EXPERIENCE FROM NINE YEARS OF EXPOSURE OF CONCRETE IN THE TIDAL/SPLASH ZONE

Olav Gautefall
M.Sc., Research Engineer
SINTEF Structures and Concrete
N-7034 Trondheim, Norway

Tor Arne Hammer
M.Sc., Senior Research Engineer
SINTEF Structures and Concrete
N-7034 Trondheim, Norway

Jan Havdahl
Research Engineer
SINTEF Structures and Concrete
N-7034 Trondheim, Norway

Øystein Vennesland
M.Sc., Senior Research Engineer
SINTEF Structures and Concrete
N-7034 Trondheim, Norway

ABSTRACT

Ten concrete blocks (1.5x1.5x0.5 m) have been exposed in the tidal/splash zone in the Trondheim fjord since 1983. Concrete parameters were concrete strength grade (C35 and C65 according to Norwegian Standard) and content of microsilica (0, 10 and 20 % as cement replacement).

After 9 years of exposure an evaluation of the corrosion condition of the reinforcement has been made based on visual inspection, surface potentials and chloride profile.

Key words: Concrete quality, water-to-cement ratio, microsilica, marine environment, chloride ingress, reinforcement corrosion

1 INTRODUCTION

Ten concrete blocks (1.5x1.5x0.5 m) of five different concrete qualities have been exposed in the tidal/splash zone in the Trondheim fjord since 1983. The blocks were cast in the fall 1982 and exposed to the marine environment 5 month after casting. Concrete variables were concrete strength grade (C35 and C65 according to Norwegian Standard) and content of microsilica (MS) of 0, 10 and 20 % of cement weight /1/.

After 2, 5 and 9 years of exposure, surveys have been made /2-4/. This paper evaluates the degree and effect of chloride ingress into the concrete blocks during 9 years of exposure.

2 MATERIAL PROPERTIES

The composition of the concretes is given in Table 1. The cement used was Rapid Portland Cement RP38 from Norcem A/S. The microsilica (MS) used was from Ila-Lilleby and added as slurry. A plasticiser (Rescon P) was used. Concrete properties are listed in Table 2.

Table 1 Concrete composition

Materials (kg/m^3)	Mix design				
	C35 0% MS	C35 10% MS	C35 20% MS	C65 10% MS	C65 20% MS
Cement (RP38)	370	275	234	457	394
Water	198	192	194	204	218
Microsilica (MS)	0	27.5	46.8	45.7	78.8
Aggregates	1790	1872	1879	1671	1654
Rescon P	2.0	2.8	4.7	8.0	7.9

Table 2 Concrete properties

Concrete mix	W/c	W/(c+s)	Air (%)	$f_{30\ d\ cylinder}$ (MPa)
C35, 0% MS	0.54	0.54	2.6	39.1
C35, 10% MS	0.70	0.63	2.0	40.5
C35, 20% MS	0.83	0.69	2.0	38.3
C65, 10% MS	0.45	0.41	1.2	62.1
C65, 20% MS	0.55	0.46	1.3	56.4

3 SPECIMEN DESIGN AND CASTING

From each mix (see Table 2) 2 blocks of size 1.5x1.5x0.5 m were cast outdoor in the fall 1982. The weather was good without rain and the temperature at daytime was about 15-18 °C and at night about 2-5 °C. The formworks were of 6 mm thick plywood supported by a wooden framework. The concretes were vibrated in the forms.

In one of the half sections of each concrete block two 8 mm wire fabrics (150 mm centre distance between the wires, type K335) of size 1200x450 mm were embedded face to face, one with 30 mm and the other with 50 mm concrete cover. The distance from the net to the corresponding top, bottom or nearest edge of the block was 150 mm.

4 EXPOSURE CONDITIONS

The blocks were exposed in the Trondheim Fjord at the end of March 1983, i.e. 5 months after casting. The blocks are placed in the tidal/splash zone, the front side with the 50 mm concrete cover facing the seaside. At low tide the blocks are exposed to air and at high tide the blocks are submerged. The normal difference between low and high tide water at this site in the Trondheim Fjord is 1.83 m.

5 TEST PROGRAM

5.1 Compressive strength

Compressive strength was measured on two Ø100x100 mm cores drilled from each of the C65 concrete blocks according to NS 3670 and 3668.

5.2 Visual inspection

Marine growth was removed and the blocks were inspected for possible damages. Cores from the C35 concretes were split and examined for any corrosion of the steels within the cores.

5.3 Surface potential

The measurements were made at the similar 8 rebar nodes on each side of the 10 blocks and performed according to ASTM C876-87 using a reference electrode of the copper/coppersulphate ($Cu/CuSO_4$) type.

5.4 Chloride ingress

Samples of concrete powder were collected by drilling in situ, using a Ø16 mm drill. Samples were taken from both top and bottom of one block of each type of concrete at both sides at levels 0-12, 12-24, 24-36, 36-48 and 48-60 mm from the surface. The Quantab-method was used to determine the total chloride content /5/. The same procedure was used in the investigation after 5 years of exposure. In the investigation after 2 years of exposure the chloride ingress was determined by crushing and analysing of cut sections from drilled concrete cores. The total chloride content was determined by the use of an ion selective electrode.

6 RESULTS AND DISCUSSION

6.1 Compressive strength development

The compressive strength development of the C65 concretes is given in Table 3.

Table 3 Compressive strength development of C65 concretes from the age of 30 days until 9 years.

Weight % of MS	Cylinder compressive strength (MPa)		
	30 days [1]	5 years [2]	9 years [2]
10 20	62.1 56.4	73.4 69.7	72.2 71.2

1) Cast cylinders, average of 3 specimens
2) Drilled cores, average of 4 specimens

As shown in Table 3 there is no significant change in compressive strength from 5 to 9 years of exposure.

6.2 Visual inspection

The surfaces of the concrete blocks revealed no rust stain. Few signs of ongoing corrosion of the embedded steel were observed, though minor rust stains could be seen. It was not possible to decide whether these stains were old surface rust from the time of casting or fresh rust due to corrosion of the embedded steel.

6.3 Surface potentials

The results from the measurements are given in Table 4. Each value represents an average of 8 readings on each side of the 10 blocks.

Table 4 Average measured surface potentials vs. $Cu/CuSO_4$ electrode (two blocks of each concrete mix)

Concrete mix	Seaside 50 mm cover		Landside 30 mm cover	
C35, 0% MS	-40	-256	-215	-332
C35, 10% MS	-161	-100	-265	-278
C35, 20% MS	-77	-330	-257	-353
C65, 10% MS	-52	-65	-273	-234
C65, 20% MS	-56	-249	-82	-346

Evaluation of the state of corrosion from surface potential measurements are often done with reference to the empirically threshold values listed in Table 5.

Table 5 Evaluation of risk of corrosion according to ASTM C876-87

Potential, E (mV)	Possibility of corrosion
E > -200	10%
-200 > E > -350	50%
E < -350	90%

According to Table 4 most of the measured surface potentials indicated an uncertain state of corrosion. The potentials at the landside (30 mm concrete cover) were lower (i.e. more negative) than at the seaside (50 mm concrete cover). This does not necessarily imply that there is a different state of corrosion of embedded steel at the two sides. The higher concrete cover on the seaside will influence the potential in a more positive direction than the lower concrete cover on the landside. It is, therefore, very difficult to directly relate potential values measured by the applied method to a definite corrosion state in a situation like this.

It was not found any relationship between surface potentials and the observed degree of rust staining on the reinforcement.

6.4 Chloride ingress

The results from the chloride analyses of the various concretes are given in Fig 1-5. Results from all three investigations are presented. The diagrams represent average values of samples taken from bottom and top of both the seaside and the landside. There was not found any significant influence of the position of the sample. In Fig 6-8 the results are reviewed according to exposure time.

The chloride analyses made after 9 years of exposure indicate a rather high initial (i.e. before exposure) chloride content of the concretes compared to the other investigations. This might be due to the in situ sampling technique used. Traces of chloride rich material from the surface of the concrete blocks might have contaminated samples from the inner of the concrete.

As expected, the chloride content has increased during the 9 years of exposure. The "surface" chloride contents of the C65 concretes have reached about the same level as the C35 concretes with MS. But the chloride contents of the C65 concretes are decreasing more rapidly with the distance from the surface into the concrete.

In Table 6 is shown estimated chloride levels at the depth of the reinforcement, 50 mm on the seaside and 30 mm on the landside respectively.

Table 6 Chloride levels (wt% of cement) at the depth of reinforcement after 9 years exposure

Concrete mix	Seaside 50 mm cover	Landside 30 mm cover
C35, 0% MS	0.5	1.2
C35, 10% MS	0.7	1.4
C35, 20% MS	0.8	2.0
C65, 10% MS	0.3	0.4
C65, 20% MS	0.4	0.5

The chloride content at the depth level of the reinforcement is quite high, especially for the C35 concretes. (This has been the situation ever since 2 years of exposure for the C35 concretes with MS). Still, no damages have been observed. If corrosion has been initiated, the process is occurring at an insignificant low rate. This might be due to the high electric resistivity caused by the MS. Another explanation according to Byfors /6/ is a possible increase of the chloride binding capacity (i.e. decrease in content of free chlorides) with the addition of MS. This is however a controversial point since Page & Vennesland /7/ and Arya et al /8/ have found an opposite effect of MS.

According to Fig 6-8 and Table 3 there is a distinct increase of the chloride ingress with increasing water-to-(cement+silica) ratios.

The influence of the MS content is not apparent. However, the results indicate lower chloride ingress by use of MS by comparing the C35 concretes without MS and C65 with 20% MS, which have approximately the same water-to-cement ratio (see Table 2). Despite high water-to-cement ratios (0.70 and 0.83) of the C35 concretes with MS, the degree of chloride ingress are of the same level as the C35 concrete without MS (w/c = 0.54).

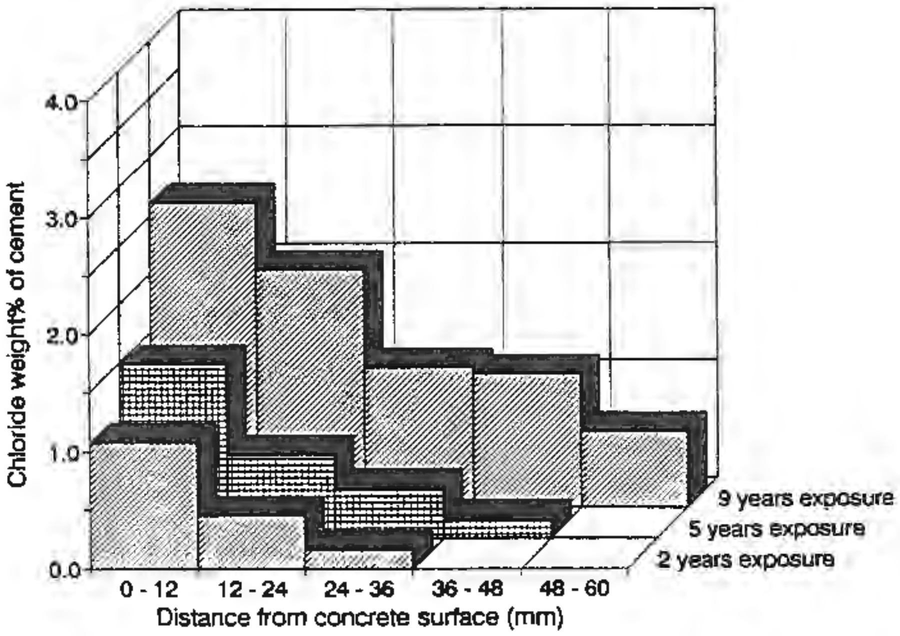

Fig 1 Average chloride profiles of C35 concrete without MS

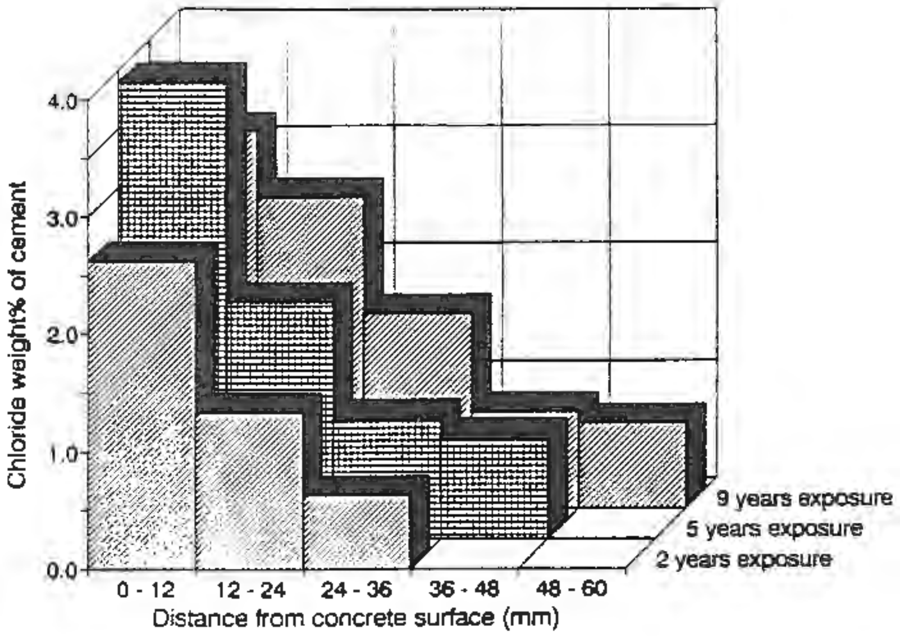

Fig 2 Average chloride profiles of C35 concrete with 10% MS

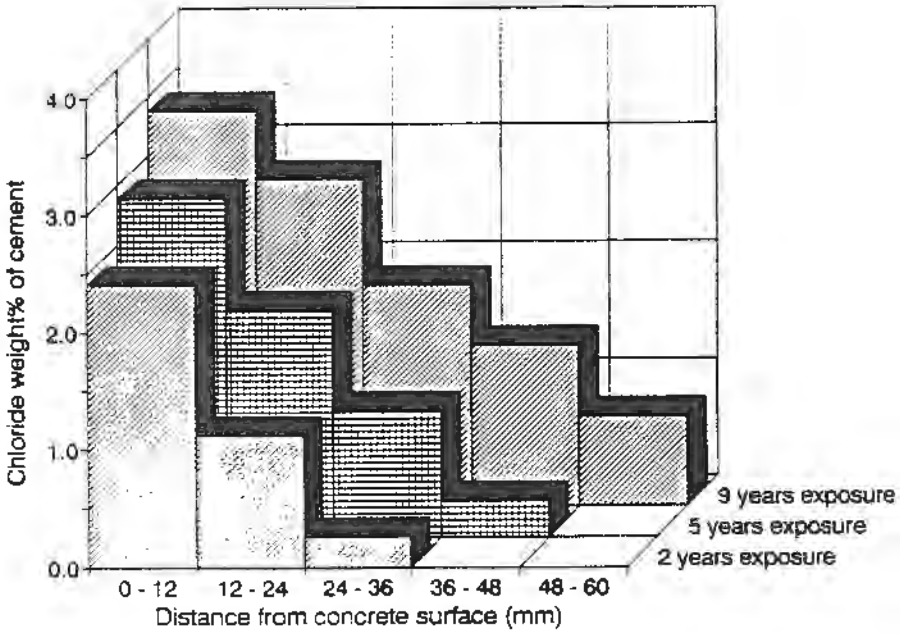

Fig 3 Average chloride profiles of C35 concrete with 20% MS

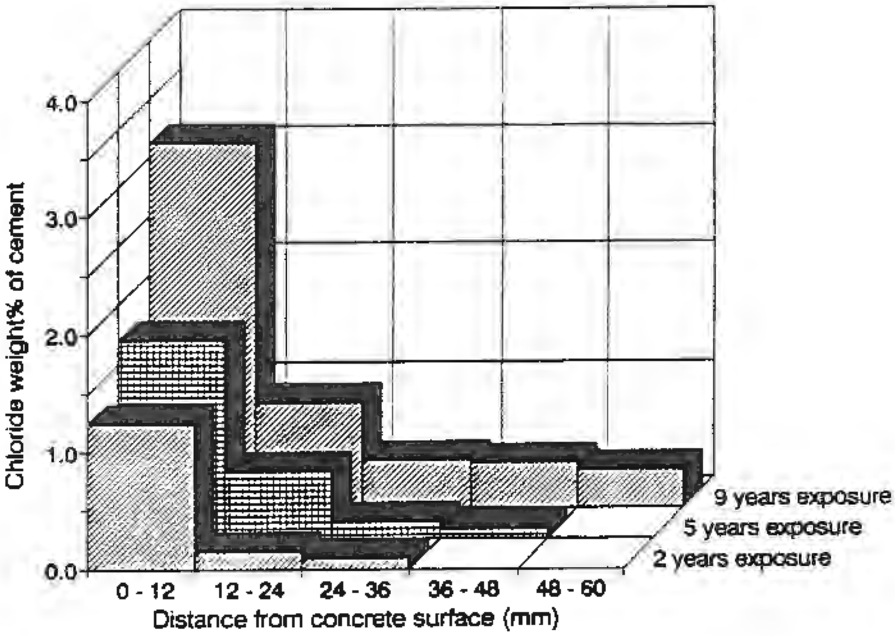

Fig 4 Average chloride profiles of C65 concrete with 10% MS

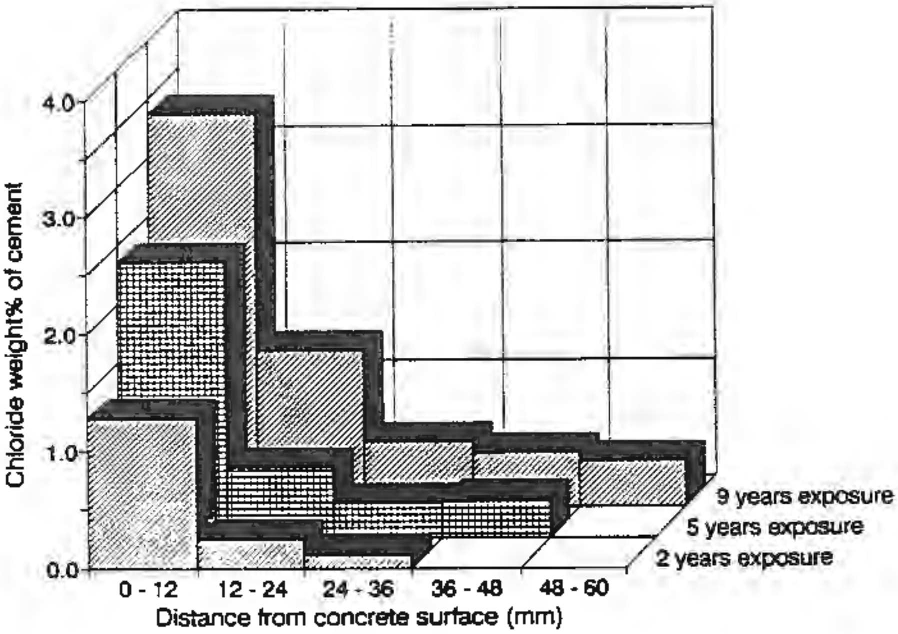

Fig 5 Average chloride profiles of C65 concrete with 20% MS

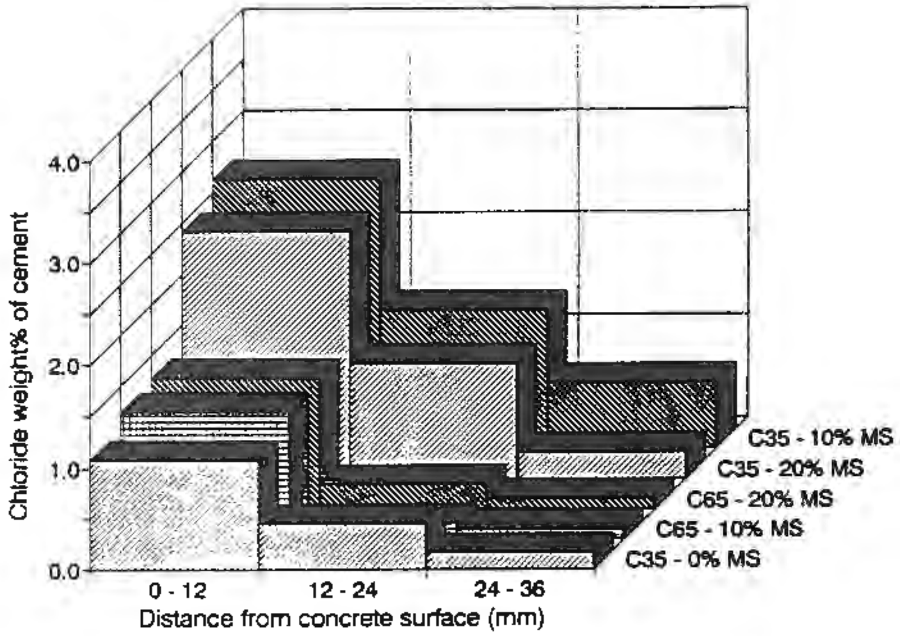

Fig 6 Average chloride profiles of concretes after 2 years of exposure

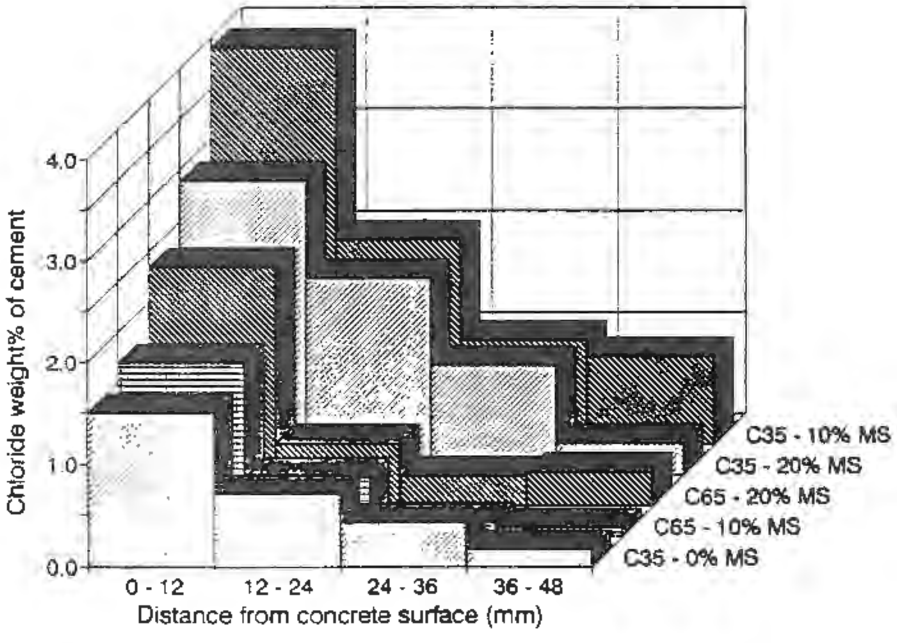

Fig 7 Average chloride profiles after 5 years of exposure

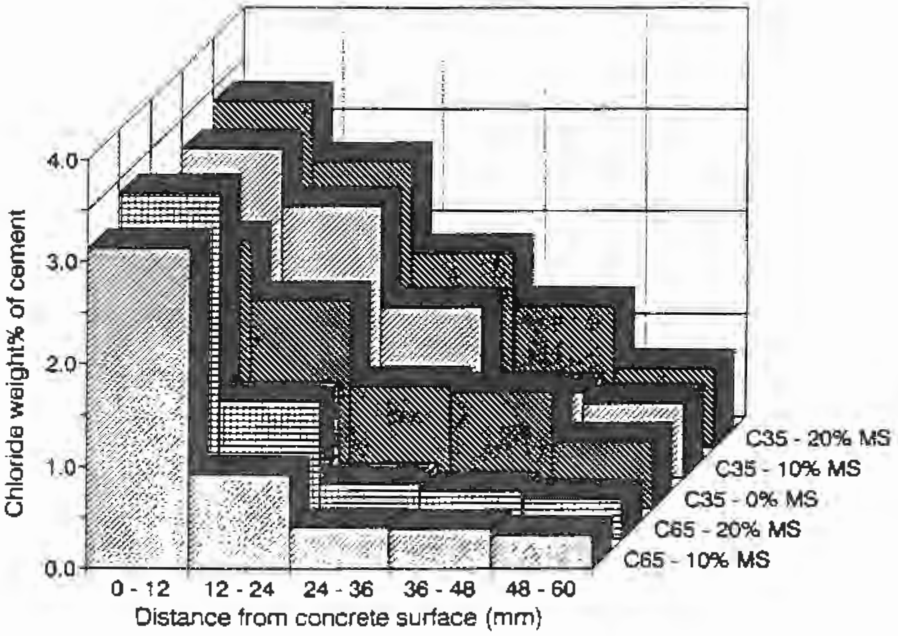

Fig 8 Average chloride profiles after 9 years of exposure

7 CONCLUSIONS

Concrete blocks of 5 different material qualities have been exposed to sea water in the tidal zone since 1983. From this study after 9 years of exposure the following conclusions can be made:

1 No damages due to reinforcement corrosion have been observed for any of the concretes. Indications of reinforcement corrosion have been observed but these indications were not unambiguous despite high chloride contents at reinforcement level.

2 The chloride content at reinforcement level and hence the risk of corrosion has increased from 5 to 9 years for all concrete qualities.

3 There is a distinct relation between the water-to-(cement+silica) ratio and chloride ingress in that concretes with ratios less than 0.41-0.46 are highly more resistant against chloride ingress than concretes with ratios 0.54-0.69.

4 The influence of microsilica on the chloride ingress is not apparent. However, the addition of microsilica seems to postpone the initiation phase despite a very high chloride ingress.

5 There has not been any significant change in compressive strength from 5 to 9 years of exposure.

8 ACKNOWLEDGEMENT

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