Fosroc

Testing Galvashield XP anodes in repairs

Foundation walls in salt storage, Hornum and beam in oil quay, Kalundborg

September 2000

COWI

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Bilagsfortegnelse

1 Introduction

1.1 Salt storage

1.1.1 Background

In connection with a special inspection of the salt storage in Hornum in June 1999 a large extent of reinforcement corrosion was observed. The salt storage was constructed with a reinforced concrete foundation with a supportive wooden roof structure. The structure measures 18 x 10 m with a gate in the East Side of the building. The foundation structure is 1 m in height (above ground level) and 30 cm wide.

The storage of salt has caused chlorides to penetrate the concrete from the internal side of the foundation walls causing corrosion of the reinforcement on the internal as well as the external side of the foundation walls. A gap between the foundation walls and the wood structure has allowed humidity from the exterior to accelerate the rate of deterioration especially near the top of the foundation.

Initial chloride analysis in 1999 showed that the chloride content in the concrete in general was high (up to 0.91 % Cl^- by weight of concrete, see appendix 9). Chloride initiated corrosion onsets by experience when the chloride content by weight of concrete exceeds 0.05-0.10 % Cl^-. The chloride content was measured higher on the upper part of the foundation wall than closer to ground level and higher on the internal side of the wall than on the external side of the wall.

Among other a petrographic analysis of the concrete was carried out in connection with the special inspection. The analysis revealed that the concrete was cast using a Portland cement with a water/cement ratio on 0.45-0.50 with some fully reacted alkali silica aggregate grains (i.e. no further reactions are anticipated). Precipitation's showed that the concrete had been exposed to humidity especially in the area near the surface (0-15 mm below the surface).

1.1.2 Repair Strategy

The following repair strategies were considered: Replacement of the entire foundation wall or a partial replacement of the foundation wall. The partial replacement strategy was chosen despite that the lifetime of such a repair is limited. The reason being that the remaining concrete still contains a considerable amount of chloride which can cause new corrosion especially in the construction joint between parent concrete and new concrete. As supplementary protection sacrificial anodes, Galvashield XP anodes from Fosroc were installed in the repair concrete towards the construction joint; one area is left as reference without anodes.

1.2 Beam in oil quay, Kalundborg

1.2.1 Background

Statoil has an oil quay in Kalundborg, which is the life nerve of the oil refinery. The quay was constructed in 1960-61. Annually the quay is called by 800 to 900 ships. The quay structure consists of caissons, rammed columns; pre-cast beams and deck elements as well as in-situ cast deck elements. A total of 225 columns support the quay.

Due to the aggressive marine environment, chloride has penetrated the concrete and caused corrosion of the reinforcement. In 1997 the deterioration had reached a stage where repair was required.

1.2.2 Repair strategy

As the quay structure is difficult to access and as there is an explosion hazard, special precautions are to be taken in relation to demolition works. Further it is inappropriate to patch repair with short intervals due to the special circumstances.

For the columns, decks and beams, the optimum repair strategy is cathodic protection using impressed current. However due to the explosion hazard, this is not a feasible solution. For the columns a combination of sacrificial anodes (Aluminium) and inhibitors (cast into repair material and applied to the surface) was selected. This part of the repair works is presented in ref. 3.

As a trial installation sacrificial Galvashield XP anodes are installed and tested on one beam. The anode installation serves as an alternative to the inhibitor solution for the structural parts above water level.

1.3 Objective

The objective of the Galvashield sacrificial anode installation both in the foundation wall of the salt storage in Hornum and in the beam in the oil quay in Kalundborg is:

- to evaluate if these anodes can effectively protect the reinforcement against corrosion and prolong the lifetime of the repair works carried out.

Two different aspects have been dealt with. On one hand the current output from the anodes has been measured as a basis for estimating the lifetime of the anodes and, on the other hand, the ability of the anodes to protect the reinforcement has been evaluated by means of potential measurements, chloride analysis and resistivity measurements.

2 The Galvashield XP anode

2.1 Cathodic protection - principle

The principle of cathodic protection is to apply an external source of current via an anode to the reinforcement, and thereby forcing the reinforcement to act as cathode, where it electrochemically can not corrode.

Cathodic protection of atmospherically exposed reinforced concrete structures using impressed current systems is today used worldwide. When designed and applied in a reliable way, the systems have been found to be able to protect the reinforcement against corrosion. The source of current with impressed current cathodic protection systems is an external power supply applied through rectifiers.

For concrete structures permanently submerged, i.e. marine structures, sacrificial anodes can be used to protect the reinforcement. The current source for protection when using sacrificial anodes is the anode itself, which sacrifices itself (and is thus consumed) as it is a less noble metal than the steel reinforcement. The driving voltage of sacrificial anodes, i.e. Zinc or Aluminium, is much smaller than the corresponding systems using impressed current. However, water is an efficient current distributor and a cathodic protection system using sacrificial anodes for submerged structures is known to be able to protect reinforcement from corrosion.

2.2 Galvashield XP anode - principle

The Galvahield XP anode is a sacrificial anode, consisting of a zinc core cast in a specially formulated mortar. Wires from the zinc core though the mortar is used to connect the anode to the reinforcement.

The Galvashield XP anode is designed especially to deal with the problem of new corrosion occurring in the parent concrete next to the construction joint between new and parent concrete. The principle of the protection is as described above with sacrificial anodes, that the zinc core sacrifices itself and thus protects the reinforcement next to the construction joint.

The Galvashield XP anode is installed approximately 1 m apart in the structure to be protected and as close to the parent concrete as possible. Fosroc provides detailed design calculations on the distance to use between the anodes, based on the reinforcement density in the area to be protected.

Fosroc estimates the lifetime of the Galvashield XP anode to be approximately 10 years, and the anode is therefore assumed to be able to protect the reinforcement next to the construction joint for a corresponding period of time.

The following treatment stages is recommended by Fosroc in connection with the Galvashield XP anode installation:

- Initial inspection and survey. Determine the extent of affected concrete
- Excavation. Break out damaged area and expose corroded steel
- Preparation. Clean, repair or replace steel as necessary
- Installation. Position units at edge of repair and test for electrical continuity
- Priming. Apply Nitoprime Zincrich primer to steel
- Reinstatement
- Apply compatible Fosroc repair mortar

Investigations carried out by Fosroc implies that the anodes can provide a current output above 60 µA, corresponding to a current density around the reinforcement on 1-2 mA/m^2, ref. 1. The current output was according to ref. 4 measured using an ammeter over the internal resistance in the instrument and the real current output is therefore likely higher when measured using a zero-resistance meter. A current density of 1-2 mA/m^2 is considered sufficient for a preventive cathodic protection installation, where the chloride content around the reinforcement is modest, ref. 1. According to ref. 2, a reasonably competent attempt should be made to remove most of the chloride bearing material prior to patching.

3 Conclusion and recommendations

3.1 Conclusion

3.1.1 Salt storage, Hornum

Demolishing was not carried out until non-corroding reinforcement was reached. This would have been too costly.

The results in the salt storage walls show that the Galvashield anodes can provide current densities up to approx. 1.1 mA/m^2 steel surface (measured during summertime at 27 degree C).

The chloride content at the reinforcement level near the construction joint area exceeds 0.24 % Cl^- by weight of concrete. Based on half cell readings the reinforcement is expected to be corroding, and the chloride content is most likely too high for the anodes to protect.

This corresponds well with the potential measurements, that show no or only a limited effect of the anodes installed in the foundation walls.

3.1.2 Beam in oil quay, Kalundborg

The results in the beam show that the Galvashield anodes can provide current densities up to approx. 0.4 mA/m^2 steel surface (measured at an ambient temperature at 18 degree C).

Assuming a current output from the anodes at 9 degree C (corresponding to the yearly average temperature in Denmark) on 200 μA each for the Kalundborg case (corresponding to approx. 0.3 mA/m^2 steel surface), the lifetime of the anode will be approx. 35-45 years. The lifetime with a current output on 1 mA/m^2 yields approx. 12 years.

The potential measurements indicate that the anode installation is able to protect the reinforcement to a satisfactory level, i.e. extending the service life of the repairs carried out. Potential measurements carried out indicate that there is only limited risk of ongoing corrosion in the existing, not repaired area of the beam, and the installation is therefore considered preventive. The chloride content in the anode area is close to the threshold value for corrosion (0.02-0.09 Cl^- by weight of concrete 0-40 mm below surface).

Resistivity measurements show that the resistivity of the repair material (Renderoc LA) is suitable for a cathodic protection installation and is approximately half the resistance of the parent concrete. This will be beneficial for an adequate current distribution.

3.1.3 General

The measurements indicate that the lifetime of the anode exceeds 10 years under the conditions tested at both test locations i.e. the Beam in oil quay in Kalundborg and the foundation walls in Hornum.

The measurements indicate that the Galvashield anode is able to protect the reinforcement where the anode is installed and used as a preventive installation only, with a low current requirement.

A financial evaluation of an anode installation compared to a traditional repair of a motorway bridge column is in favour of the anode installation.

3.2 Recommendations

We note that there is no recommended limit to the chloride content in the reinforcement depth in the parent concrete. It should be investigated if demolishing to non-corroding reinforcement is adequate, or an upper limit should be set on the chloride content in the parent concrete.

The reason for this is that the higher the chloride content the higher is the requirement to min. depolarisation value over 4 or 24 hours in order to ensure an adequate protection.

Further, we note that there is no recommendation regarding the resistivity of the repair material. As a high resistivity mortar/concrete will limit the current output from the anode, it could be relevant to recommend a comparatively low resistance repair materials (i.e. Renderoc LA) when used in combination with the Galvashield anode.

As the current distribution from the repair zone to the parent concrete is important the cathodic protection is more efficient the lower the resistivity of the parent concrete is. Also, according to Fosroc recommendations, the anodes should be placed as close to the repair zone as possible.

Finally, as the lifetime of the anode is closely related to the ambient temperature it could be considered to limit the expected lifetime when used in areas with high temperature (Middle East i.e.).

4 Repair works

4.1 Salt storage, Hornum

A partial repair strategy was selected, where the upper approx. 30 cm of the foundation walls was demolished. The demolished areas were sandblasted and the surface treatment on the internal side of the walls was removed as well. The horizontal reinforcement bars was removed, the stirrups were kept.

New shuttering was made and the existing reinforcement was supplemented with new reinforcement bars, thus extending the height of the wall to 1.2 (internal side) and 1.3 m (external side).

Galvashield XP anodes were installed, one per running m, alternating between the internal and external reinforcement. In the reference area, no anodes were installed. The steel to concrete surface area ratio in the non repaired areas is 0.22 approx., and 0.35 approx. in the repaired area. According to Fosroc the radius of cover of the Galvashield XP anode is approximately 0.55 m for the repaired area. This corresponds to one anode each 1.1 m, however as the anode is fixed to the reinforcement spaced each 0.20 m one anode per running m was installed.

The foundation walls were reestablished using concrete for aggressive environment and with a required compressive strength exceeding 30 MN/m². A surface treatment using Nitocote EP403 (2 component epoxy-based, chemical resistant and abrasion-resistant) treatment was applied on the internal side of the foundation wall and on the upper side of the wall.

Between the first and second measurement campaign (between October 1999 and March 2000) three of the external walls had been painted, among other the South wall, where the test areas are located.

In Appendix 1, the layout of the test areas can be seen.

In Appendix 2, photos from the installation and repair works can be seen.

4.2 Beam in oil quay, Kalundborg

The concrete on the lowest 0.15 m of the beam was demolished. Three anodes were installed in the beam each 0.70 m apart. The steel to concrete surface area ratio in the repaired area is 0.66 approximately (and 0.5 approx. in the existing area). According to Fosroc the radius of cover of the Galvashield XP anode is approximately 0.39 m for the repaired area. This corresponds to one anode each 0.8 m. The anodes were installed 0.7 m apart.

Nitoprime Zincrich was applied to the existing reinforcement. The beam was reestablished using repair mortar (Renderoc LA).

5 Test methods and test programme

5.1 Test methods

5.1.1 Chloride analysis

Chloride analysis is carried out according to DS 423.28, which for all practical purposes corresponds to BS 1881: Part 124.

5.1.2 Half cell potential measurements

Half cell potential measurements i.e. measuring the half cell potential difference between the reinforcement and a reference electrode have been carried out using both the embedded Manganoxide reference electrodes (ERE-20) and using an external Ag/AgCl-electrode.

The half cell potential has been measured with the anodes connected to the reinforcement, immediately after disconnecting the anodes (inst. off potential), 2, 4 and 24 hours after disconnection.

5.1.3 Current measurements

The current output from the anodes has been measured over a shunt by using a potentiostat. As the equilibrium current output is to be measured, the current have been measured before anodes were disconnected from the reinforcement. Disconnecting and connection over the potentiostat has been carried out as fast as practically possible (less than 2 sec). Where the current has been measured after disconnection, the anode and reinforcement connection was left to stabilise for min. ½ hour.

5.1.4 Electrical resistance measurement

The electrical resistance between the anodes and the reinforcement as well as between the reference electrodes and the reinforcement was measured using an AC-technique.

In addition the resistance of the concrete has been measured on drilled cores using an AC-technique and the corresponding resistivity have been calculated using the core dimensions.

5.2 Test Programme

5.2.1 Laboratory tests

A concrete block measuring 30 x 30 x 30cm was cast with an upper and a lower reinforcement mesh and with a Galvashield XP anode in the centre. Connections from each of the reinforcement meshes and the anode were lead to the surface of the concrete, allowing for current measurement.

The objective of the test has been to establish the current output using a potentiostat related to the ambient temperature.

The current output was measured in the temperature range 5°C (refrigerator) to approx. 40°C (oven) in both dry and wet condition (water applied up to approx. 4 hours before measurement for the wet condition testing).

5.2.2 Salt storage, Hornum

Two test areas on the South side of the foundation wall were selected one area for installation of anodes and one area serving as reference area. The location of the test areas can be seen on the sketch in Appendix 1 and on the photos in Appendix 2. The anodes were placed between 0.25 and 0.35 m from the construction joint.

Two Ø 100 mm cores were drilled in the parent concrete as close to the repair zone as practical possible from the internal side of the wall in both the anode area and the reference area. The cores in the reference area were drilled 8.35 and 9.35 m from the East wall. The cores in the anode area were drilled 7.5 and 8.5 m from the West wall as shown in Appendix 1. Chloride analyses according to DS 423.28 were carried out on sawn and ground slices from the cores, 4 slices of 20 mm from the internal side and two slices from the external side of the wall. The cores were drilled from the internal side of the wall. When receiving the cores part of the external side was missing. The depth of the two slices from the external side of the wall has been estimated based on a total thickness of the wall on 0.30 m.

The anodes in the test area were electrical insulated from the reinforcement using a shrink hose. A cable was connected to each of the anodes allowing for external connection of the anodes to the reinforcement, and allowing for measurements of the current output from the anodes.

Four ERE-20 reference electrodes were installed in each of the two test areas, the anode test area and the reference area. Two of the electrodes were installed in the parent concrete (in drilled Ø25 mm holes) and two electrodes were installed in the repair material (tying the electrode to the reinforcement). In the repaired area the distance between the electrode and one of the anodes were 200 and 400 mm, respectively.

Reinforcement connections (three connections in each test area) were made.

All cables from the anode area as well as from the reference area were lead to separate junction boxes on the external side of the foundation wall.

5.2.3 Beam in oil quay, Kalundborg

The general layout of the anode installation is seen in Appendix 3. Both an area where anodes are located and an area without anodes have been tested.

On the selected beam the three anodes were electrical insulated from the reinforcement using a shrink hose. A cable was connected to each of the anodes allowing for external connection of the anodes to the reinforcement, and allowing for measurements of the current output from the anodes.

At the location of the drilled in reference electrodes the concrete dust was collected and chloride analysis carried out using DS 423.28. The depth of the hole is approx. 40 mm.

Two cores were drilled from the reference area. One core was drilled from the parent concrete and one core from the repair material, Renderoc LA. Unfortunately the weather did not allow for drilling cores in the anode area, as was originally planned. The cores were used for electrical resistivity measurements of the Renderoc material and the parent concrete as well as chloride measurements by sawing, crushing and analysing for chloride content.

Four ERE-20 reference electrodes were installed in the anode area, and two reference electrodes in the reference area. Two of the electrodes in the anode area and one electrode in the reference area were installed in the parent concrete, two of the electrodes in the anode area and one electrode in the reference area were installed in the repaired area. The horizontal distance between the anodes and the reference electrodes used is 0.10 and 0.25 m, respectively.

A reinforcement connection was installed in both the anode and the reference area.

All cables from the anode area installation were lead to a junction box located on the beam side. The cables from the reference area are located at the place of installation and terminated using a splicing sleeve.

6 Results

6.1 Laboratory tests

In appendix 1, a photo of the reinforcement and anode layout in the test block can be seen before casting of the concrete has taken place.

In figure 1, the current output from the anode can be seen for different temperature conditions, and with the concrete block in both wet and dry condition.

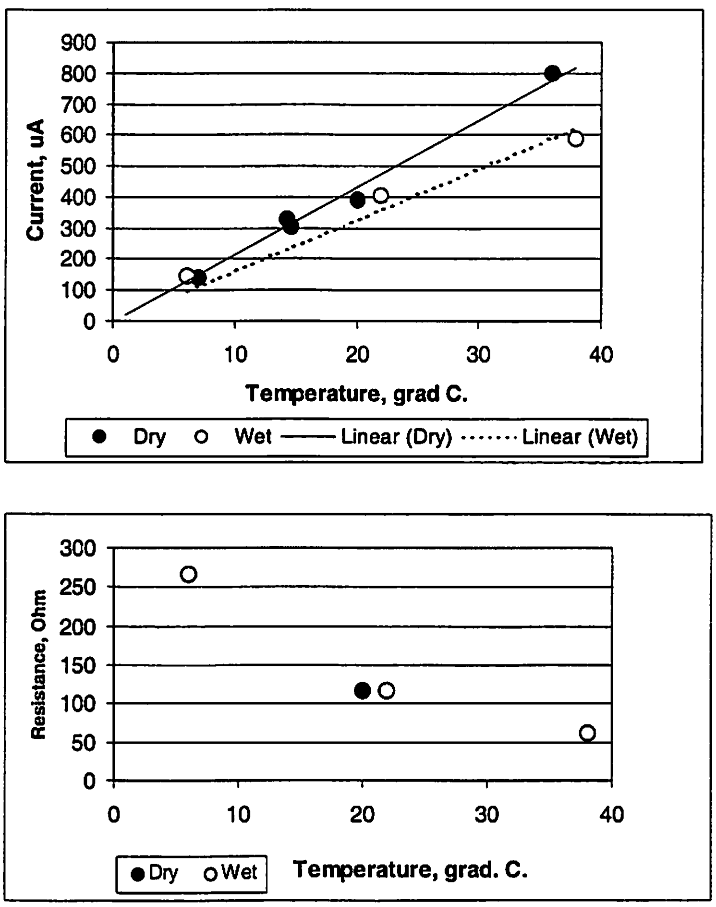


Figure 1. Current output (using a potentiostat) and AC-resistance from Galvashield Anode when test block is exposed to different temperatures and in both wet and dry condition.

It can be seen that the temperature has a pronounced effect on the current output from the anodes as well as on the resistance of the concrete.

Likewise, it appears that the humidity has only a slight effect on the current output from the anodes. It is a possibility that the anodes and reinforcement mesh was not humidified to a satisfactory level.

6.2 Salt storage, Hornum

6.2.1 Chloride analysis

The results of the chloride analyses carried out in connection with the anode installation can be seen in Table 1. The wall thickness is 0.30 m.

Core, Location	Depth below surface from the internal side of the wall mm	Chloride content, % Cl^- by weight of concrete
1, Reference area, towards East	0-20	0.37
	20-40	0.30
	40-60	0.32
	60-80	0.29
	220-240	0.07
	240-260	0.13
2, Reference area, towards West	0-20	0.11
	20-40	0.13
	40-60	0.10
	60-80	0.05
	220-240	0.07
	240-260	0.17
3, Anode area, towards East	0-20	0.31
	20-40	0.24
	40-60	0.13
	60-80	0.06
	240-260	0.15
	260-280	0.24
4, Anode area, towards West	0-20	0.36
	20-40	0.18
	40-60	0.12
	60-80	0.05
	200-220	0.00
	220-240	0.02

Table 1. Measured chloride profiles in foundation wall in reference and anode area.

The concrete cover to the inner as well as the outer reinforcement layer is 20-30 mm.

The chloride content near the inner reinforcement inside of the wall is therefore approximately 0.13-0.30 % Cl^- by weight of concrete in the reference area and 0.18-0.24 % Cl^- by weight of concrete in the anode area.

The chloride content near the outer reinforcement is accordingly approximately 0.24 % Cl^- by weight of concrete in the anode area (one of the two locations) and exceeding 0.13-0.17 % Cl^- by weight of concrete in the reference area.

6.2.2 Current measurements

The results of the current measurements can be seen in Table 2. The complete measurements including measurements over a resistance can be seen in Appendix 5.

Date	Temperatures degree C	Anode no.	Current, µA
			Using a potentiostat
5/10-99	approx. 9	0	
		1	
		2	
		3	
		0-3	
2/3-00	5	0-3	< 33
20/6-00	25	0-3	
21/6-00	28	0	1744/1567
		1	1660
		2	1420
		3	1100

Table 2. Current output from Galvashield anodes at Hornum. For measurements over a resistance, see Appendix 5.

6.2.3 Potential measurements

The results from the potential mapping can be seen in Appendix 6.

Measurements with external electrodes

From the results it can be seen that the potentials measured in the parent concrete both in the reference area and in the anode area before casting of new concrete are more negative than the value where corrosion is probable, ref. 5. This indicates that there is ongoing corrosion in both of the areas.

It can further be seen that the potential in the repaired area increase with time from casting, as expected due to hardening of the concrete and an increased resistance of the repair material. With time the increase in potential gradient over the construction joint and thus the probability of corrosion increases.

From the results it can be seen that the 24 hour depolarisation values over the construction joint in March 2000 was approx. 10-55 mV and immediately below the joint between -1 and 6 mV.

The corresponding values from June 2000 show predominant positive depolarisation values when measured over 2 and 4 hours but both positive and negative depolarisation values when measured over 24 hours.

Measurements on cast-in electrodes

The potentials measured on electrodes cast into parent concrete are more negative in absolute value than potentials measured from the external side using a handheld electrode. This is likely to be a result of hardening of the mortar surrounding the electrodes, thus in time the potential is expected to increase towards more positive potentials.

The decay measurements over 24 hours show a very limited effect of the anodes in the repaired area (4-10 mV decay measured 200 and 400 mm from the anode), and practically no effect in the parent concrete (0-3 mV decay).

6.3 Beam in oil quay, Kalundborg

6.3.1 Chloride analysis

The chloride content in the dust samples collected at the location of the reference electrodes R1, R2 and R5, the latter in the reference area can be seen in table 3.

Location	Chloride content % Cl^- by weight of concrete (one Ø25 mm hole, 0-approx. 40 mm below surface)
R1 (approx. 350 mm from anode A1)	0.02
R2 (approx. 150 mm from anode A2)	0.09
R5 (reference area, approx. 50 mm above construction joint)	0.15

Table 3. Chloride content in concrete, where reference electrodes were installed in parent concrete.

The chloride content in the drilled cores can be seen in table 4. It was not possible to drill cores from the anode area, which was originally intended.

Location	Chloride content % Cl- by weight of concrete
Reference area, 0-26 mm below surface	0.24
Reference area, 26-59 mm below surface	0.16

Table 4. Chloride content in core drilled in the reference area, existing concrete.

6.3.2 Current measurements

The results of the current measurements can be seen in Table 5. The complete measurements including measurements over a resistance can be seen in Appendix 7.

Date	Temperature	Anode no.	Current, µA
			Using a potentiostat
14/10-99	Approx. 9	1	
		2	
		3	
		1-3	
24/1-00	2	1	76/97
		2	35
		3	< 33
		1-3	34
3/7-00	16	1	610
		2	240
		3	280
		1-3	220
3/8-00	18	1	180
		2	380
		3	350
		1-3	810

Table 5 Current output from Galvashield anodes at Kalundborg. For measurements over a resistance, see Appendix 7.

The results from the potential measurements can be seen in Appendix 8.

Based on the depolarisation measurements it can be seen that there is a positive effect of the anodes both in the parent concrete and in the repair concrete. Table 6 shows the depolarisation values measured in July and August 2000.

Date	Area, repair/existing	2/2.5 h decay mV	4 h decay mV	24 h decay mV
3 July 2000	Reference, repair (R6)	0		
	Reference, exist. (R5)	0		
	Anode, exist (A1, R1)	23		
	Anode, exist (A2, R2)	11		
	Anode, repair (A1, R3)	11		
	Anode, repair (A2, R4)	38		
3-4 August 2000	Reference, repair (R6)	1	1	1
	Reference, exist. (R5)	0	1	0
	Anode, exist (A1, R1)	32	36	40
	Anode, exist (A2, R2)	17	18	21
	Anode, repair (A1, R3)	15	16	10
	Anode, repair (A2, R4)	50	55	61

Table 6. Depolarisation values measured in July and August 2000.
Reference electrode no. 1 is located approx. 350 mm from anode no. 1.
Reference electrode no. 2 is located approx. 150 mm from anode no. 2.
Reference electrode no. 3 is located approx. 250 mm from anode no. 1 and
Reference electrode no. 4 is located in close proximity to anode no.2.

6.3.3 Resistance measurements

Two concrete cores were drilled on 4 August 2000 from the reference area one in the existing concrete and one in the repair concrete. The resistance and the corresponding resistivity were measured on the cores immediately after drilling and blotting the cores dry for drilling water. The resistance of the repair material, Renderoc LA was in addition measured after saturation in Calciumhydroxid. The results are presented in Appendix 10 and can be seen in Table 7.

Area	Location	Condition	Depth below surface mm	Diameter mm	Resistance kΩ	Resistivity kΩcm
Reference	Existing	Surface dry	0-31 (3 mm plaster)	27	5.4	8.5
		Surface dry	31-67	23	9.7	12.3
Reference	Repair	Surface dry	0-32	23	4.0	5.1
		Surface dry	32-58	23	3.1	5.3
		After saturation	0-32	23	9.8	12.8
		After saturation	32-58	23	4.5	7.7

Table 7. Resistance and resistivity of cores drilled in the reference area in the existing and repaired area, respectively.

7 Comments

7.1 Chloride content

7.1.1 Salt storage, Hornum

The environment of the salt storage is highly aggressive towards reinforced concrete structures, with chloride content in the parent concrete, next to the construction joint area exceeding 0.24 % Cl^- by weight of concrete. This level is normally considered enough to initiate corrosion and especially with a chloride gradient over the joint on the same level. According to Fosroc, ref. 4, no recommended upper limit of the chloride content over the construction joint is set when using the Galvashield anode, however it is recommended to demolish concrete until non-corroded reinforcement is reached. This ensures according to ref. 4, that the installation will be a preventive cathodic protection installation. This strategy has not been used in connection with the salt storage foundation wall at Hornum.

7.1.2 Beam in oil quay, Kalundborg

The chloride content of the parent concrete in the beam at Kalundborg has an apparent lower value than in the salt storage. It should be considered that the chloride content represents one Ø23/25 mm hole each and is thus a subject to a certain degree of inaccuracy.

The chloride content in the anode area in the depth of the reinforcement is somewhere between 0.02 and 0.09% Cl^- by weight of concrete - assuming that the chlorides are homogeneously distributed in the area. The chloride content in the reference area is somewhat higher (exceeding 0.15% approximately in the depth of reinforcement.

7.2 Current output

7.2.1 Salt depot, Hornum

The current output of the anodes is highly dependent on the ambient temperature at the time of measurement. We note that the current output measured at the salt depot exceeds the output from the beam in Kalundborg, and of the test block measured under laboratory conditions.

One possible explanation is that corrosion of the reinforcement from the time of installation of the Galvashield anodes has been ongoing, which requires a higher current output. The lifetime of the anodes must under these circumstances be expected to be decreased when compared to installing the anodes as preventive measure according to Fosroc recommendations. However the estimated lifetime with the max. current density measured still exceeds 10 years (the lifetime estimated by Fosroc in any case).

As the corrosion rate increases with temperature, it appears that the current output from the anodes adjusts to this requirement.

The current output measured from the anodes at Hornum during summer time (27 degree C) is approx. 760μA from one anode (2200μA for 4 anodes, as measured over resistance approx. 35-40 % too low a value ref. Appendix 5, and divided by 4 anodes). Assuming that the protection diameter of one anode is 550 mm to exposed surfaces, the current output corresponds to approx. 1.1 mA/m^2 steel surface.

The corresponding current output during wintertime (approx. 5 degree. C) is below 0.02 mA/m^2 concrete surface and 0.05 mA/m^2 steel surface.

7.2.2 Beam in oil quay, Kalundborg

The current output from the anodes corresponds well with the results from the test block measured in the laboratory.

The current output from the anodes during summertime (18 degree C) corresponds to 430 $\mu A/m^2$ (0.4 mA/m^2) concrete surface area and during wintertime (2 degree C) 10 $\mu A/m^2$ (0.01 mA/m^2) steel surface.

7.2.3 General remarks

The Galvashield anodes appear to be able to provide a current density (under optimum conditions) that corresponds to what is normally considered adequate for a preventive cathodic protection installation i.e. 1-2 mA/m^2. This is only possible during summer time, and corresponds well with the time for maximum current requirement at the time of optimum for corrosion activity.

The Galvashield anode consists of approx. 80 g of Zinc. Assuming an average current output from the anode on (corresponding to an average temperature in Denmark on 9 degree C) 200 μA equal to 0.3 mA/m^2 steel surface (for the beam in Kalundborg), the lifetime of the anode can be estimated to 35-45 years. An average current output of 1 mA/m^2 steel would under the same assumptions yield approx. 12 years.

7.3 Potential measurements

For cathodic protection installations the following performance criteria is normally applied for reinforced structures exposed to the atmosphere:

Min. 100 mV depolarisation when measured over 24 hours.

Ref. 6 suggests lower polarisation values for structures with only limited amount of chloride in the reinforcement level, corresponding to a preventive cathodic protection installation and higher polarisation values for high chloride contents around the reinforcement. Table 7 shows the requirements to polarisation in relation to the chloride content according to ref. 6. Polarisation values are for practical purposes measured as depolarisation values.

Chloride content		Necessary polarisation*
kg/m^3	% Cl^- by weight of concrete density assumed: 2400 kg/m^3	mV
< 0.6	0.025	0
0.6-1.2	0.025-0.05	60
1.2-3.0	0.05-0.125	80
3.0-6.0	0.125-0.25	100
6.0-12.0	0.25-0.5	150
* in order to obtain a corrosion rate lower than 0.1 mm/year or more than 20 years until signs of corrosion occur		

Table 7. Polarisation criteria according to ref. 6. The chloride content has been converted from kg/m^3 to % Cl^- by weight of concrete by assuming a concrete density on 2400 kg/m^3.

According to ref. 6, 100-150 mV depolarisation over 24 hours should be found for the reinforcement in the salt depot in Hornum to be adequately protected. This has not been found.

The data from the beam in Kalundborg imply that reinforcement with a chloride content on up to 0.025-0.05 % Cl^- by weight of concrete around the reinforcement can be protected. The chloride content 0-40 mm below surface for reference electrode 1 is 0.02 and the corresponding 24 hour depolarisation is 40 mV. The chloride content 0-40 mm below surface for reference electrode 2 is 0.09 and the corresponding 24 hour depolarisation is 21 mV.

In addition, Ref. 9 shows that depolarisation measurements during summertime is lower than in winter. Taking this into account (up to approximately 90%) the measurements are close to fulfilling the requirements in Ref. 6. In any case it could be considered to space the anodes closer.

7.4 Resistance

The resistance of the repair material used will have a high impact on the ability of the anodes used to protect the parent concrete, meaning that a lower resistance material is likely to provide a better current distribution from the anode in the repair material to the reinforcement in the parent concrete.

The resistivity of the repair material in natural condition after approximately 10 months of maturity is approx. 5 kΩcm and of the repair material 8-12 kΩcm.

The resistivity of the repair material in saturated condition has been found between 7.7 and 12.8 kΩcm.

The resistivity of Fosroc materials have at previous occations been measured in saturated condition. The results are shown in Table 8.

Material	Resistivity Measured 13.05.93	Measured 21.-24.06.99 Sealed in plastic bag at 20°C		Measured 04.08.00	Measured 16.08.00
	Saturated condition 28 days maturity Ref. 7	35 days maturity	56 days maturity Ref. 8	"Natural" condition 10 months maturity	Saturated condition 10 months maturity
Renderoc S	11.3				
Topcrete HD	HD: 8.9	HD: 13.6 0-8: 45.8	HD: 13.5 0-8: 50.8		
Conbextra	GP: 4.8	GP: 4.1 BB: 4.5 HF: 3.4	GP: 4.4 BB: 4.3 HF: 3.3		
Renderoc HB	HB: 15.4	HB25: 32.0 HB40: 9.5	HB25: 30.6 HB40: 9.7		
Renderoc LA	7.8	10.6	9.9	5.1-5.3	7.7-12.8
Renderoc GP		3.3	3.3		
Parent concrete Kalundborg				8.5-12.3	

Table 8. Resistivity of Fosroc repair material

The resistivity of Renderoc LA in the natural moist condition at Kalundborg is seen to be approx. 100 % lower than the resistivity of the parent concrete. This should ensure a good current distribution from the anode through the repair material to the parent concrete.

Further, the resistivity of Renderoc LA at Kalundborg is low (approximately 5.2 kΩ cm), which is suitable for cathodic protection. The resistivity of the parent concrete (8.5-12.3 kΩcm) is as expected higher than that of the repair material, and the distribution of current into the parent concrete will, to some extent, be limited. The location of anodes close to the construction joint is, therefore, crucial for a satisfactory protection level. In addition, the parent concrete should not have too high a resistivity, i.e. should not contain epoxy-material and similar.

7.5 Cost implications

Assuming that a motorway column is to be repaired, the following cost implications can be calculated when using Galvashield anodes in connection with the repair and when not using them.

The following is assumed:

The column is diameter 0.6 m and 4 m high. The chloride content in the depth of the reinforcement is 0.05 % Cl^- by weight of concrete 2.5 m above ground level, and 0.10 % Cl^- by weight of concrete 2 m above ground level.

The steel to concrete ratio is approx. 0.66 and therefore 3 anodes are to be located in the circumference of the column. Traditional repair works are to be carried out to 2 m above ground level in connection with the anode installation and 2.5 m above ground level in connection with the traditional repair.

The cost of the anodes is DKK 180 each. The cost of traditional repair is 1000 DKK/m² for demolishing and 1600 DKK/m² for formwork and casting to 50 mm below surface.

The lifetime of the anode installation is assumed to be 10 years plus the time before new signs of deterioration have developed (approx. 10 years). The lifetime for the traditional repair is approx. 10 years, corresponding to the time before new signs of deterioration have developed.

Cost of traditional repair (year 0)

$$2.5\text{m} \times 2\pi \times \frac{0.6}{2}\text{m}^2 \times (1000 + 1600\ \text{DKK/m}^2) = 12246\ \text{DKK}$$

Cost of anode installation (year 0)

$$2 \times 2\pi \times \frac{0.6}{2}\text{m}^2\ (1000 + 1600\ \text{DKK/m}^2) + 3 \times 180\ \text{DKK} = 10342\ \text{DKK}$$

The cost using the anode solution is approximately 15% cheaper than the traditional repair cost (used in the example). Consequently, a financial evaluation on a 25 year service life basis will be in favour of the anode installation - provided that the anodes can protect the reinforcement at a chloride content approximately double the threshold value (given in the example).

8 References

1. G. Sergi. "An intelligent sacrificial cathodic protection system for concrete repairs".

2. C. L. Page. "Cathodic protection of reinforced concrete - principles and applications" Proc. Int. Conf. Repair of Concrete Structures - From theory to practice in a marine environment, Svolvær, ed. A. Blackvoll, Norweigian Road Research Laboratory, Oslo (1997), pp 123-131.

3. A. Andersen, R. Sørensen, K. Carlsen. "Reparationsstrategi for oliepier" (Repair strategy for oil-quay), Stads- og Havneingeniøren, Nov. 1999 - in Danish.

4. Phone conversation between Birit Buhr, COWI, DK and Nigel Davison, Fosroc UK on 20 July 2000.

5. ASTM C876-91: Standard Test Method for Half Cell Potentials of Uncoated Reinforcing Steel in Concrete.

6. Technical alert. Criteria for the Cathodic Prevention of Reinforced Concrete Bridge Elements, Strategic Highway Research Program, National Research Council, 1994.

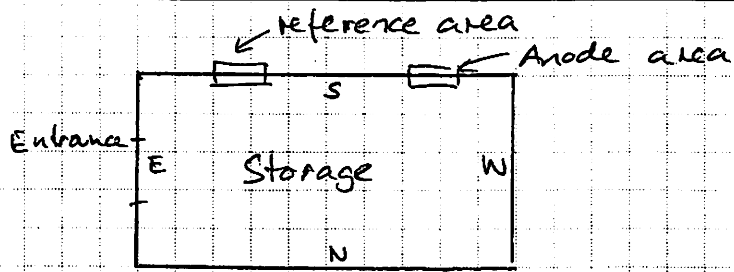
7. "Resistivitetsmålinger af produkter fra Fosroc A/S" BAC Bergsøe Anti Corrosion. 17.05.93.

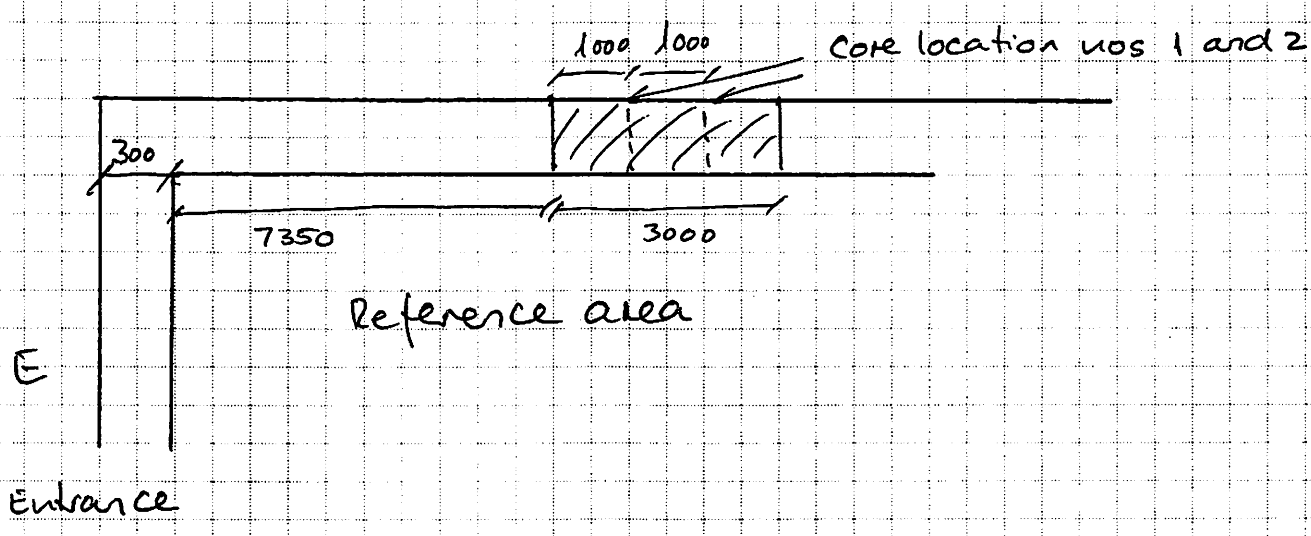
8. "Bestemmelse af resistivitet for reparationsprodukter", FORCEinstituttet, 03.08.99.

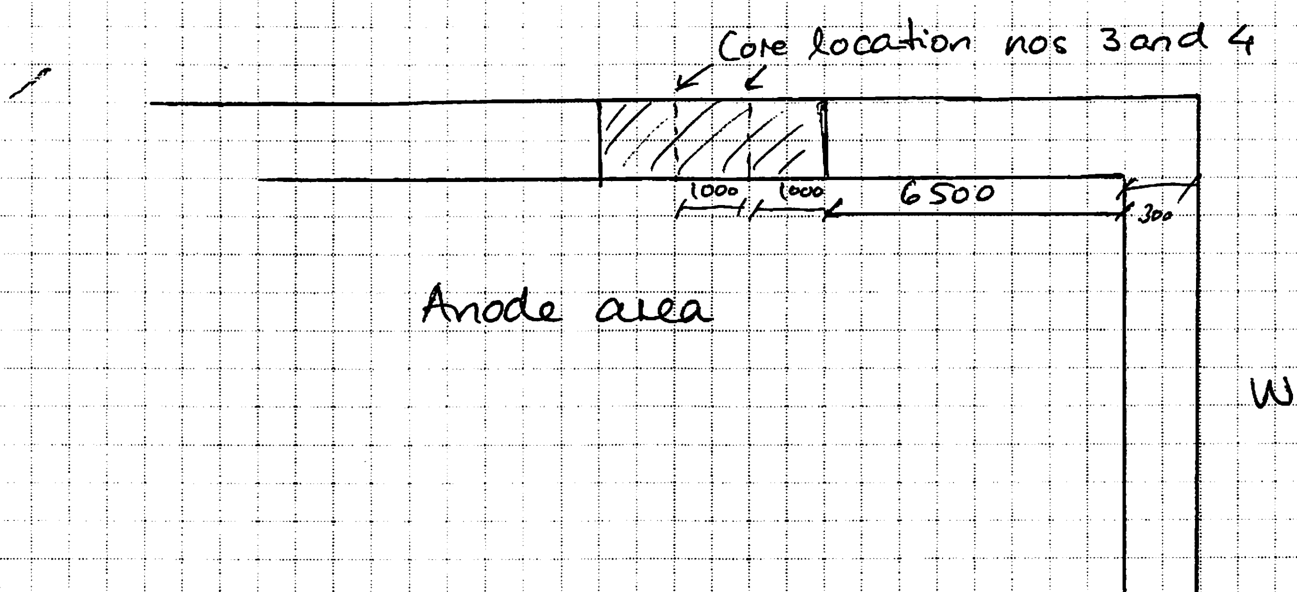
9. L. Bertolini et al: "New experiences on cathodic protection of reinforced concrete structures", Corrosion of reinforcement in concrete structures, eds C. L. Page, P. B. Bamforth and J. W. Figg. The Royal Society of Chemistry, Cambridge (1996).

Appendix 1 Test locations on Southern foundation wall on salt storage in Hornum

COWI		Sag nr.	Objekt Hornum	Side
Dato	Beregn.			
Dato	Kontrol			





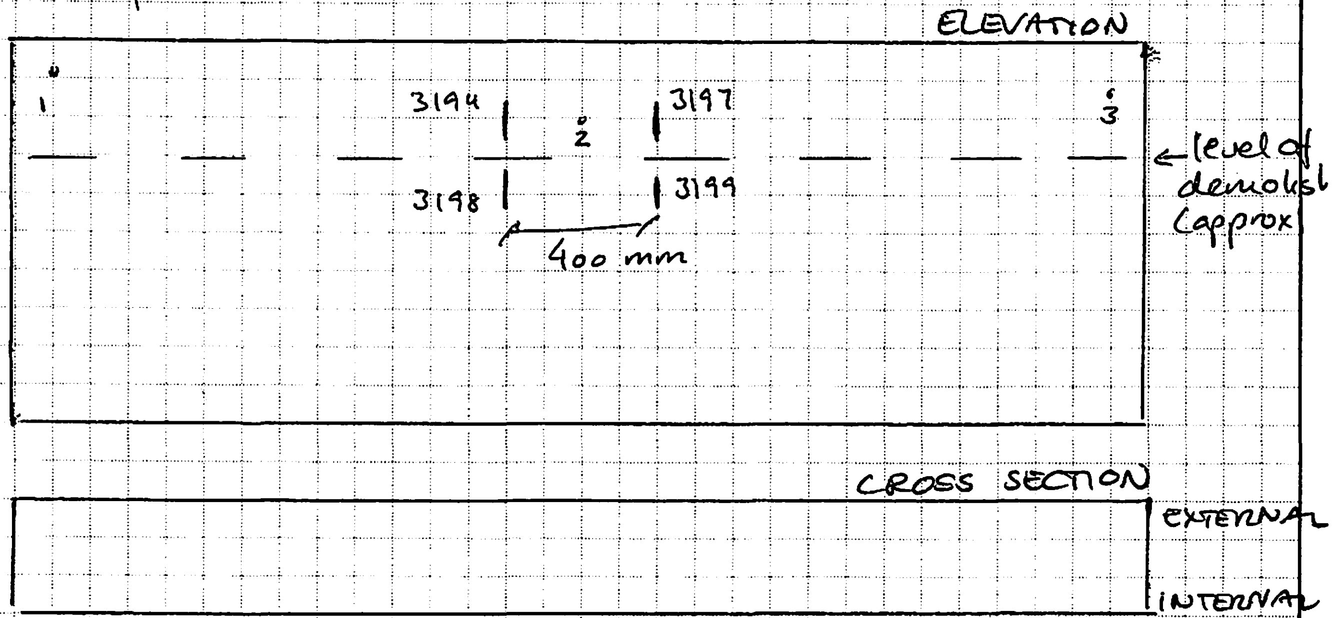


July 2000 / BBU

Not to scale

COWI	Sag nr.	Objekt	Side
Dato / Beregn.			
Dato / Kontrol			

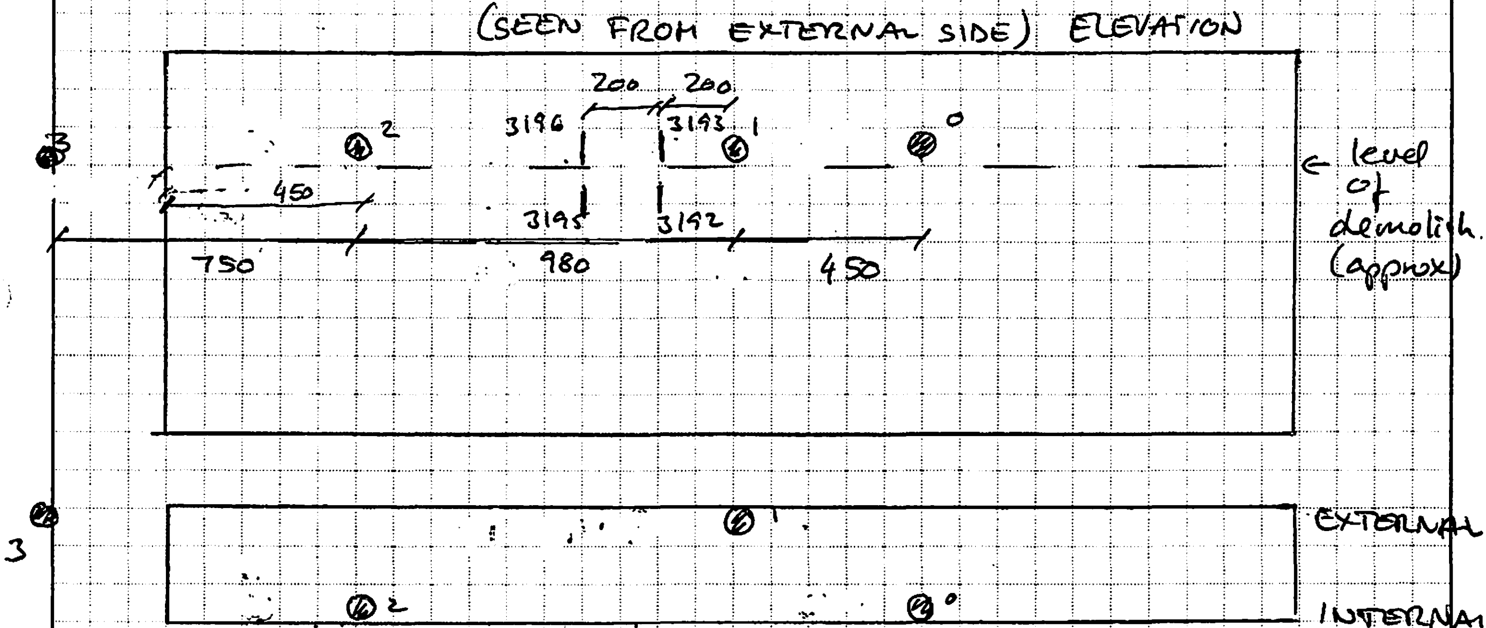
Reference area



| Reference electrode - ERE-20

° Reinforcement connection

⊗ Anode



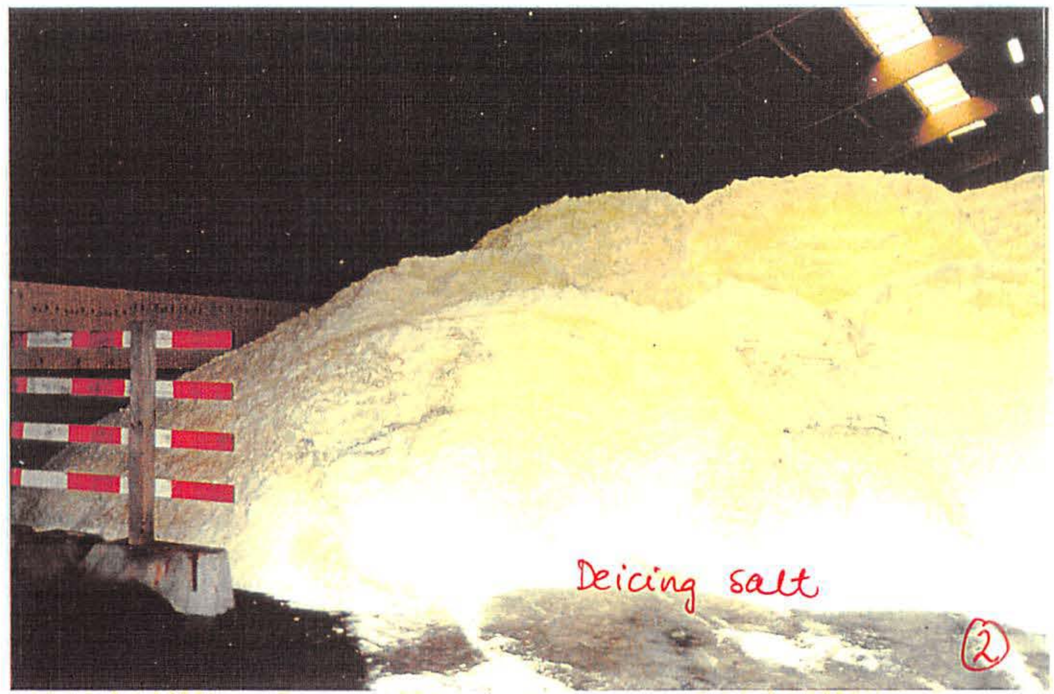
Cal. value vs. SCE	
3192	170
3193	170
3194	169
3195	169
3196	171
3197	171
3198	170
3199	169

NOT TO SCALE

JULY 2000 / BBU

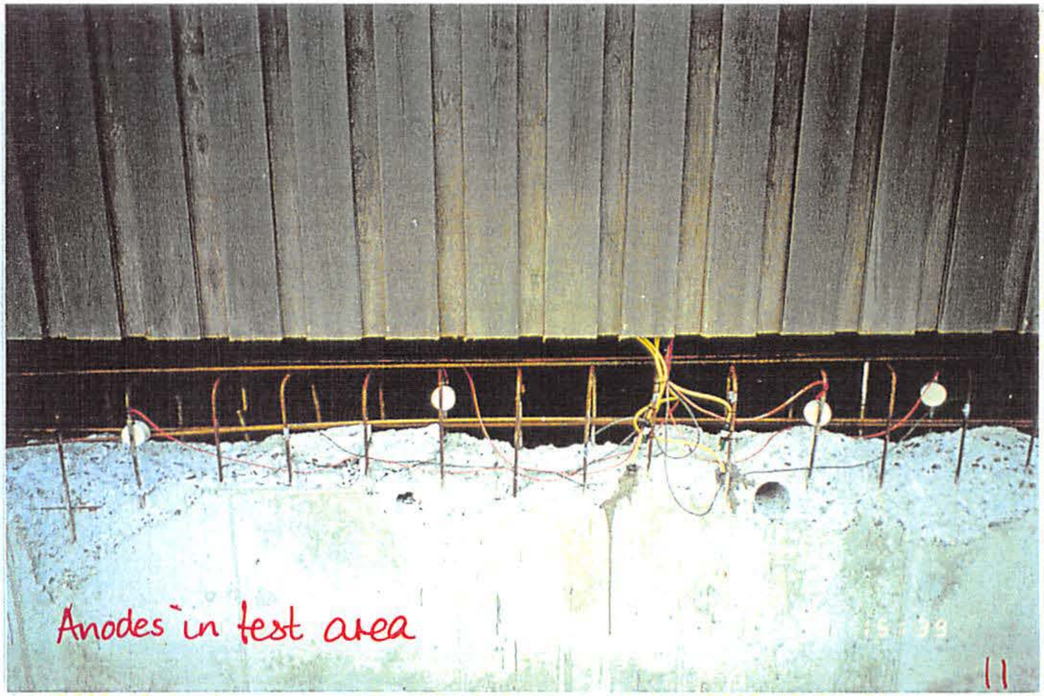
Appendix 2 Photos - Hornum

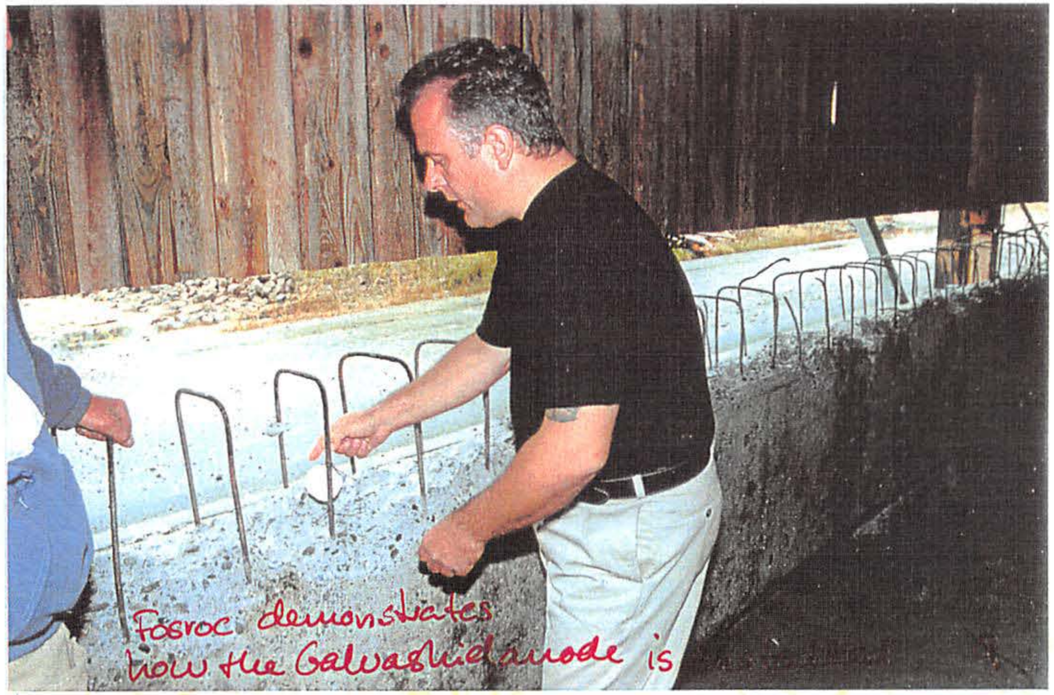

1

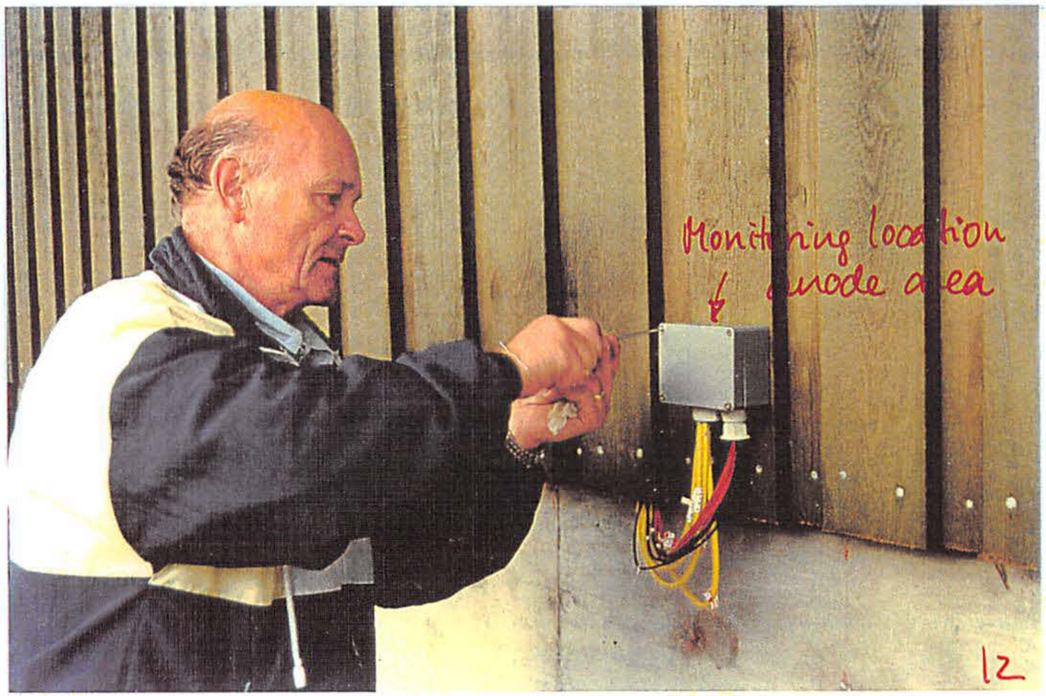

Deicing salt
2

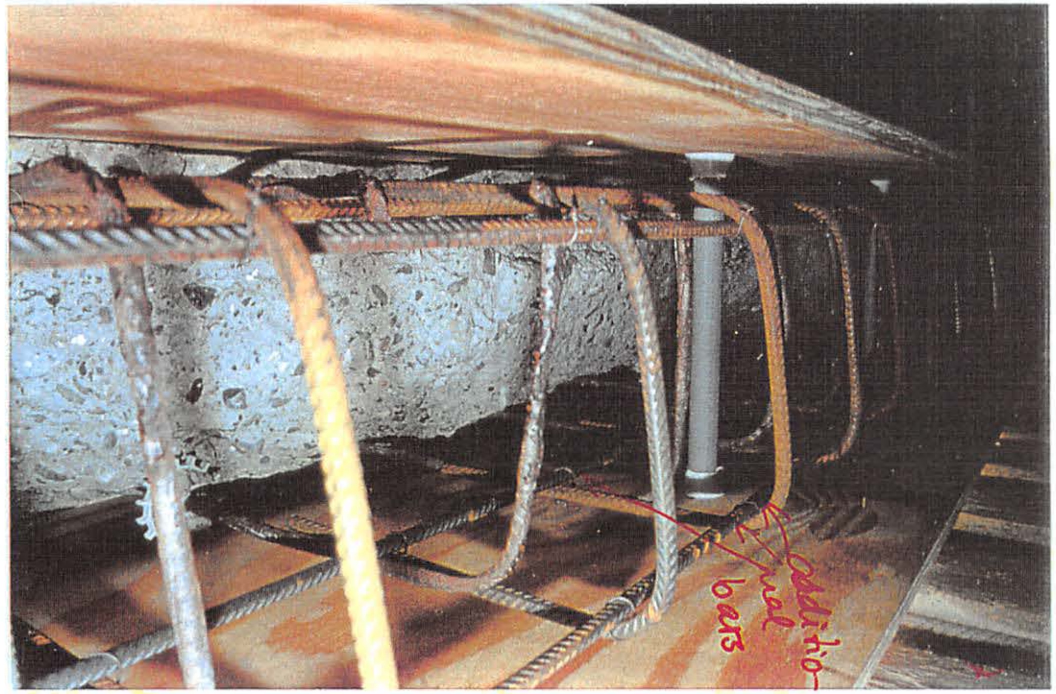

sandblast
3


After demolishing, corroded bars
4

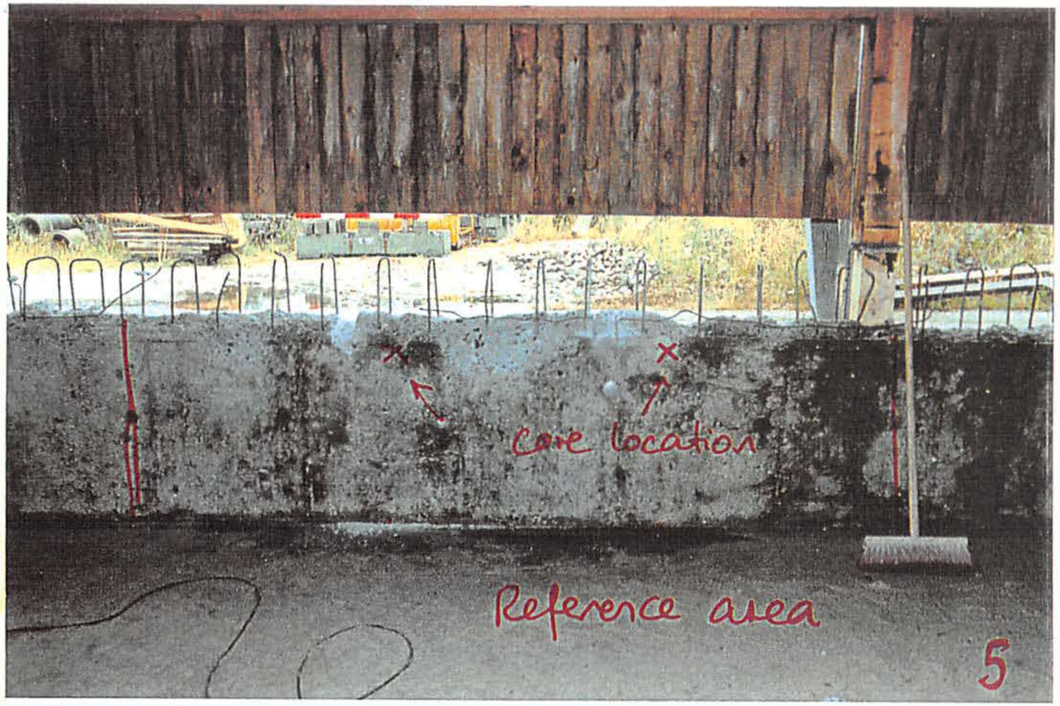

Anodes in test area
11

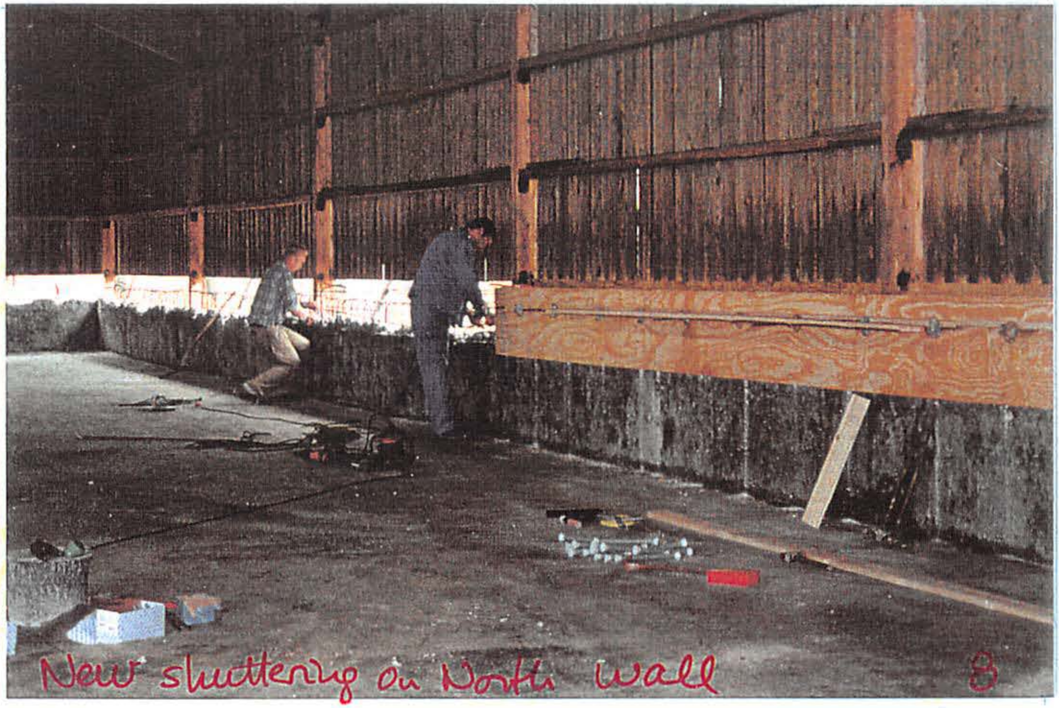

Fosroc demonstrates
how the Galvashield anode is

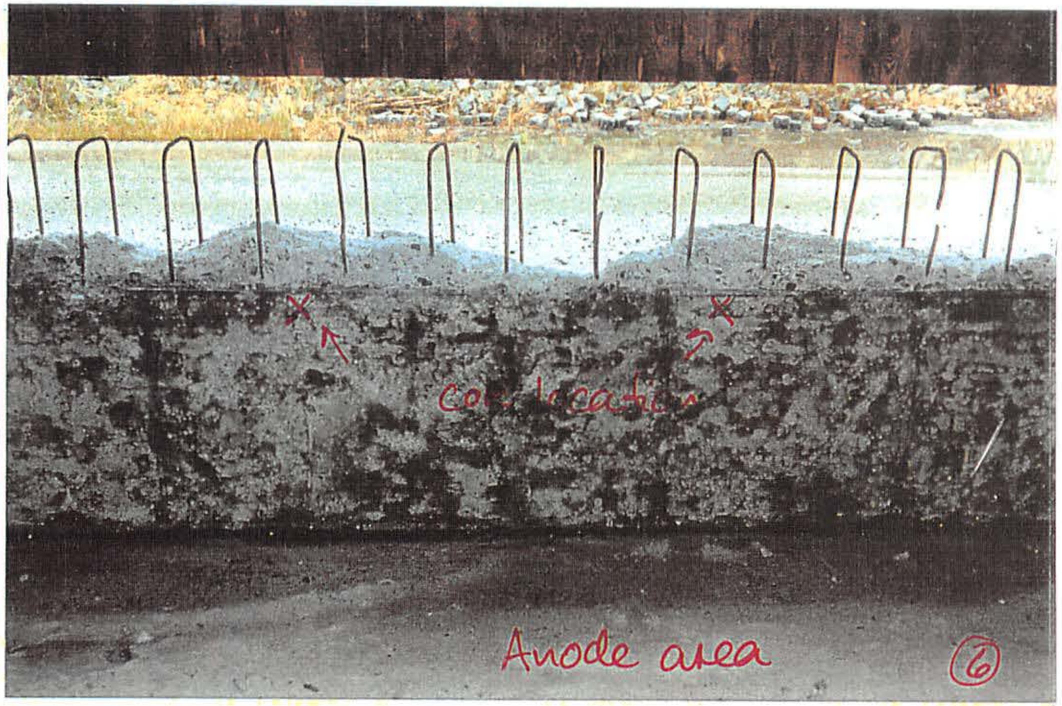

Monitoring location
& anode area
12


additional
bars


South foundation wall
7

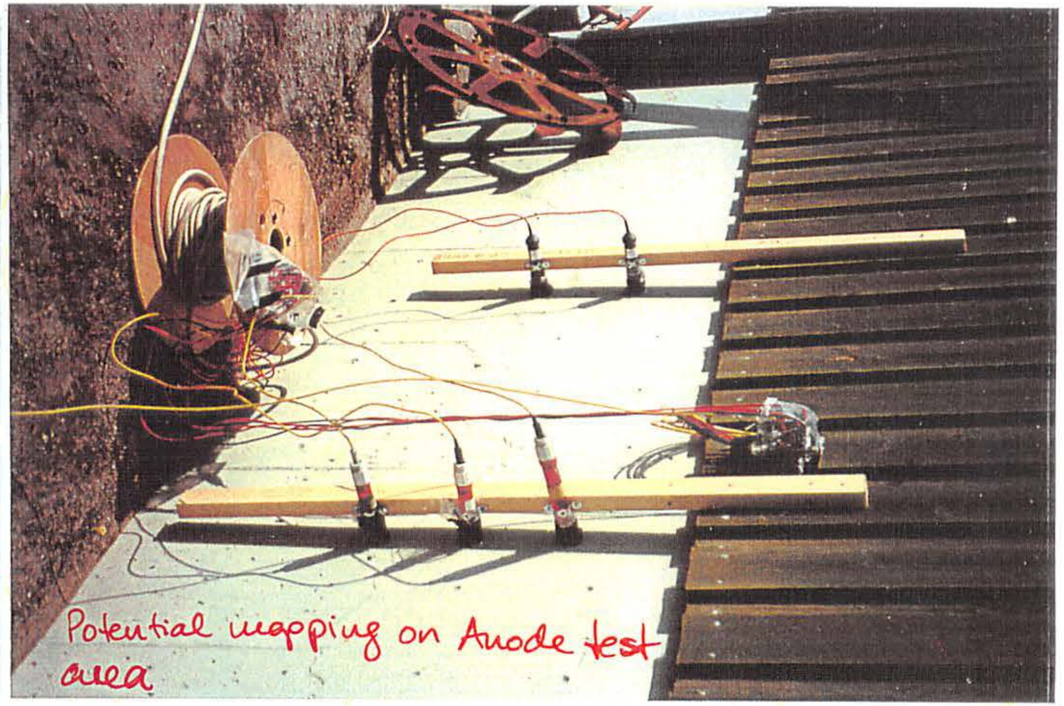

core location
Reference area
5


New shuttering on North wall
8

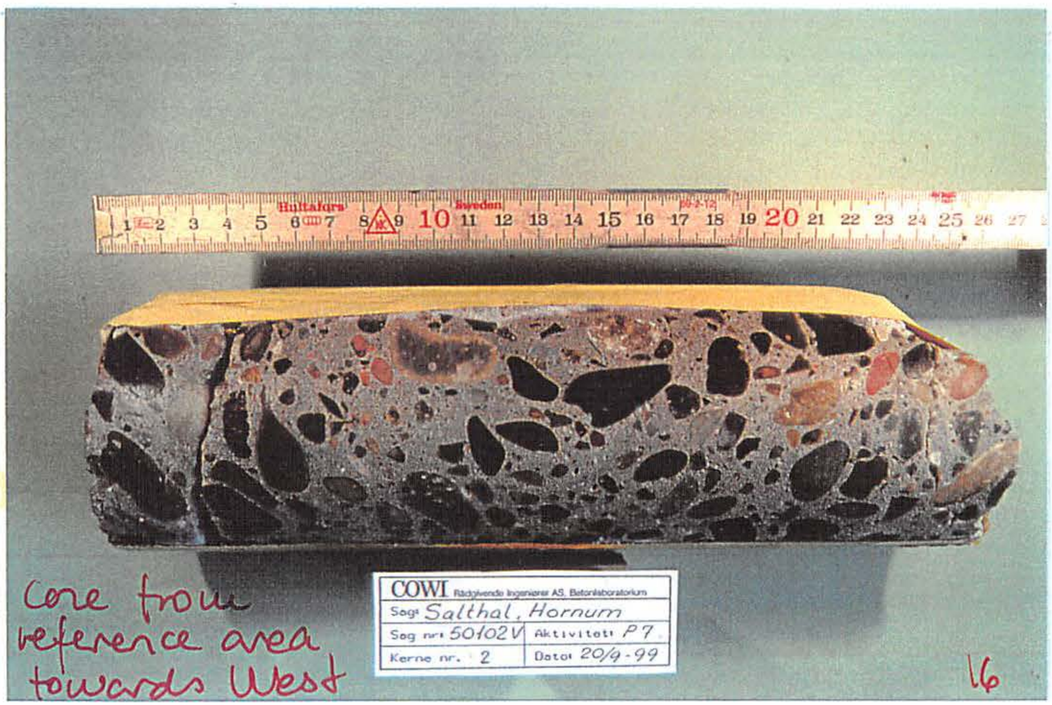

Anode area
6

Core from reference area, towards East

15

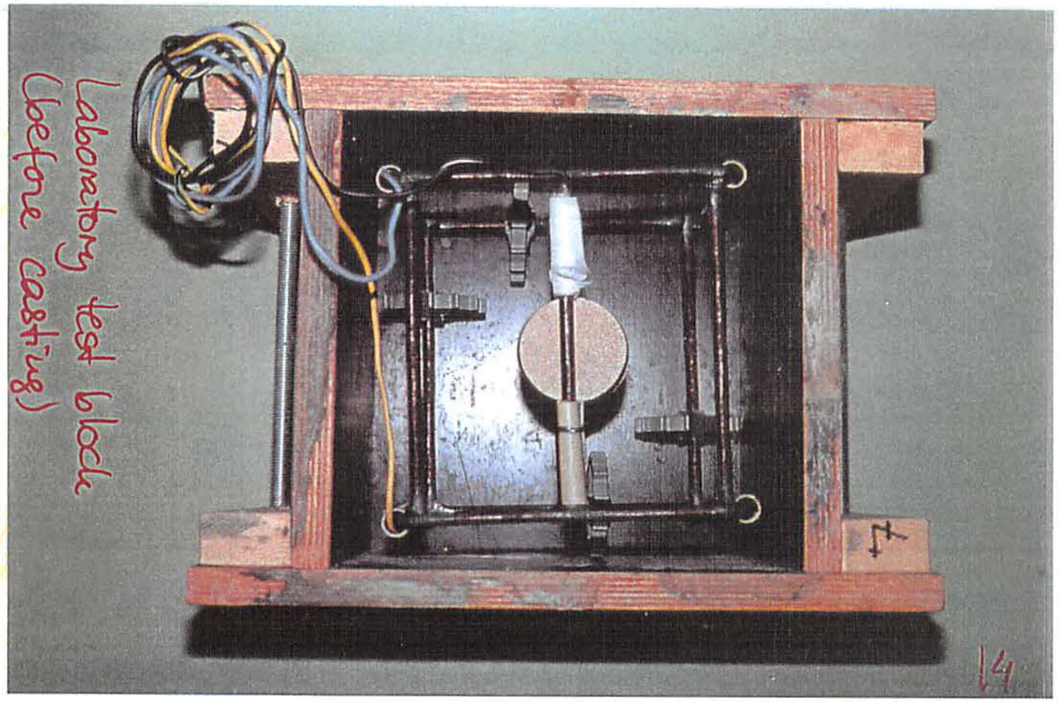


Potential mapping on Anode test area



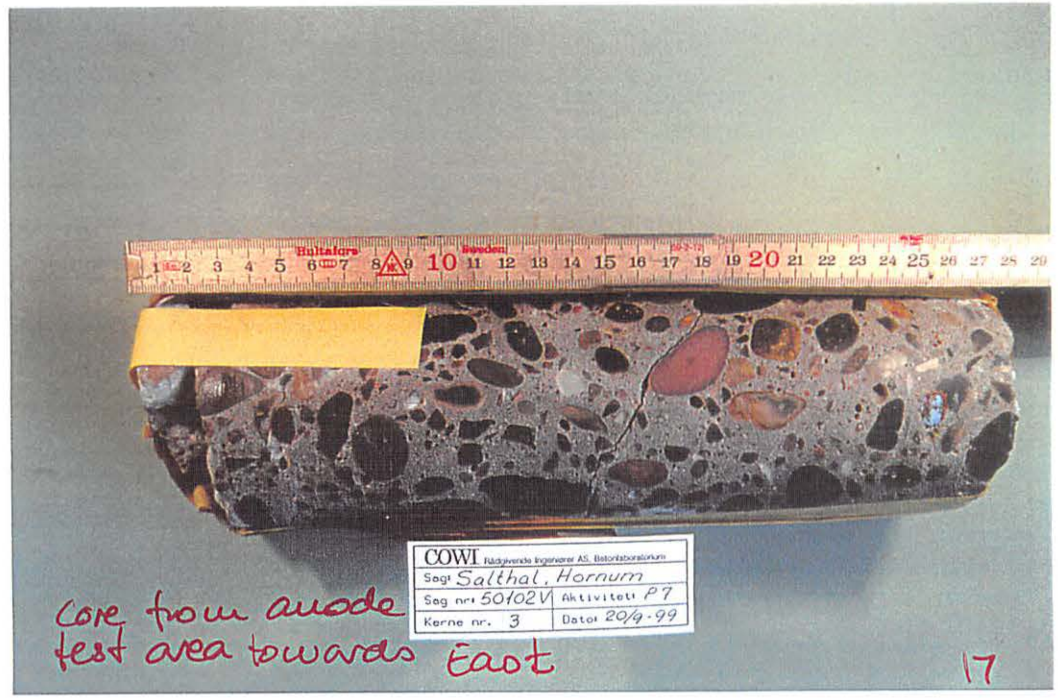
Core from reference area towards West

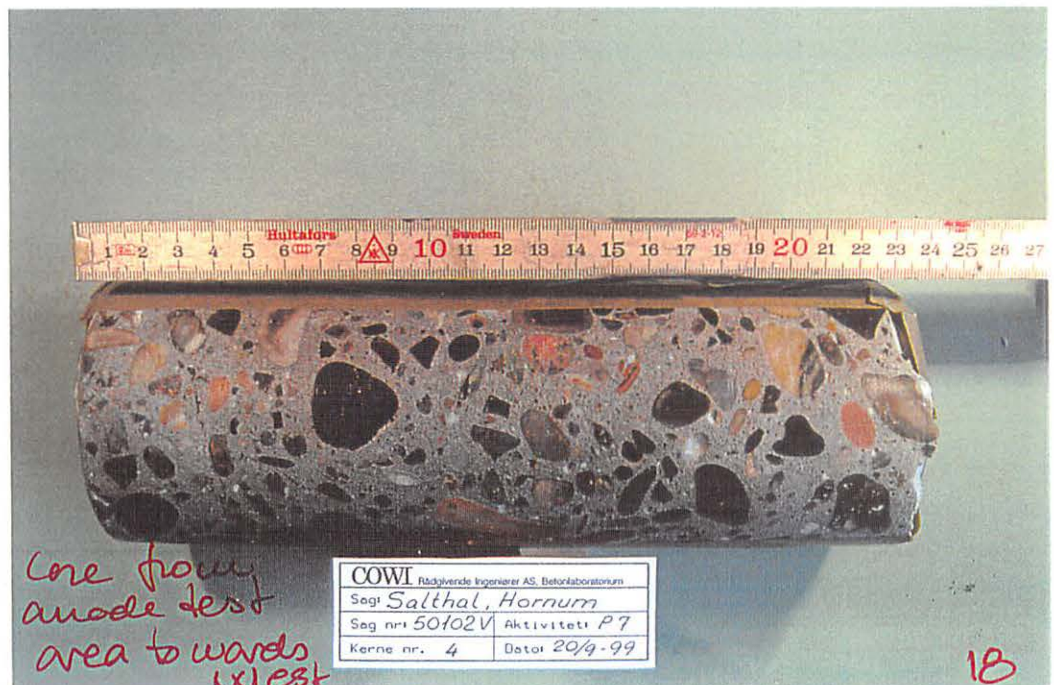
16



Laboratory test block (before casting)

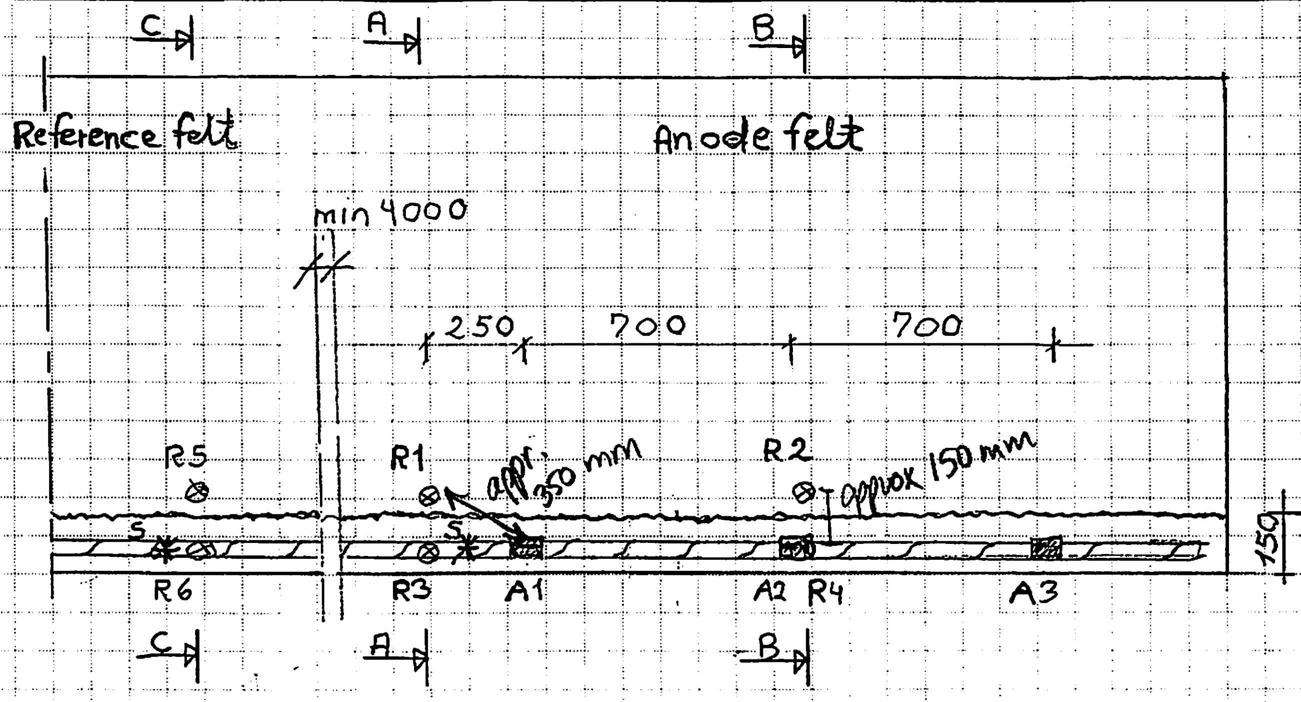
14

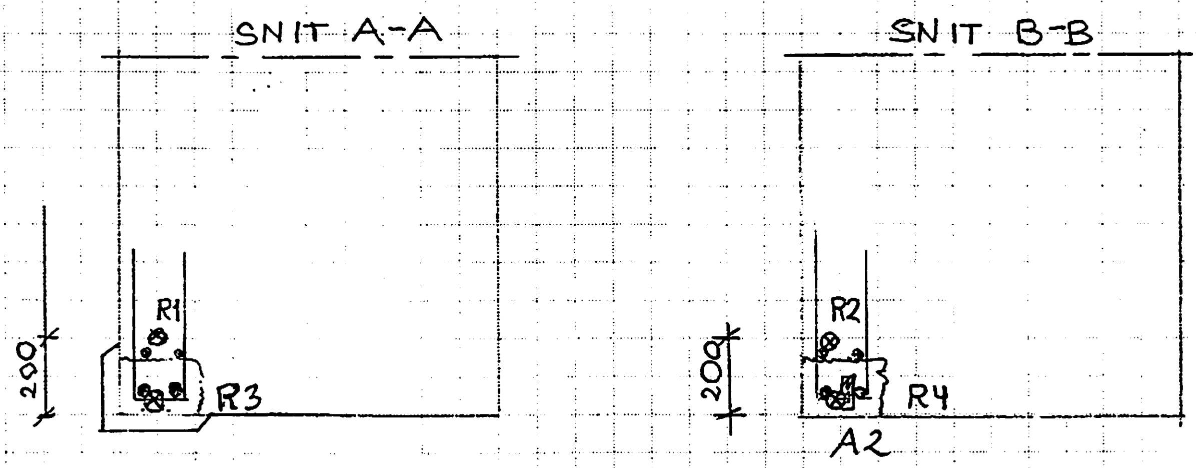

COWI Rådgivende Ingeniører AS, Betonlaboratorium
Sag: Salthal, Hornum
Sag nr: 50102V Aktivitet: P7
Kerne nr. 3 Dato: 20/9-99
Core from anode test area towards East
17

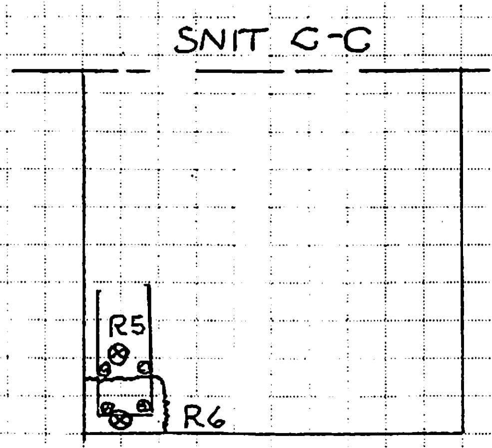

COWI Rådgivende Ingeniører AS, Betonlaboratorium
Sag: Salthal, Hornum
Sag nr: 50102V Aktivitet: P7
Kerne nr. 4 Dato: 20/9-99
Core from anode test area towards West
18

Appendix 3 Installation sketch - Kalundborg beam

COWI		Sag nr.	Objekt	Side
Dato 5/9-99	Beregn. AxA	50102	Statoil, betonbjælke-pier A (concrete beam)	
Dato	Kontrol		Galvashield Fosroc, prøvefelt	







NOTE: mål 1:20

R = Reference elektrode
ERE 20

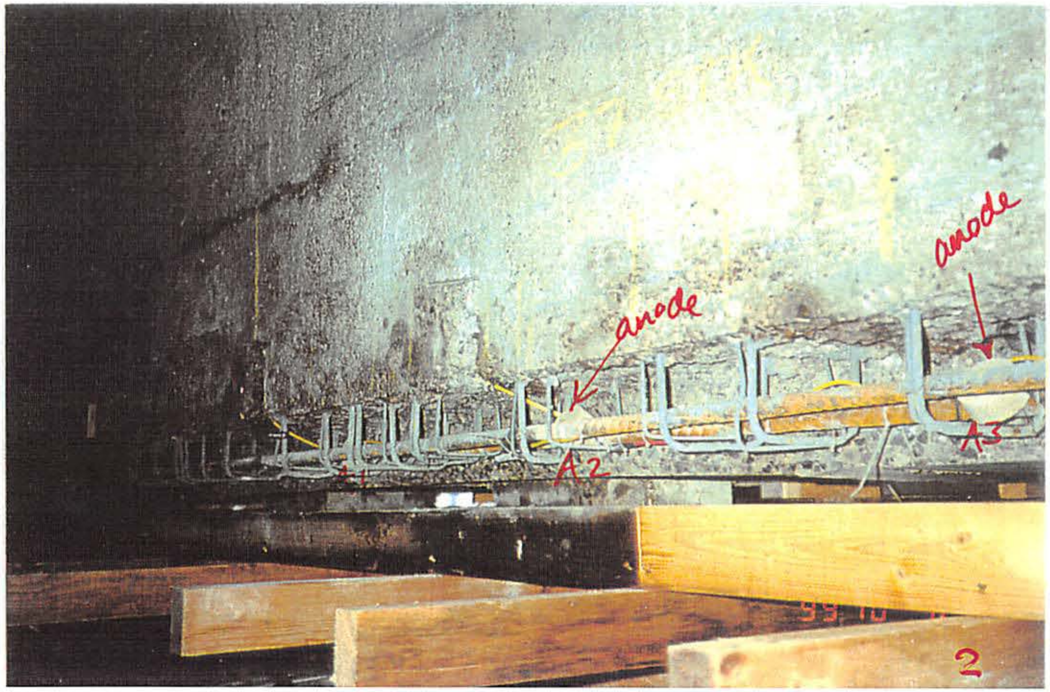
A = Anode Galvashield

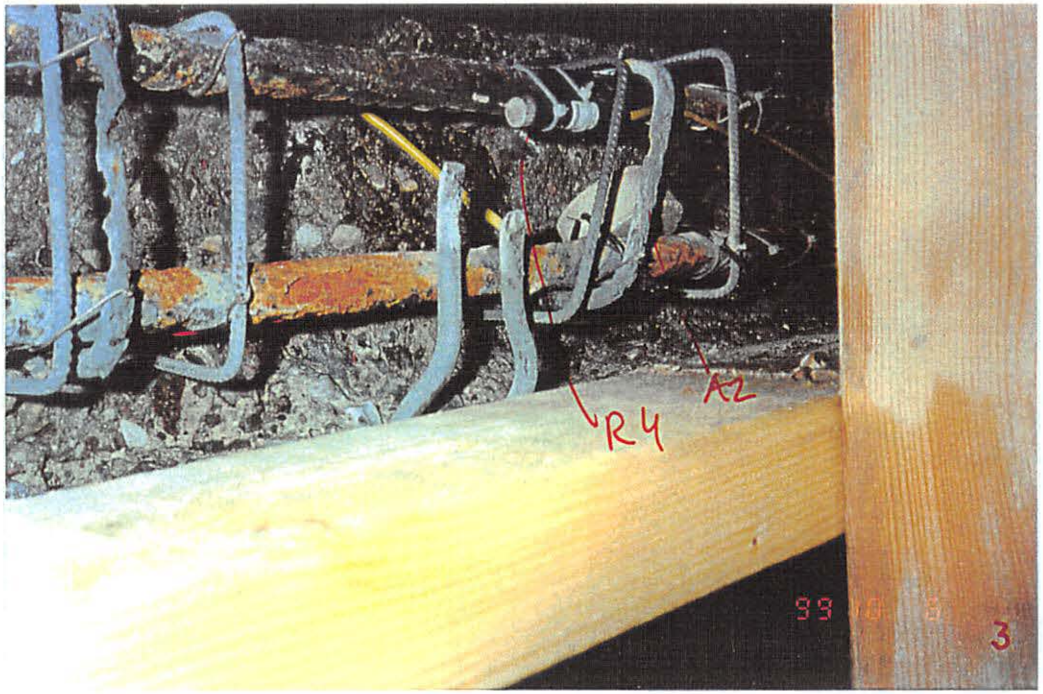
s* = Stelforbindelse
Reinforcement connection

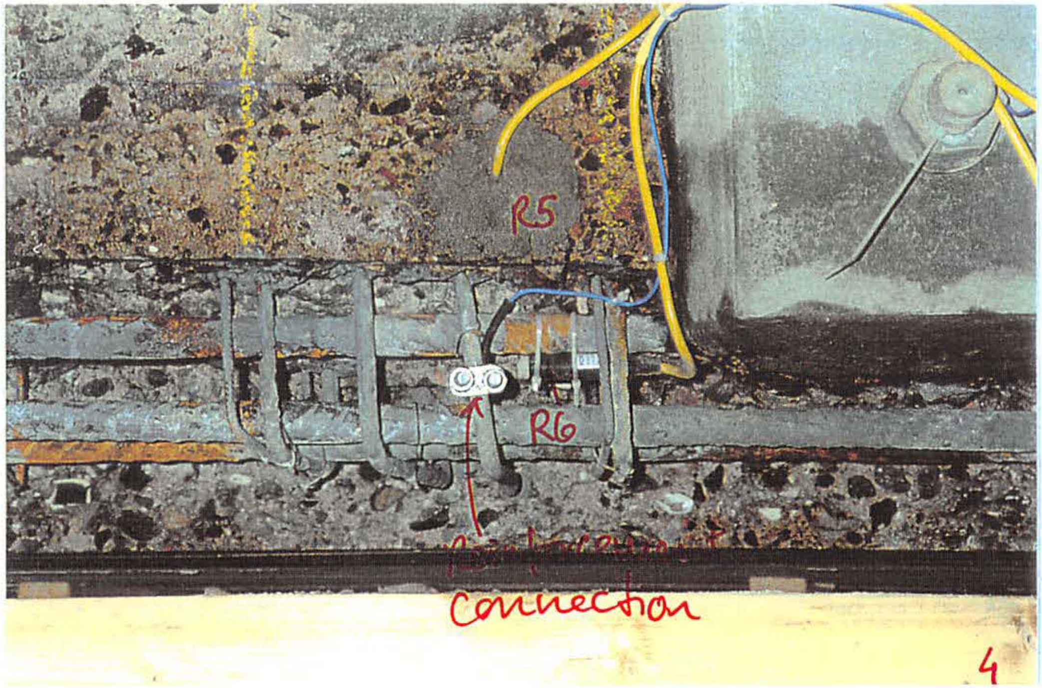
Ident. nr.		Kal. vers. SCE
R1	N 318	164
R2	N 307	163
R3	N 299	167
R4	N 315	165
R5	N 322	164
R6	N 300	168

Appendix 4 Photos, Beam in oil quay, Kalundborg


1


anode
anode
A2
A3
2


R4
A2
3


R5
R6
connection
4

Appendix 5 Current measurements, Salt Storage, Hornum

Current measurement, Salt storage, Hornum

Date	Temperature	Anode no.	Current, uA Using a potentiostat	over resistance after 10 sec. Current, uA	Stable value Current, uA	Resistance
05/10/99	ca. 9	0		195		1 kohm
05/10/99	ca. 9	1		177		1 kohm
05/10/99	ca. 9	2		171		1 kohm
05/10/99	ca. 9	3		157		1 kohm
02/03/00	5	0-3	<33			
20/06/00	25	0-3				
21/06/00	28	0	1744/1567	1400		100 ohm
	28	1	1660	1400		100 ohm
	28	2	1420	1200	870	100 ohm
	28	3	1100	1200		100 ohm
	28	0-3		3000	2200	100 ohm

Appendix 6 Potential measurements, Salt Storage, Hornum

External measurements

Date	On	Off/Inst. off	1 h off	2 h off	4 h off	24 h off
Aug 16, 1999		x				
Oct. 5, 1999	x				x	
Mar. 3-4, 2000	x	x	x			x
Jun. 20-21, 2000	x	x		x	x	x

Measurements on installed reference electrodes

Reference electrodes were cast in on Aug. 18, 1999

Date	On	Off	1.5/2 h off	3.5/4 h off	24 h off
Oct. 5, 1999	x	x	x	x	
Mar. 3-4, 2000	x				x
Jun. 20-21, 2000	x				x

Hornum Measurements on cast in electrodes

Potentials vs. Ref.

		New concrete	New concrete	Parent concrete	Parent concrete	Depolarisering	New concrete	New concrete	Parent concrete	Parent concrete
Anode area No.		3196	3193	3195	3192		3196	3193	3195	3192
Cast on		18/08/99	18/08/99	20/08/99	20/08/99	Hours				
Date of measurement	05/10/99 On	-452	-429	-563	-505					
	05/10/99 inst. Off	-451	-429	-563	-505					
	05/10/99 1,5 t off	-445	-427	-560	-503	1.5 hours	6	2	3	2
	05/10/99 3,5 t off	-445	-427	-560	-503	3.5 hours	6	2	3	2
	03/03/00 On	-466	-440	-594	-520					
	04/03/00 24 t off	-457	-428	-590	-515	24 hours	9	12	4	5
	20/06/00 On	-451	-421	-564	-503					
	20/06/00 On	-450	-420	-564	-501					
	21/06/00 24 t off	-440	-416	-561	-501	24 hours	10	4	3	0

Reference area		3194	3197	3198	3199
Cast on		18/08/99	18/08/99	20/08/99	20/08/99
Date of measurement	05/10/99 On	-419	-428	-498	-477
	03/03/00 On	-428	-434	-493	-480
	20/06/00 On	-415	-423	-483	-465

Resistance measurements, KOhm

	3194	3197	3198	3199	3196	3193	3195	3192
05/10/99	5.34	4.62	5	4.87	5.53	4.8	5.08	7.44

Anode area, On (before the anodes are disconnected from the reinforcement)

20-Jun-00

Potentials vs. SCE

(light grey shading) internally installed anode
(dark shading) externally installed anode

20 juni, on

	0	25	50	75	100	125	150	175	200	225	250	275	300
125	13	11	2	24	-24	34	-35	15	0	21	1	10	35
100	26	43	-23	2	-3	-12	-19	-43	-31	-9	-88	-59	-4
75	-102	-182	-87	-120	-173	-171	-188	-187	-127	-290	-238	-140	-185
50	-297	-173	-270	-315	-288	-333	-372	-318	-316	-301	-280	-256	-349
25	-297	-309	-278	-311	-325	-330	-333	-324	-336	-313	-328	-327	-381
0	-356	-354	-295	-323	-332	-342	-351	-341	-344	-333	-321	-334	

← demolishing, location varies

20 june 2000, 2 timer after disconnecting the anodes

	0	25	50	75	100	125	150	175	200	225	250	275	300
125	48	65	36	46	-3	62	2	42	14	48	32	43	53
100	48	83	-48	24	-2	26	-21	-42	-42	0	-97	-55	-12
75	-42	-116	-86	-78	-153	-153	-177	-172	-125	-275	-248	-156	-182
50	-234	-219	-236	-286	-240	-295	-346	-295	-256	-256	-248	-226	-306
25	-265	-287	-230	-280	-283	-303	-321	-292	-278	-266	-286	-309	-347
0	-325	-337	-272	-299	-301	-313	-336	-318	-299	-287	-285	-307	

20 june 2000, 4 timer after disconnecting the anodes

	0	25	50	75	100	125	150	175	200	225	250	275	300
125	52	64	41	49	-1	62	3	45	-14	34	23	48	23
100	44	49	-46	28	8	35	15	-52	-10	-13	-94	-61	34
75	-70	-127	-84	-55	-185	-164	-168	-183	-146	-270	-263	-167	-180
50	-252	-214	-236	-279	-275	-314	-352	-316	-273	-268	-245	-218	-310
25	-276	-285	-231	-275	-292	-322	-328	-312	-297	-290	-288	-304	-348
0	-330	-338	-263	-289	-311	-320	-341	-332	-323	-307	-292	-311	

21 june 2000, 24 timer after disconnecting the anodes

	0	25	50	75	100	125	150	175	200	225	250	275	300
125	25	59	29	21	-6	20	-6	31	-48	11	11	36	17
100	19	54	-14	-10	-19	-4	[illegible]	-80	-17	-30	-105	-64	-53
75	-87	-142	-93	-134	-260	-189	-166	-198	-150	-289	-252	-164	-196
50	-282	-250	-257	-317	-302	-340	-387	-327	-298	-293	-278	-246	-342
25	-295	-310	-260	-326	-322	-347	-360	-347	-314	-314	-321	-328	-379
0	-357	-341	-291	-317	-323	-348	-365	-352	-345	-337	-330	-352	

Difference between 2 t off and on

	0	25	50	75	100	125	150	175	200	225	250	275	300		
125	35	54	34	22	21	28	37	27	14	27	31	33	18	Mean	26
100	22	40	25	22	1	38	40	1	11	9	-9	4	-8	Variation	19
75	60	66	1	42	20	18	11	15	2	15	-10	-16	3	Mean repaired area	22
50	63	-46	34	29	48	38	26	23	60	45	32	30	43	Variation repaired area	16
25	32	22	48	31	42	27	12	32	58	47	42	18	34	Mean parent area	28
0	31	17	23	24	31	29	15	23	45	46	36	27		Variation parent area	21

Difference betwen 4 t off and on

	0	25	50	75	100	125	150	175	200	225	250	275	300		
125	39	53	39	25	23	28	38	30	-14	13	22	38	-12	Mean	20
100	18	6	23	26	11	47	34	-9	-41	-4	-6	-2	38	Variation	21
75	32	55	3	65	-12	7	20	4	-19	20	-25	-27	5	Mean repaired area	18
50	45	-41	34	36	13	19	20	2	43	33	35	38	39	Variation repaired area	22
25	21	24	47	36	33	8	5	12	39	23	40	23	33	Mean parent area	21
0	26	16	32	34	21	22	10	9	21	26	29	23		Variation parent area	21

Difference between 24 t off and on

	0	25	50	75	100	125	150	175	200	225	250	275	300		
125	12	48	27	-3	18	-14	29	16	-48	-10	10	26	-18	Mean-all	-4
100	-7	11	-9	-12	-16	8	-24	-37	-48	-21	-17	-5	-49	Variation	21
75	15	40	-6	-14	-87	-18	22	-11	-23	1	-14	-24	-11	Mean repaired area	-3
50	15	-77	13	-2	-14	-7	-15	-9	18	8	2	10	7	Variation repaired area	25
25	2	-1	18	-15	3	-17	-27	-23	22	-1	7	-1	2	Mean parent area	-5
0	-1	13	4	6	9	-6	-14	-11	-1	-4	-9	-18		Variation parent area	21

Referencefelt, On, anodes outside the reference area connected to the reinforcement

20-Jun-00

vs. Ag/AgCl

	0	25	50	75	100	125	150	175	200	225	250	275	300
125	-38	-77	-139	-17	-35	-75	-7	0	-37	-30	1	13	-10
100	-67	-163	-209	-94	-102	-45	13	-36	-109	-68	-142	-132	-64
75	-341	-353	-373	-287	-239	-309	-175	-157	-194	-263	-315	-386	-231
50	-386	-339	-344	-418	-266	-310	-306	-251	-217	-284	-272	-310	-311
25	-336	-422	-424	-427	-367	-304	-319	-268	-235	-305	-284	-253	-310
0	-403				-356	-330	-324	-333	-299	-322	-315	-305	-328

21 June 2000, 24 hours after disconnecting the anodes

	0	25	50	75	100	125	150	175	200	225	250	275	300
125	-27	-72	-137	-10	-21	-37	-4	-1	-37	-29	-4	13	-50
100	-62	-136	-205	-99	-76	-10	25	-39	-67	-30	-111	-101	-60
75	-327	-340	-355	-283	-244	-296	-165	-113	-185	-241	-305	-397	-207
50	-396	-344	-344	-440	-254	-310	-303	-236	-205	-310	-288	-321	-312
25	-335	-449	-418	-436	-388	-312	-316	-264	-211	-317	-283	-256	-315
0	-403				-373	-343	-325	-327	-300	-343	-303	-303	-342

Difference

	0	25	50	75	100	125	150	175	200	225	250	275	300	Mean	4
125	11	5	2	7	14	38	3	-1	0	1	-5	0	-40	Average	16
100	5	27	4	-5	26	35	12	-3	42	38	31	31	4	repair	
75	14	13	18	4	-5	13	10	44	9	22	10	-11	24	parent	
50	-10	-5	0	-22	12	0	3	15	12	-26	-16	-11	-1		
25	1	-27	6	-9	-21	-8	3	4	24	-12	1	-3	-5		
0	0				-17	-13	-1	6	-1	-21	12	2	-14		

Eksterne målinger Measurements vs Ag/AgCl.

anode 3-udv ext. | anode2-ind int. | anode 1-udv ext | anode 0-ind. int

04/03/00 On

-92

-163 -98 -80 -74 -131 -109 -120 -128 -92 -96 -154 -230 -227 -124 -192 -190 -164 -91 -95

anode 3-udv	anode2-ind	anode 1-udv	anode 0-ind.
-310	-159	-320	-219
-270	-218	-297	-224
-273		-320	-319
-279		-357	

37 cm   37 cm

04/03/00 24 timer off

-52

-60 -26 -60 -19 -141 -120 -38 -68 -68 -41 -162 -74 -144 -71 -172 -74 -145 -63 -126

anode 3-udv	anode2-ind	anode 1-udv	anode 0-ind.
-98	-78	-144	-106
-160	-135	-227	-169
-263		-301	-320
-273		-355	

24 timers depolarisering

40

103 72 20 55 -10 -11 82 60 24 55 -8 156 83 53 20 116 19 28 -31

anode 3-udv	anode2-ind	anode 1-udv	anode 0-ind.
212	81	176	113
110	83	70	55
10		19	-1
6		2	

= construction joint

Hornum saltlager
referencefelt, 2,udvengig
1900-03-03
Hornum saltlager
referencefelt,24t off,udv.
1900-03-04

change in potential readings (mV CSE)

	0	25	50	75	100	125	150	175	200	225	250	275	300	
125	15	21	51	13	17	15	17	36	22	25	46	41	47	New concrete
100	26	25	23	19	-1	19	-11	24	31	13	25	20	13	
75	24	22	10	18	34	-17	-12	32	7	22	7	-5	30	← approx. location
50	16	31	37	19	25	20	19	10	12	9	-5	16	7	parent concrete
25	12	-1	12	25	25	26	20	22	33	14	12	17	17	
0	-10				13	40	31	24	28	10	22	11	11	

Hornum saltlager
anodefelt,2, on-udvendig
1900-03-03
Hornum saltlager
anodefelt,2, 24t off,udv.
1900-03-04

change in potential readings (mV CSE)

	0	25	50	75	100	125	150	175	200	225	250	275	300	
125	23	34	26	26		36	49	45	22	-2	12	29	11	new concrete
100	30	38	48	22	24	57	90	42	35	24	28	27	9	
75	19	11	32	17	14	31	35	22	28	-6	2	6	24	
50	-7	-4	-5	-14	-2	-2	0	-1	5	3	-2	8	5	parent concrete
25							-5	-7	5	4	1	4	5	
0							-8	-1	14	-4	8	5		

Anode no. 2 (int.)
Anode no. 1 (ext).
Anode no. 0 (int.)

Hornum saltlager
referencefelt, 2,udvengig
1900-03-03
PG-C : 870

BLOODHOUND Cyberdan 130151108

resistance readings (kOhm)

	0	25	50	75	100	125	150	175	200	225	250	275	300
125	102	143	81	275	170	181	287	94	144	262	110	137	150
100	55	126	141	127	55	19	41	54	99	35	67	40	44
75	19	55	17	40	15	29	66	47	28	45	11	5	57
50	4	22	30	4	20	7	16	29	43	10	7	24	19
25	4	9	4	3	13	11	15	20	21	10	15	48	14
0	3				3	5	6	73	10	6	7	17	8

potential readings (mV CSE) Cu/CuSO4

	0	25	50	75	100	125	150	175	200	225	250	275	300
125	-211	-227	-297	-187	-219	-212	-186	-226	-238	-220	-226	-203	-216
100	-269	-322	-342	-278	-270	-263	-203	-255	-277	-264	-298	-294	-268
75	-482	-497	-504	-465	-430	-428	-375	-360	-354	-437	-440	-463	-446
50	-493	-483	-487	-504	-386	-430	-432	-390	-369	-414	-402	-427	-447
25	-463	-495	-520	-503	-473	-429	-439	-414	-391	-427	-418	-385	-441
0	-479				-474	-443	-432	-440	-431	-432	-432	-404	-447

Hornum saltlager
referencefelt,24t off,udv.
1900-03-04
PG-C : 870

BLOODHOUND Cyberdan 130151108

resistance readings (kOhm)

	0	25	50	75	100	125	150	175	200	225	250	275	300
125	152	120	222	418	196	243	247	161	167	468	296	395	479
100	97	145	74	203	33	21	115	76	134	34	53	40	43
75	42	67	34	74	23	266	115	64	23	54	7	9	87
50	9	41	147	7	26	16	24	29	36	13	17	37	27
25	13	7	6	11	22	23	19	41	51	12	70	173	16
0	3				3	9	13	13	13	8	15	13	9

potential readings (mV CSE)

	0	25	50	75	100	125	150	175	200	225	250	275	300
125	-196	-206	-246	-169	-202	-197	-169	-190	-216	-195	-180	-162	-169
100	-243	-297	-319	-259	-271	-244	-214	-241	-246	-246	-273	-274	-255
75	-458	-475	-494	-447	-396	-445	-387	-328	-347	-415	-433	-468	-416
50	-477	-452	-450	-485	-361	-410	-413	-380	-357	-405	-407	-411	-440
25	-451	-496	-508	-478	-448	-403	-419	-392	-358	-413	-406	-368	-424
0	-489				-461	-403	-401	-416	-403	-422	410	-393	-436

Hornum saltlager
anodefelt,2, on-udvendig
1900-03-03
PG-C : 870

BLOODHOUND Cyberdan 130151108

resistance readings (kOhm)

	0	25	50	75	100	125	150	175	200	225	250	275	300
125	116	257	157	111		135	113	132	101	153	125	131	253
100	55	53	48	101	49	58	57	46	73	35	41	33	89
75	42	63	77	48	81	52	45	153	98	9	57	52	56
50	8	6	15	11	6	7	4	5	5	7	16	11	5
25							3	5	5	7	10	6	4
0							8	2	3	3	3	3	

potential readings (mV CSE)

	0	25	50	75	100	125	150	175	200	225	250	275	300
125	-202	-186	-184	-205		-214	-230	-215	-220	-167	-192	-180	-173
100	-199	-187	-221	-229	-238	-246	-287	-270	-240	-244	-273	-256	-231
75	-303	-356	-340	-347	-396	-415	-416	-397	-351	-389	-398	-346	-389
50	-390	-382	-390	-434	-426	-475	-493	-443	-411	-400	-400	-395	-453
25							-477	-445	-428	-409	-419	-448	-482
0							-450	-438	-446	-430	-431	-442	

Hornum saltlager
anodefelt,2, 1 t off, udv.
1900-03-03
PG-C : 870

BLOODHOUND Cybardan 130151108

resistance readings (kOhm)

	0	25	50	75	100	125	150	175	200	225	250	275	300
125	85	140	101	100		98	106	107	73	107	102	110	177
100	54	33	31	88	43	48	56	50	70	41	51	35	53
75	24	26	52	32	70	34	23	131	83	10	43	60	44
50	7	6	13	9	10	6	5	5	9	8	21	16	7
25							3	6	5	8	7	3	4
0							3	2	3	3	2	3	

potential readings (mV CSE)

	0	25	50	75	100	125	150	175	200	225	250	275	300
125	-193	-172	-175	-195		-196	-203	-201	-214	-175	-196	-185	-172
100	-183	-174	-197	-223	-228	-222	-230	-249	-230	-237	-265	-255	-233
75	-294	-353	-328	-345	-391	-401	-394	-389	-345	-387	-400	-352	-390
50	-406	-389	-402	-447	-437	-482	-491	-449	-411	-399	-401	-392	-453
25							-483	-455	-428	-411	-418	-443	-485
0							-463	-454	-449	-445	-432	-439	

Hornum saltlager
anodefelt,2, 24t off,udv.
1900-03-04
PG-C : 870

BLOODHOUND Cyberdan 130151103

resistance readings (kOhm)

	0	25	50	75	100	125	150	175	200	225	250	275	300
125	115	291	229	145		142	148	224	93	122	138	434	231
100	65	52	48	142	80	76	102	77	92	117	53	103	63
75	23	442	116	35	111	57	42	206	101	16	57	137	103
50	12	36	15	10	20	12	5	5	6	9	30	22	19
25							3	3	6	9	10	11	9
0							4	4	4	4	3	4	9

potential readings (mV CSE)

	0	25	50	75	100	125	150	175	200	225	250	275	300
125	-179	-152	-158	-179		-178	-181	-170	-198	-169	-180	-151	-162
100	-169	-149	-173	-207	-214	-189	-197	-228	-205	-220	-245	-229	-222
75	-284	-345	-308	-330	-382	-384	-381	-375	-323	-395	-396	-340	-365
50	-397	-386	-395	-448	-428	-477	-493	-444	-406	-397	-402	-387	-448
25							-482	-452	-423	-405	-418	-444	-477
0							-458	-439	-432	-434	-423	-437	-480

remarks

	0	25	50	75	100	125	150	175	200	225	250	275	300
125													
100													
75													
50													
25													
0													s

Hornum saltlager
anodefelt, 1, udvendigt
1999-10-05
PG-C : 870

BLOODHOUND Cyberdan 130151108

resistance readings (kOhm)

	0	25	50	75	100	125	150	175	200	225	250	275	300
125	35	32	17	18	20	20	21	29	23	27	21	23	20
100	45	29	29	17	14	13	28	16	23	20	15	13	18
75	31	21	26	19	15	13	23	31	25	4	22	21	19
50	1	0	3	1	2	1	0	1	1	2	3	4	0
25	1	0	3	0	1	1	0	1	2	1	2	1	0
0	0	0	1	0	0	0	0	0	0	0	0	0	

potential readings (mV CSE)

	0	25	50	75	100	125	150	175	200	225	250	275	300
125	-211	-190	-225	-244	-225	-227	-241	-230	-253	-208	-217	-213	-229
100	-174	-199	-203	-248	-238	-262	-290	-294	-240	-247	-279	-269	-244
75	-323	-346	-307	-372	-389	-388	-347	-378	-345	-405	-406	-322	-378
50	-385	-395	-397	-451	-431	-469	-488	-454	-424	-412	-395	-384	-464
25	-430	-438	-410	-457	-452	-468	-485	-466	-442	-428	-430	-459	-487
0	-445	-445	-435	-441	-446	-452	-456	-456	-445	-444	-444	-462	

Hornum saltlager
anodefelt, 1,4t udvendigt
1999-10-05
PG-C : 870

BLOODHOUND Cyberdan 130151108

resistance readings (kOhm)

	0	25	50	75	100	125	150	175	200	225	250	275	300
125	12	10	9	11	15	14	13	17	14	16	14	14	15
100	16	13	14	9	7	9	13	10	14	12	13	11	13
75	15	10	13	11	9	12	18	20	16	3	18	14	15
50	1	0	3	1	1	1	0	1	1	2	3	5	0
25	1	0	3	0	1	0	0	1	2	1	2	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	

potential readings (mV CSE)

	0	25	50	75	100	125	150	175	200	225	250	275	300
125	-234	-241	-247	-259	-261	-262	-255	-259	-262	-239	-246	-249	-251
100	-224	-223	-243	-273	-271	-268	-269	-289	-264	-273	-302	-294	-279
75	-322	-339	-344	-395	-397	-406	-386	-415	-366	-407	-429	-374	-420
50	-387	-396	-398	-449	-433	-469	-487	-453	-421	-410	-397	-381	-466
25	-434	-443	-411	-459	-455	-469	-485	-465	-442	-429	-432	-462	-488
0	-453	-452	-439	-445	-449	-453	-457	-457	-448	-444	-446	-463	

Hornum saltlager
referencefelt, 1, udvendigt
1999-10-05
PG-C : 870

BLOODHOUND Cybercan 130151103

resistance readings (kOhm)

	0	25	50	75	100	125	150	175	200	225	250	275	300
125	15	17	25	30	19	17	21	14	14	13	15	13	19
100	13	18	18	24	11	13	15	15	14	17	11	15	16
75	10	10	17	24	6	5	16	25	16	12	2	1	16
50	2	7	8	1	6	3	6	6	12	3	2	5	4
25	4	1	0	1	3	2	6	8	9	5	4	14	6
0	0				1	1	2	1	2	1	2	2	2

potential readings (mV CSE)

	0	25	50	75	100	125	150	175	200	225	250	275	300
125	-241	-245	-261	-246	-243	-258	-245	-258	-269	-254	-261	-245	-246
100	-277	-334	-346	-287	-298	-290	-258	-287	-309	-281	-317	-312	-290
75	-494	-515	-501	-482	-449	-439	-388	-363	-342	-474	-430	-478	-411
50	-489	-452	-477	-520	-393	-438	-421	-382	-345	-437	-413	-441	-426
25	-458	-530	-524	-527	-477	-436	-439	-393	-371	-436	-400	-396	-430
0	-497				-485	-453	-455	-451	-428	-460	-425	-428	-440

Hornum saltlager
anodefelt.0 udvendigt
1999-08-16
PG-C : 870

BLOODHOUND Cyberdan 130151103

resistance readings (kOhm)

	0	25	50	75	100	125	150	175	200	225	250	275	300
100													
75	1	1	1	2	1	1	1	3	1	1	3	5	2
50	3	2	1	1	1	2	1	2	2	2	3	2	1
25	3	2	2	1	1	4	1	3	2	1	3	2	2
0	1	1	1	1	1	2	1	1	1	1	1	1	2

potential readings (mV CSE)

	0	25	50	75	100	125	150	175	200	225	250	275	300
100													
75	-413	-414	-471	-489	-481	-487	-492	-448	-414	-396	-363	-396	-444
50	-392	-411	-434	-492	-472	-481	-468	-425	-401	-386	-364	-403	-444
25	-416	-432	-451	-513	-481	-482	-480	-420	-435	-448	-439	-451	-473
0	-434	-442	-457	-467	-468	-475	-459	-439	-459	-454	-476	-460	-478

remarks

	0	25	50	75	100	125	150	175	200	225	250	275	300
100													
75				c									
50				c									
25				c									
0				c									

Hornum saltlager
anodefel.0 indvendigt
1999-08-16
PG-C : 870

BLOODHOUND Cyberdan 130151108

resistance readings (kOhm)

	0	25	50	75	100	125	150	175	200	225	250	275	300
100													
75	3	2	1	3	3	4	3	5	5	2	3	2	3
50	2	1	1	2	2	2	2	2	2	3	2	2	4
25	2	2	2	2	1	2	1	5	2	3	2	2	2
0	2	2	2	1	1	2	1	3	1	2	2	1	2

potential readings (mV CSE)

	0	25	50	75	100	125	150	175	200	225	250	275	300
100													
75	-413	-442	-462	-518	-483	-473	-513	-468	-426	-425	-395	-420	-453
50	-424	-430	-456	-514	-488	-487	-524	-469	-428	-413	-393	-425	-491
25	-422	-454	-478	-542	-504	-518	-549	-442	-424	-405	-408	-448	-521
0	-446	-463	-529	-536	-535	-523	-531	-454	-447	-427	-443	-460	-550

remarks

	0	25	50	75	100	125	150	175	200	225	250	275	300
100													
75					B				B				
50													
25													
0													

Hornum saltlager
Reference.0 udvendigt
1999-08-16
PG-C : 870

BLOODHOUND Cyberdan 130151109

resistance readings (kOhm)

	0	25	50	75	100	125	150	175	200	225	250	275	300
100													
75	16	9	1	2	7	10	7	8	4	5	1	5	26
50	10	5	2	3	6	14	9	13	6	10	3	9	9
25	12	7	4	4	8	13	11	9	5	2	1	0	12
0	4	5	3	2	6	6	3	4	3	2			2

potential readings (mV CSE)

	0	25	50	75	100	125	150	175	200	225	250	275	300
100													
75	-294	-388	-452	-426	-452	-346	-394	-411	-480	-485	-552	-591	-525
50	-301	-371	-449	-397	-394	-310	-384	-419	-446	-411	-536	-448	-462
25	-336	-382	-448	-399	-384	-333	-377	-420	-435	-481	-538	-530	-426
0	-420	-443	-449	-448	-405	-397	-435	-451	-445	-490			-525

mirror imaged.

remarks

	0	25	50	75	100	125	150	175	200	225	250	275	300
100													
75								B					
50			C										
25			C										
0			C										

Hornum saltlager
Reference.0 indvendigt
1999-08-16
PG-C : 870

BLOODHOUND Cyberdan 130151138

resistance readings (kOhm)

	0	25	50	75	100	125	150	175	200	225	250	275	300
100													
75	17	10	2	5	3	24	2	4	7	3	2	2	6
50	6	12	2	2	4	5	3	3	3	4	2	1	3
25	5	3	3	1	2	2	2	4	1	2	1	2	2
0	1	1	1	1	1	1	1	1	1	1	2	1	1

potential readings (mV CSE)

	0	25	50	75	100	125	150	175	200	225	250	275	300
100													
75	-342	-394	-466	-460	-473	-411	-436	-461	-533	-571	-585	-598	-604
50	-446	-425	-524	-511	-486	-466	-446	-481	-574	-570	-590	-611	-601
25	-511	-540	-548	-520	-551	-512	-541	-546	-527	-540	-593	-593	-599
0	-477	-484	-516	-513	-544	-528	-499	-494	-533	-533	-573	-579	-585

remarks

	0	25	50	75	100	125	150	175	200	225	250	275	300
100													
75					B				B				
50								B					
25													
0											r	r	r

Appendix 7 Current measurements, Beam in oil quay, Kalundborg

Appendix 8 Potential measurements, Beam in oil quay, Kalundborg

Reference electrodes were cast in on Oct. 6, 1999.

Log-book

Date	On	Off	10 min. off	2 h /2.5 h off	4 h off	23 h off	24 h off	25.5 h off
Oct. 14, 1999	x	x						
Jan 24, 2000	x	x	x					
Jul 3, 2000	x	x		x				
Aug 3-4, 2000	x	x		x	x	x	x	x

Current measurements, Beam, Kalundborg

Date	Temperature	Anode no.	Current, uA Using a potentiostat	over resistance after 10 sec. Current, uA	Stable value Current, uA	Resistance
14-10-99	ca. 9	1		800		1 ohm
14-10-99	ca. 9	2		600		1 ohm
14-10-99	ca. 9	3		1000		1 ohm
14-10-99	ca. 9	1 til 3		1200	300	1 ohm
24-01-00	2	1	76/97			
24-01-00	2	2	35			
24-01-00	2	3	< 30			
24-01-00	2	1 til 3	34			
03-07-00	16	1	610			
03-07-00	16	2	240			
03-07-00	16	3	280			
03-07-00	16	1 til 3	220			
03-08-00	18	1	180			
	18	2	380			
	18	3	350			
	18	1 til 3	810		700	1 ohm

Referencefelt

Reference-elektroder			Dato: 14-10-99	
			Potentiale, mV vs. ref.	AC-modstand
Placering	nr.	Indstøbt dato	On	kohm
i rep.	6	06/10/99	-454	2.53
i rep.				
i eksisterende	5	06/10/99	-484	3.30
i eksisterende				

Anodefelt

Reference-elektroder			Dato: 14-10-99			
			Potentiale, mV vs. ref.			AC-modstand
Placering	nr.	Indstøbt dato	off	on 0t	on 0,5t	kohm
i eksisterende	1	06/10/99	-362	-377	-372	3.13
i eksisterende	2	06/10/99	-363	-370	-369	5.19
i rep.	3	06/10/99	-365	-370	-371	2.03
i rep.	4	06/10/99	-372	-393	-385	3.17

				strøm 12:35	strøm 13:00	strøm 12:35
		Dato:		1 ohm shunt	1 ohm shunt	Fluke 87- BAC
Anoder	nr.	Modstand (anod	Spænding mV mod arm.	microAmp (målt i	microAmp (m	microAmp
	1+2+3	.-	.-	*800**	300	
	1	107	848	*600**		*250**
	2	114	863	*1000**		*170**
	3	93	700	*1200**		*170**

**Hastigt faldende værdier*

	Dato
	Tid
Anoder frakoblet armering	
Strømmåling	
Potentiale, referenceelektroder	
EKP-måling, start	
EKP-måling, slut	
AC-måling, elektroder	

Referencefelt

Reference-elektroder			Dato: 24-01-00	
			Potentiale, mV vs. ref.	AC-modstand
Placering	nr.	Indstøbt dato	On	kohm
i rep.	6	06/10/99	-415	7.07
i rep.				
i eksisterende	5	06/10/99	-446	7.10
i eksisterende				

Anodefelt temperatur oC: 2

Reference-elektroder			24/01/00			
			Potentiale, mV vs. ref.			AC-modstand
Placering	nr.	Indstøbt dato	on/off 3 mdr+10 dg	off 10 min.	10 min. Depol	kohm
i eksisterende	1	06/10/99	-341	-346	-5	7.97
i eksisterende	2	06/10/99	-327	-326	1	12.67
i rep.	3	06/10/99	-314	-312	2	5.89
i rep.	4	06/10/99	-323	-320	3	8.68

			strøm 12:30	strøm 13:00		strøm 12:45
		Dato:	kompensationsmålemetode			Elma 200microA
Anoder	nr.	Modstand (anod	microAmp 1. Måling	microAmp 2. Måling**		microAmp
	1+2+3	124.7	76	*97*		80-70*
	1	400	35	.-		*150-40**
	2	390	<30	.-		*40-20**
	3	333	34	.-		*160-40**

** måling foretaget ca. ½ time efter skiftevis afbry. af anoder **Hastigt faldende værdier*

	Dato
	Tid
Anoder frakoblet armering	
Strømmåling	
Potentiale, referenceelektroder	
EKP-måling, start	
EKP-måling, slut	
AC-måling, elektroder	

Referencefelt

Reference-elektroder			Dato: 03-07-00	
			Potentiale, mV vs. ref.	AC-modstand, on/off
Placering	nr.	Indstøbt dato	On10:10/off 12:30	kohm
i rep.	6	06/10/99	-424/-424	3.61/3.54
i rep.				
i eksisterende	5	06/10/99	-450/-450	4.21/4.22
i eksisterende				

Anodefelt temperatur oC: 15 ved on/off og 17,5 ved off 2 timer

Reference-elektroder			03/07/00			
			Potentiale, mV vs. ref.			AC-modstand
Placering	nr.	Indstøbt dato	on/off 8 mdr+ 27 dg	off 2 timer	2 timers depol.	kohm
i eksisterende	1	06/10/99	-361/-361	-338	23	4.84
i eksisterende	2	06/10/99	-337/-337	-326	11	6.03
i rep.	3	06/10/99	-324/-324	-313	11	3.39
i rep.	4	06/10/99	-355/-355	-317	38	4.49

			strøm 10:10			
Temp.	15gr.C	Dato:3/7-00	**kompensationsmålemetode**			
Anoder	nr.	Modstand (anod	microAmp 1. Måling			
	1+2+3	59	610			
	1	187	240			
	2	174	280			
	3	155	220			

		modstand	strøm 10:10	modstand		strøm 12:30
Temp.	17,5gr.C	Dato:3/7-00	**shuntmodstand 1 ohm**			
Anoder	nr.	Modstand	mV=mA	Modstand		mV=mA
	1+2+3	59	610	58	610	280
	1	187	.-	180	240	.-
	2	174	.-	169	280	.-
	3	155	.-	150	220	.-

STATOIL, FOSROC
DATO: 3. - 4. aug. 2000
Måleresulteter:

Placering	nr.	korr. pot	inst. off.pot	off.pot.2,5t	off pot.4t	off.pot.23t	off.pot.24t	off.pot.25,5t
Anodefelt	:	mV	mV	mV	mV	mV	mV	mV
i eksistere	1	-362	-374	-342	-338	-334	-334	-333
i eksistere	2	-363	-342	-325	-324	-321	-321	-321
I rep.	3	-365	-328	-313	-312	-309	-309	-309
I rep.	4	-372	-368	-318	-313	-307	-307	-307
Referencefelt:								
i eksistere	5	-484	-423	-423	-422	-423	-423	-423
i rep.	6	-454	-447	-446	-446	-447	-447	-446

Polarisering/depolarisering

Placering	nr.	Korr. Pot.	polarisering	depol. 2,5t	depol. 4t	depol. 23t	depol. 24t	depol. 25,5t
Anodefelt	:	mV	mV	mV	mV	mV	mV	mV
i eksistere	1	-362	12	32	36	40	40	41
i eksistere	2	-363	-21	17	18	21	21	21
I rep.	3	-365	-37	15	16	19	19	19
I rep.	4	-372	-4	50	55	61	61	61
Referencefelt:								
i eksistere	5	-484	-61	0	1	0	0	0
i rep.	6	-454	-7	1	1	0	0	1

Referencefelt					
Reference-elektroder			Dato:03-08-2000		
			Potentiale, mV vs. ref.	AC-modstand	mV
Placering	nr.	Indstøbt dato	on/off	kohm	off 2 timer
i eksisterende	5	06-10-99	-423/-423	3,35	-423
i rep.	6	06-10-99	-447/-447	4,02	-446
Anodefelt		temperatur oC:	18		
Reference-elektroder			Dato:03-08-2000		
			kl. 11:00		kl. 13:00
			mV	AC-modstand	mV
Placering	nr.	Indstøbt dato	on/off 9 mdr+ 28 dg	kohm	off 2 timer
i eksisterende	1	06-10-99	-374/-374	4,71	-342
i eksisterende	2	06-10-99	-342/-342	5,81	-325
I rep.	3	06-10-99	-328/-328	3,22	-313
I rep.	4	06-10-99	-368/-368	4,22	-318
Temp.			**kompensationsmålemetode**		
Anoder	nr.	Modstand (anod	microAmp		
	1+2+3	53	810		
	1	170	180		
	2	159	380		
	3	141	350		
			shuntmodstand 1 ohm		
Anoder	nr.		mV=mA		
	1+2+3		0,7		

Referencefelt					
Reference-elektroder			Dato:03-08-2000		
			Potentiale, mV vs. ref.	AC-modstand	mV
Placering	nr.	Indstøbt dato	on/off	kohm	off 4 timer
i eksisterende	5	06-10-99			-422
i rep.	6	06-10-99			-446
Anodefelt		temperatur oC:	18		
Reference-elektroder			Dato:03-08-2000		
			kl. 11:00		kl. 15:00
			mV	AC-modstand	mV
Placering	nr.	Indstøbt dato	on/off	kohm	off 4 timer
i eksisterende	1	06-10-99			-338
i eksisterende	2	06-10-99			-324
I rep.	3	06-10-99			-312
I rep.	4	06-10-99			-313

Referencefelt					
Reference-elektroder			Dato:04-08-2000		
			Potentiale, mV vs. ref.	AC-modstand	mV
Placering	nr.	Indstøbt dato	on/off	kohm	off 23 timer
i eksisterende	5	06-10-99			-423
i rep.	6	06-10-99			-447

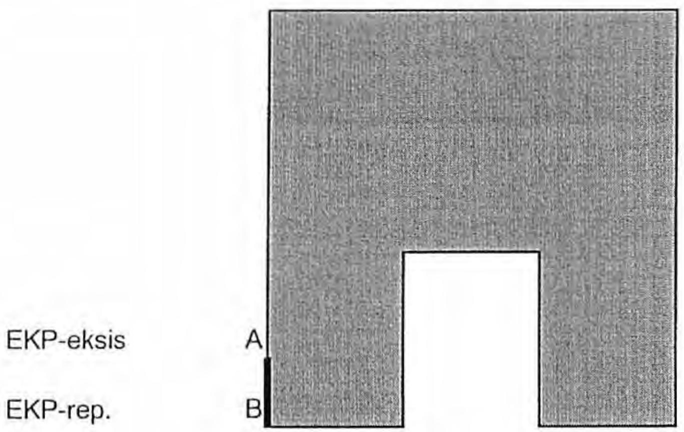
Anodefelt		temperatur oC:	17		
Reference-elektroder			Dato:04-08-2000		
			kl. 11:00		kl. 10:00
			mV	AC-modstand	mV
Placering	nr.	Indstøbt dato	on/off	kohm	off 23 timer
i eksisterende	1	06-10-99			-334
i eksisterende	2	06-10-99			-321
I rep.	3	06-10-99			-309
I rep.	4	06-10-99			-307

Referencefelt					
Reference-elektroder			Dato:04-08-2000		
			Potentiale, mV vs. ref.	AC-modstand	mV
Placering	nr.	Indstøbt dato	on/off	kohm	off 24 timer
i eksisterende	5	06-10-99		3,34	-423
i rep.	6	06-10-99		3,99	-447
Anodefelt		temperatur oC:	17		
Reference-elektroder			Dato:04-08-2000		
					kl. 11:00
			mV	AC-modstand	mV
Placering	nr.	Indstøbt dato	on/off	kohm	off 24 timer
i eksisterende	1	06-10-99		4,67	-334
i eksisterende	2	06-10-99		5,76	-321
I rep.	3	06-10-99		3,2	-309
I rep.	4	06-10-99		4,18	-307

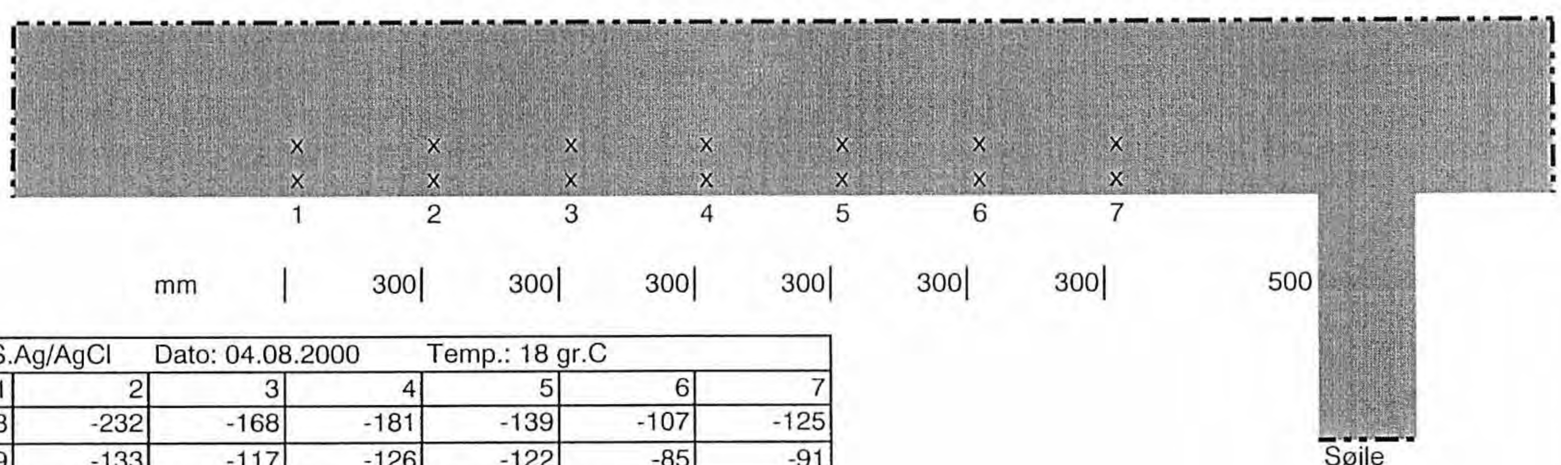
Referencefelt					
Reference-elektroder			Dato:04-08-2000		
			Potentiale, mV vs. ref.	AC-modstand	mV
Placering	nr.	Indstøbt dato	on/off	kohm	off 25,5 timer
i eksisterende	5	06-10-99			-423
i rep.	6	06-10-99			-446
Anodefelt		temperatur oC:	17		
Reference-elektroder			Dato:04-08-2000		
			kl. 11:00		kl. 12:30
			mV	AC-modstand	mV
Placering	nr.	Indstøbt dato	on/off	kohm	off 25,5 timer
i eksisterende	1	06-10-99			-333
i eksisterende	2	06-10-99			-321
I rep.	3	06-10-99			-309
I rep.	4	06-10-99			-307

STATOIL, FOSROC
EKP-målinger

Bjælketværsnit



Bjælke



Måleresultater mV VS.Ag/AgCl	Dato: 04.08.2000		Temp.: 18 gr.C			
	1	2	3	4	5	6	7
A	-178	-232	-168	-181	-139	-107	-125
B	-149	-133	-117	-126	-122	-85	-91

EKP-måling1.xls08-08-00

Appendix 9 Chloride Analysis

COWI

COWI Betonlaboratorium

Bestemmelse af kloridindhold ved Volhard titrering

Sagsnr.:	50176A	Sagsnavn:	Saltlageret, Hornum
Dato:	22-06-99	Init:	UPJ
		Sagsing.:	JRE
		Rekvirent:	JRE

Prøveudtagningsmetode: 1-4=borestøv, Kerne 1 og 2=knust beton

Metodereference: Hærdnet betons kloridindhold
Svarer i alle væsentlige punkter til Dansk Standard 423.28

Resultatskema:

Prøvebetegnelse	Dybde	Prøvemasse g	kloridindhold % Cl- af betonvægten
1	0-25 mm	10,01	0,72
	25-50 mm	10,00	0,69
2	0-25 mm	10,02	0,59
	25-50 mm	10,02	0,50
3	0-25 mm	10,01	0,63
	25-50 mm	10,03	0,89
4	0-25 mm	10,03	0,26
	25-50 mm	10,01	0,29
Kerne 1	0-20 mm	10,01	0,60
	20-40 mm	10,01	0,41
	40-60 mm	10,03	0,26
	60-80 mm	10,00	0,16
	80-100 mm	10,02	0,04
	100-120 mm	10,00	0,01
Kerne 2	0-20 mm	10,01	0,62
	20-40 mm	10,02	0,59
	40-60 mm	10,01	0,91
	60-80 mm	10,03	0,58
	80-100 mm	10,01	0,41
	100-120 mm	10,03	0,33

COWI Betonlaboratorium

Bemærkninger: Kloridindholdet er angivet som masse% af tør beton, og kan omregnes til:
Natriumklorid% ved at gange med 1.65
Calciumklorid% ved at gange med 1.57
Chloridindholdet i forhold til cementvægten ved at gange med 6-8

Udført: [signature] Godkendt: [signature]

COWI

COWI Betonlaboratorium

Bestemmelse af kloridindhold ved Volhard titrering

Sagsnr.:		Sagsnavn:	Fosroc
Lab.nr.:	52042-W-12	Init:	UPJ
Dato:	26-06-2000	Sagsing.:	BBU
		Rekvirent:	BBU

Prøveudtagningsmetode: Knust beton

Metodereference: Hærdnet betons kloridindhold
Svarer i alle væsentlige punkter til Dansk Standard 423.28

Resultatskema:

Prøvebetegnelse	Dybde	Prøvemasse g	Kloridindhold % Cl- af betonvægten
Kerne	0-27 mm	10,00	0,24
	27-59 mm	10,00	0,16

COWI Betonlaboratorium

Bemærkninger:

Kloridindholdet er angivet som masse% af tør beton, og
kan omregnes til:
Natriumklorid% ved at gange med 1.65
Calciumklorid% ved at gange med 1.57
Chloridindholdet i forhold til cementvægten ved at gange med 6-8

Udført: U. Jeppesen

Godkendt:

V1 (ml) Mængde AgNC	V2 (ml) Mængde NH4SCN
9,00	2,15
7,00	2,60

Appendix 10 Resistance of concrete

Dato: 04-08-2000		Længde			Diameter			Modstand	Resistivitet
Statoil, Fosroc	Prøvenr.	L1 mm	L2 mm	gennemsnit mm	D1 mm	D2 mm	gennemsnit mm	kohm	Kohm*cm
Betonkerner i referencefelt:									
Eksisterende beton									
Kerne 1, 0-26,6 mm (heraf ca. 3 mm sprøjtepu	1 uden mætning	31,3	21,8	26,6	22,9	23,0	23,0	5,43	8,46
Kerne 1, 26,6-59,3 mm	2 uden mætning	35,7	29,6	32,7	23,0	23,0	23,0	9,65	12,27
I reparation									
Kerne 2, 0-32,0 mm	3 uden mætning	33,2	30,8	32,0	23,0	23,0	23,0	3,96	5,14
Kerne 2, 32,0-56,5 mm	4 uden mætning	25,2	23,7	24,5	23,2	23,1	23,2	3,08	5,30
Kerne 2, 0-32,0 mm	3 efter mætning	33,2	30,8	32,0	23,0	23,0	23,0	9,84	12,78
Kerne 2, 32,0-56,5 mm	4 efter mætning	25,2	23,7	24,5	23,2	23,1	23,2	4,48	7,73

Uden mætning: Målinger udført umiddelbart efter hjemkomst
Efter mætning: Måling udført efter lagring i Calciumhydroxid til konstant vægt.

Udført af:
Kontrolleret af:
Godkendt af:

KING FREDERIK IX's AWARD
FOR EXCELLENCE
IN EXPORT

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