CHLORIDE PENETRATION IN MARINE ENVIRONMENT

Part 2: Results from field tests on coastal bridges in Norway

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Abstract: At Gimsøystraumen and Giske bridges a total of 32 concrete slabs are instaled. The slabs are locaeted at different levels above seawater on the north, south, east and west side of the pillars and superstructure. After 46 weeks of exposure chloride contents at increasing depths and in-situ diffusion coeffisients have been calculated.

The mean value of the achieved in-situ coeffisients is 5.17 x 10^{-12} m^2/s. Comparable laboratory results, based on concrete cubes with sawed surface exposed for 3 and 6 weeks in salt spray chamber and bulk diffusion tests, show values is about four times higher.

The in-situ chloride profiles clearly show variations in chloride penetration depending on the location. Highest amounts are typically found on the northern side closest to sea water. This variation shows that the environmental effect has to be accounted for when estimating future chloride penetration.

Keywords: Concrete, chloride penetration, environmental effect

1. INTRODUCTION

Reinforcement corrosion in marine environment is induced primarily by ingress of chlorides into the concrete from seawater or by airborne chlorides. Much work has been done during the past years to map the extent of this problem, and it has been demonstrated by several researchers that the main transport mechanism is diffusion. However, while the diffusion model fits quite well for concrete tested in the laboratory this is not necessary the case for concrete exposed in a natural environment. The Bridge departments examination of several coastal bridges in 1991/92 showed clearly that laboratory results gave very conservative values with respect to diffusion coeffisients. The report conluded that diffusion coeffisients based on laboratory results alone was not valid for prediction of in-situ chloride penetration.

This paper present results from a field investigation in Nordland and Møre og Romsdal counties. The field test is conducted as a part of the authers project which focus on chloride penetration and the effect of variations in environmental exposure.

Further, the field test is part of a program where the aim is to evaluate the use of laboratory results, with respect to in-situ chloride penetration. Laboratory studies are performed at the Road Laboratory in Oslo, where salt spray chamber and bulk diffusion methods are used. The main goal in the project is to develop a "prediction model" for chloride penetration that takes into account the environmental effect.

2. EXPERIMENTAL

2.1 Material and specimen preparation

For laboratory and field investigations concrete cubes (100x100x100 mm) and slabs (50x300x500 mm) were cast . Reference concrete group 1 with w/c ratio 0.6, according to Norwegian Standard 3099, was used for specimens in the field. In addition a typical concrete used by the road authorities, with w/c ratio 0.4 and 5 % silica fume was used for supplementary laboratory tests. The mix designs are shown in table 1.

Table 1. Mix designs

		w/c ratio 0.6	w/c ratio 0.4
Cement OPC	(kg/m^3)	350	390
Water	(kg/m^3)	210	167
Fine Aggregate 0-8 mm	(kg/m^3)	980	940
Coarse Aggregate 8-16 mm	(kg/m^3)	230	870
Coarse Agg. crushed 8-16 mm	(kg/m^3)	535	-
Silicafume	(%)		5
Plasticizer	(L/m^3)	-	3
Superplasticizer	(L/m^3)	-	3.5
AEA	(L/m^3)	-	0,15
Mean strength	(MPa)	43.9	69.5

Both slabs and cubes were cast and water cured for more than 90 days in the laboratory before testing and instalation. The slabs are fastened to the bridgestructure with expansion bolts. Between the slabs and original structure a thin layer (10-15 mm) of mortar was used to separate old and new concrete. To prevent any leakage the transition sone was sealed with silicon and coated with epoxy after instalation.

2.2 Exposure

At Gimsøystraumen bridge in the northern part of Norway. 16 slabs were instaled in october 1993. On the superstructure (north, south and lower edge) 6 slabs, 3 slabs on pillar no. 2 at a level 1.25 meter above the foundation (north, south and west) and 7 slabs on pillar no. 3 at a level 1.25 m and 2.75 m (north, south and east). The foundation top is 2.5 m above mean sea water level. In addition to the slabs mounted on the bridge, 3 slabs were submerged at the bottom of the sea close to the bridge. After 46 weeks of exposure a 160 mm sections were cut from the upper part of the slabs. The sections were prepared and grinded in the laboratory.

The same principle was followed at Giske bridge at the western coast of Norway. The sections cut out from these slabs have been prepared and grinded, but the final result from the chloride analyses has not yet been prepared.

3. RESULTS AND DISCUSSION

In this chapter preliminary results from the field test is presented. As allready mentioned only results from Gimsøystraumen are completely analysed, but some results from Giske show the same trend and indicate the same relationship with respect to environmental effect.

All specimens has been grinded in millimeter levels parallell to the exposed surface. For each level the amount of total chloride concentration has been analysed. The spectrofotometric technique has been used. Based on measured penetration depth effective in-situ diffusion coeffisients has been calculated according to the following solution of Ficks's 2. law:

$$C(x,t) = C_s - (C_s - C_i)\,\mathrm{erf}(x/2(D_{eff}\,t)^{-1/2})$$

$C(x,t)$	= Amount of chlorides in depth x after time t
C_s	= Calculated chloride consentration at the surface
C_i	= Initial chloride consentration in the concrete
D_{eff}	= Effective diffusion coeffisient
x	= Distance from exposed surface
t	= Time of exposure
erf	= Error function $\mathrm{erf}(x) = 1-(1+a_1x+a_2x^2+a_3x^3+a_4x^4)^{-4}$
	$a_1 = 0{,}278393$
	$a_2 = 0{,}230389$
	$a_3 = 0{,}000972$
	$a_4 = 0{,}078108$

The values D_{eff} and C_s are found by nonlinear regression analyses (least square principle) and curve fitting of Fick's 2. law. No points has been left out from the chloride profiles in these calculations, which is performed in Excel.

In table 2 data on calculated effictive in-situ diffusion coeffisients, D_{eff}, and surface concentration of chlorides, C_s, are given for the slabs exposed at Gimsøystraumen bridge. In the calculations adjustments are made for measured Cl-values lower than approximatly 0.016 % mass of concrete, due to limitations in the methode used. However, this is only done when it is obvious that the measured value represents limitations in the metode, but it implicates limitations for some of the calculations due to low chloride contents. Especially for the values representing the slabs instaled on the superstructure this seems to be the case.

Table 2. Calculated values for D_{eff} and C_s based on in-situ chloride profiles.

Location	In-situ D_{eff} (10^{-12} m^2/s)	C_s (% mass of concrete)	Penetration g/m^2
Pillar 2 north level 1.25	4,47	0,237	37,99
Pillar 2 south level 1.25	8,37	0,137	25,21
Pillar 2 west level 1.25	12,0	0,195	35,24
Pillar 3 north level 1.25	6,55	0,179	31,27
Pillar 3 west level 1.25	4,15	0,127	21,27
Pillar 3 east level 1.25	4,37	0,095	16,19
Pillar 3 north level 2.75	7,16	0,167	29,64
Pillar 3 south level 2.75	1,3	0,074	11,54
Pillar 3 east level 2.75	4,3	0,066	11,12
Box girder north R1	4,36	0,084	14,2
Box girder south R1	4,99	0.066	11,57
Box girder lower edge R1	(0,55)	0,057	9,26
Box girder north R4	3,92	0,055	9,2
Box girder south R4	-	-	0
Box girder lower edge R4	(0,04)	0,064	9,48
Submerged A	(6,81)	0,32	52,36
Submerged B	(15,2)	0,36	64,79

The values marked ( ) are not part of the calculated mean value

Figure 1 shows the measured chloridprofiles and illustrates even better the differences in exposure conditions.

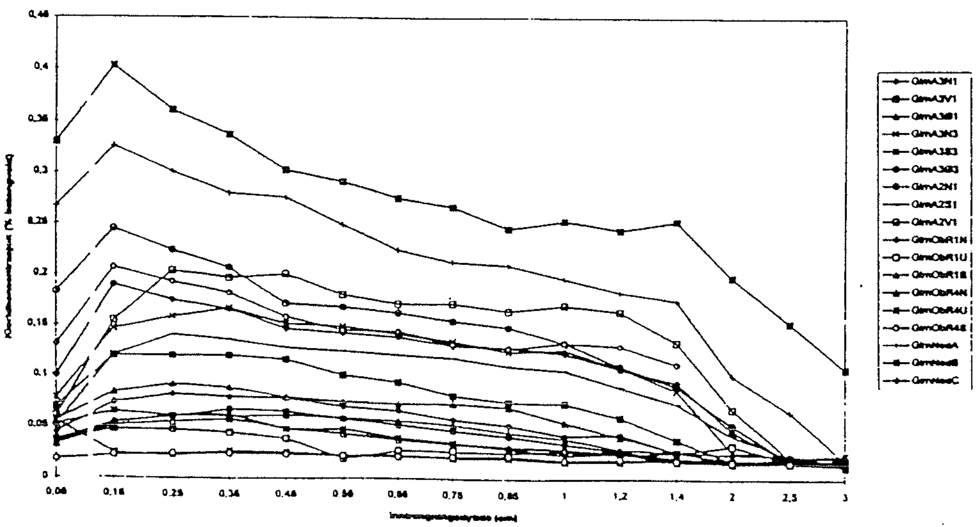

Figure 1. Measured in-situ chloride profiles, % mass of concrete vs. depth (cm)

In table 3 calculated laboratory diffusion coeffisients, D_{lab}, and surface concentration of chlorides, $C_{s\text{-}lab}$, are shown. The test specimens are concrete cubes with sawed exposure surface. All results shown in table 3 are based on 0.6-concrete, and the cubes were cast together with the slabs exposed in the field.

Table 3. Calculated values for D_{lab} and $C_{s\text{-}lab}$ based on measured chloridprofiles.

Methode	**D_{lat} (10^{-12} m^2/s)**	**$C_{s\text{-}lab}$ (% mass of concrete)**	**Penetration g/m^2**
Bulk 16.5 % NaCl-solution	14,9	1,173	138,69
(42 days exposure)	18,4	1,044	111,19
Bulk 16.5 % NaCl-solution	17,5	0,943	109,04
(21 days exposure)	16,0	1,044	115,83
Bulk 3.0 % NaCl-solution	28,9	0,411	51,84
(21 days exposure)	24,3	0,42	53,84
Salt spray chamber 3.0 %	25,4	0,516	68,5
(42 days exposure)	30,9	0.441	62,05
Salt spray chamber 3.0 %	26,5	0,365	48,13
(21 days exposure)[1)]	22,2	0,403	50.22

1) 1 hour spraying and 7 hours drying

The mean value of the achieved in-situ coeffisients is 5.17 x 10^{-12} m^2/s. Compared with laboratory results the value is about four times higher after relatively short time. This illustrates to some extent the effect of laboratory results versus in-situ results.

4. CONCLUDING REMARKS

Table 2 shows a distinct variation in amount of chlorides penetrated through the concrete surface. This variation due to the environment has to be accounted for in a prediction model. An approach might be to use the amount of penetrated chlorides at each location, and combine this with potensial diffusivity and penetration of the same concrete based on laboratory results. A key factor in the model will be the value C_s. The value should be determined as the maximum potential level for the concrete investigated, based on a metode that represent a realistic exposure condition at the construction. This will represent a system that accounts for different chloride contents depending on the severity of the exposure.

The approach will be examined further within this project, but so far no work has been done in this respect. Which laboratory methode to use for evaluation of chloride penetration is to some extent studied in the project. Tests are performed with salt spray chamber and bulk diffusion methods (3 % and 16.5 % NaCl-solutions). Migration tests (12 V) will, depending on resources, be conducted.