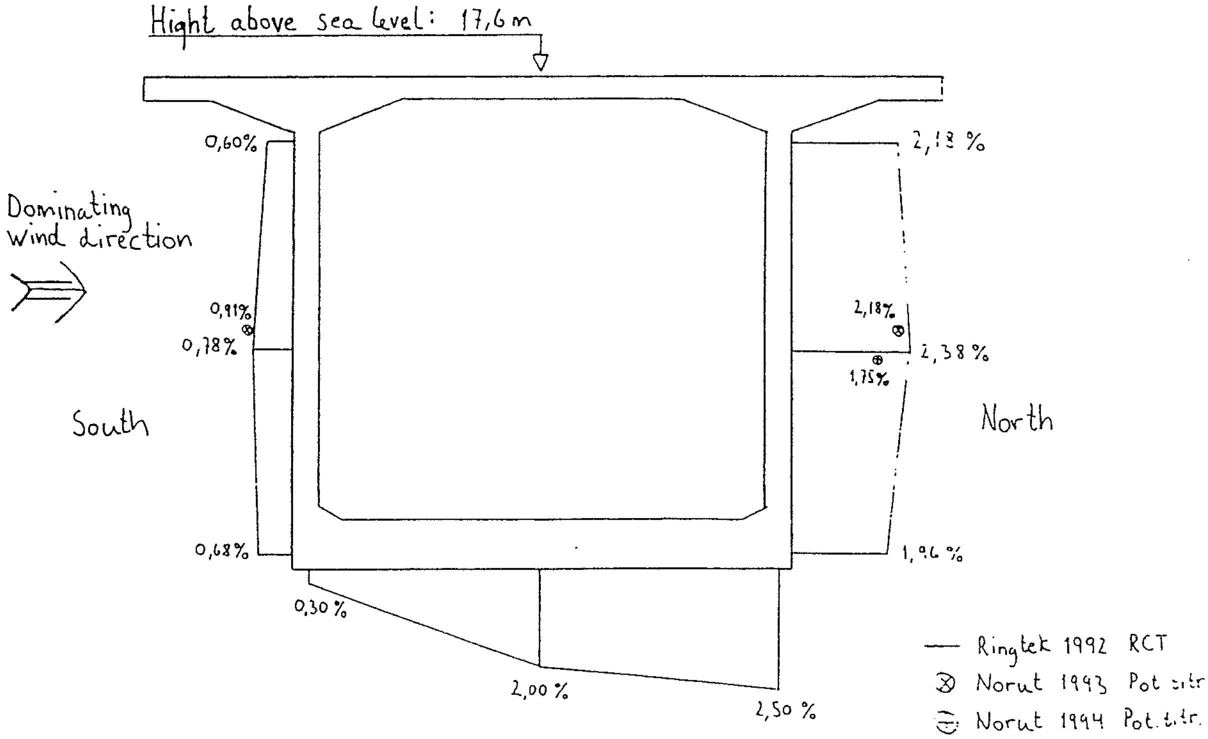

Fig. 6 Chloride load (C_s) on the superstructure at cross section B, 114 m west of axis no. 2. Recorded values in % by weight of cement.

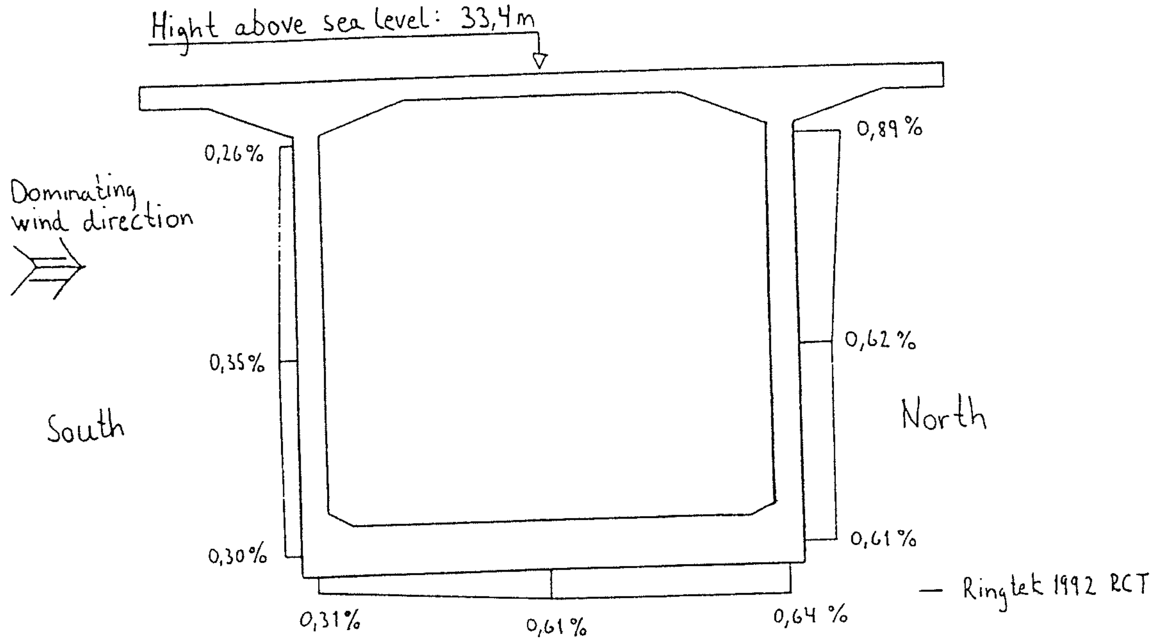

Fig. 7 Chloride load (C_s) on the superstructure at cross section C, 114 m west of axis no. 4. Recorded values in % by weight of cement.

The figures presented show very clearly how the chloride load, which is acting on the structure, is effected by factors as lee / windward side and the height of the structure above the sea level. The exact magnitude of the chloride load might be questionable, but if we use the quantitative numbers in fig. 5 - 7 we might have an idea about the size of these factors.

We can make a comparison between the chloride load on the box girder at different levels above the sea. The chloride load values on the lowest part of the box girder on the north side at cross section no. A and C are compared. The value at cross section no. A at this point is 3,99 %, while the value at cross section no. C is 0,61 %. From this, we can state that the chloride load is up to 6,5 times lower when the superstructure rises from 8 m to 28 m above the sea level.

We can also make a comparison of the chloride load on the lee side and on the windward side at cross section no. A. The chloride load values on the lowest part of the box girder on the north side and on the south side are compered. The value on the north side is 3,99 %, while the value on the south side is 0,53 %. We can record, that at the height of 8 m above the sea level, the chloride load is up to 8 times higher on the lee side than on the windward side. For all locations the environmental chloride load is a lot heavier on the lee side than on the windward side, but the effect is of most importance for the parts of the superstructure closest to the sea level.

Measurements of concrete cover have been performed both in the Ringtek survey (ref. 1) and in connection with the trial repair in 1993 (ref. 3). The recorded concrete cover at the superstructure varies from 22 mm - 35 mm. Especially, the use of fixing bars within the cover zone has lead to the development of deterioration. The most serious areas of deterioration are on the north side of the box girder close to the sea level. Hence, the damage recorded at the superstructure of the bridge is consistent with the recorded chloride load.

4.5 Reliability of the results from the extended condition survey

The results from the 40 control measurements performed by Rescon (ref. 2) using exactly the same concrete powder drilled out in 1992, were consistent with the results from Ringtek (ref. 1). The results showed an average deviation between the measurements performed by Ringtek (RCT-method) and Rescon (titration NS 3671) of ± 15 %.

The results from the Norut analyses in 1993 and 1994, using the potentiometric titration method, does also show very good correspondence with the results from the extended condition survey using the RCT method. Based on these results, the accuracy of the RCT-method is considered as good enough for chloride analyses in condition surveys.

5. CONCLUSIONS

After the discussion, the following conclusions can be drawn:

i. The height above the sea level is of major importance for the environmental chloride load exposed to the superstructure. The chloride load is up to 6,5 times lower when the superstructure rises from 8 m to 28 m above the sea level.

ii. The chloride load is a lot heavier on the lee side than on the windward side. The effect is of most importance for the parts of the superstructure closest to the sea level. At the height of 8 m above the sea level the chloride load is up to 8 times higher on the lee side than on the windward side.

iii. The recorded chloride load is consistent with the damage recorded at the superstructure of the bridge.

iv. The calculated diffusion coefficient (D) varies from 22 - 48 mm^2/year. The average is 35 mm^2/year with a standard deviation of 7,5 mm^2/year. This indicates uniform concrete quality in the structure.

v. The accuracy of the RCT-method is considered as good enough for chloride analyses in condition surveys.

vi. The use of 10 mm steps for powder sampling does not detect high concentrations of chlorides in thin layers of the concrete.

vii. The analysed chloride value closest to the surface must be treated with care in assessments after condition surveys. In calculations of D and C_s the value closest to the surface should be left out.

6. ACKNOWLEDGEMENT

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7. REFERENCES

All of the references are written in Norwegian.

1. Østvik J.M. og Normann D: "Gimsøystraumen bru, Prøvetaking 1992", Rapport, Ringtek 21.01.93.

2. Norderup Michelson E og Tjugum G: "Sjekking av tidligere Cl-prøver", Notat, OFU Gimsøystraumen bru, Rescon 15.09.93.

3. Larsen C.K.: "Resultater fra forhåndskartleggingen, feltundersøkelser og laboratorieanalyser, Prøvereparasjon I, 1993", Rapport nr. A-94-015, OFU Gimsøystraumen bru 27.05.94.

4. Hognestad S., Kristiansen B. og Myrdal R.: "Sluttrapport Prøvereparasjon II, 1994", Rapport nr. A-94-017, OFU Gimsøystraumen bru 01.12.94.