

# CP Survey Report

## ROV Survey Galvanic Anodes

Trondheim Havn dep. Verdal

## Cathodic Protection Survey Report

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## 1. Introduction

Deepwater Norway AS has been contracted by Trondheim Havn to carry out Cathodic Protection Survey of Galvanic Anodes for the Verdal harbour.

Deepwater Norway AS has carried out the CP survey for the Verdal harbour. The survey is based on the information received from the client, original technical data of the anodes, installation diagram for the galvanic anodes. The anodes are evenly distributed in two elevations along the length of the shell and sheet pile structures, see distribution drawings in the Appendixes.

The survey has taken into account the Galvanic Anode Cathodic Protection (GACP) system with the purpose of evaluations that the existing Galvanic Anode Cathodic Protection (GACP) system can still provide sufficient cathodic protection for the Verdal Harbour.

## 2. Definitions and Abbreviations

CP	Cathodic Protection
GACP	Galvanic Anode Cathodic Protection
Ag/AgCl	Silver/Silver Chloride reference electrode (All potential numbers in this report are vs. Ag/AgCl wrt. Seawater. All potential references in this report are given with ref to Ag/AgCl.
SoW	Scope of Work
Al-In-Zn:	Aluminium- Indium - Zinc
DNV	Det Norske Veritas
CP Protection potential	-800 mV vs Ag/AgCl wrt. Seawater /1/
ROV II	Deepwater`s CP contact probe
ROV	Remotely Operated Vehicle

### 3. Executive Summary

The harbour is considered to be sufficiently protected against corrosion with the overall measured potentials within the cathodic protection criterion /1/. The anodes shows an estimated consumption of around 40% after nine years, which gives a significantly lower current demand than used in the design /3/. The measured anode potentials show that the CP system is active, with low or insignificant degree of passivation. The remaining life of the CP system is calculated to 8 years.

Next inspection is recommended for 2018 with the same program with some additional cleaning of anodes and sheet piles.

### 4. CP system description

The CP system installed to cathodically protect the pile sheets consist of 106 Al-In-Zn anodes, each 74,7 Kg /2/ designed by Skarpenord Corrosion AS /3/. The galvanic anodes are flush mounted, evenly distributed in two rows along the length of the harbor. The anodes were installed in 2007 with a total net anode mass of 7 918 Kg, with a design life of 15 years and is currently in 9<sup>th</sup> year of exposure.

### 5. Scope of Work

The SoW for the inspection and procedure is described in /4/:

- General visual inspection of pipe sheets and anodes
- Contact measurements on selected number of anodes for anode electrochemical potential measurements
- Dimensional measurements on selected number of anodes to determine anode mass consumption over 9 years
- Contact measurements on pile sheets to measure structures electrochemical potential to verify level of CP

### 6. Report Findings

#### 6.1 Visual inspection

The anodes were inspected visually for mechanical damages, general evaluation of conditions and extent of marine growth. The visual inspection reveal that the sheet piles and anodes are covered by marine growth. Apparently, the steel is covered mostly by softer marine growth, but seems intact with no wear or damages. It was, however noted that a ladder dropped and was left hanging on the cell piles. The anodes are covered with harder marine growth, see pictures below.



Figure 6-1 Picture showing sheet piles with marine growth and anode with cleaned section



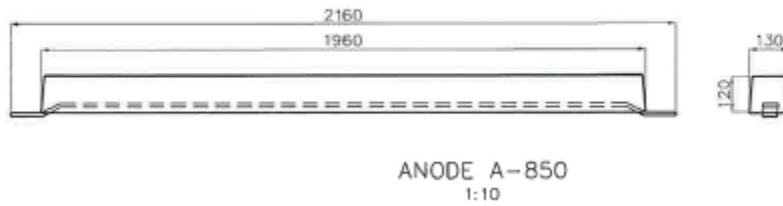
Figure 6-2 Picture of cleaned anode showing large pits and hard marine growth outside the jetted area

## 6.2 Galvanic anodes

Direct contact potential readings with an ROV II probe were carried out on 11 of the 106 anodes. **Table 6-1** below shows the findings. Anode consumption (%) were measured by utilizing a gauge incorporated on the ROV handle, fabricated to comply with the original anode dimensions. 16 of the 106 anodes were measured for consumption evaluations. The first anode on the shell piles is buried or not physically present.

**Table 6-2** below shows the anodes consumption in percentage of the original anode dimension.

The original anode dimension is shown below:



**Figure 6-3: Original anode dimensions /3/**

### 6.2.1 Contact Readings- Anodes

**Table 6-1: Direct contact potential readings of the Anodes.**

Section	Number of Anode	Measured Potential (mV)
Cell Shell Piles	1	-1044
	2	-1039
Section A-A along port side	3	-1040
	4	-1017
	5	-1041
	6	-989
	7	-1028
Section B-B along port side	8	-1022
	9	-1065
Section C-C along port side	10	-1046
	11	-1027

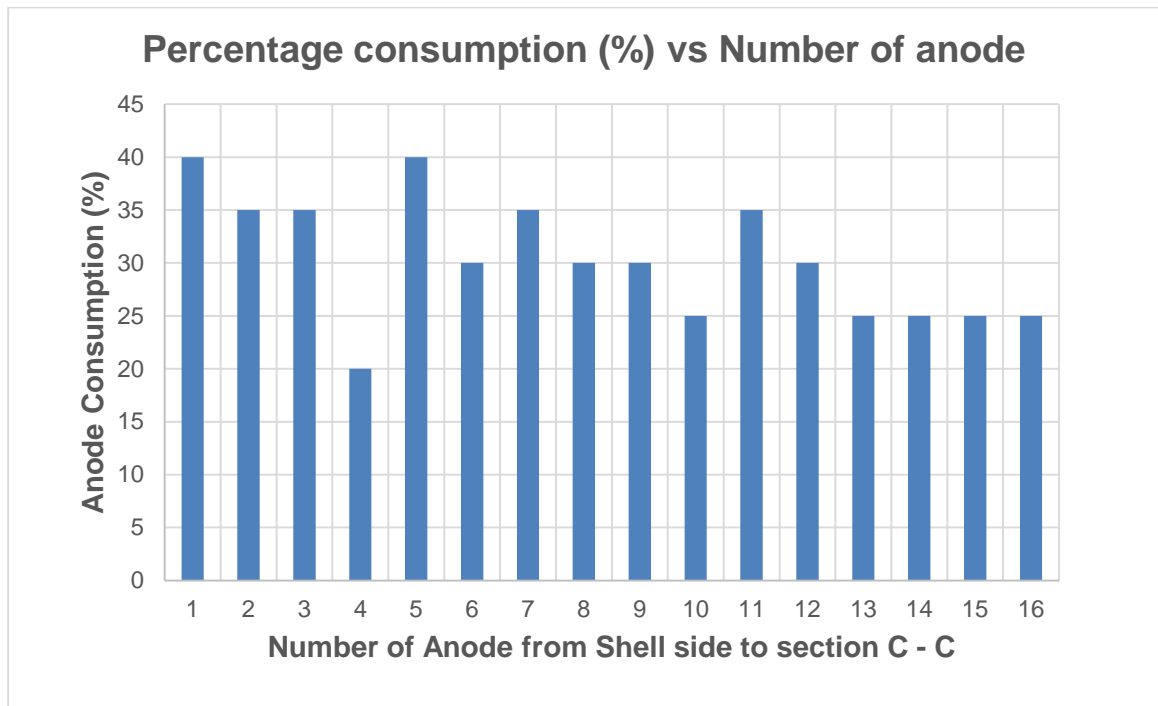
The potential measurements above shows that the anodes are active with good potential levels. One exception is anode number 6 showing a potential of -989 mV. This reading may indicate that this anode is showing tendency of passivation, or the reading may be caused by poor contact between the ROV II stab nose and the anode mass due to hard marine growth.

### 6.2.2 Consumption Measurements (% of original anode dimension)

The following table shows measured anode consumption with the fabricated gauge. It should be noted that, though the actual anodes were cleaned with hydra jetting there was still some hard marine growth left which may cause inaccuracy of the measurements.

**Table 6-2: Percentage consumption readings of the original anode dimension [Figure 6-3].**

Section	Number of Anode	Anode Consumption (%)
Cell Shell piles	1	40
Section A- A along the port side	2	35
	3	35
	4	20
	5	40
	6	30
	7	35
	8	30
	9	30
Section B -B along the port side	10	25
	11	35
	12	30
	13	25
Section C- C along the port side	14	25
	15	25
	16	25



**Figure 6-4: Graph showing measured anode consumption**

Six (6) of sixteen (16) anodes were measured to 35-40% consumption. From the inspection videos (sent separately on e-mail) one can see that marine growth is significant and is hiding most of the anode surfaces, but one can see larger pits and some uneven consumption on the anodes (see also Figure 6-1 and Figure 6-2). Hence, as a conservative approach evaluation of remaining life in the sections below are based on 40% consumption over 9 years.

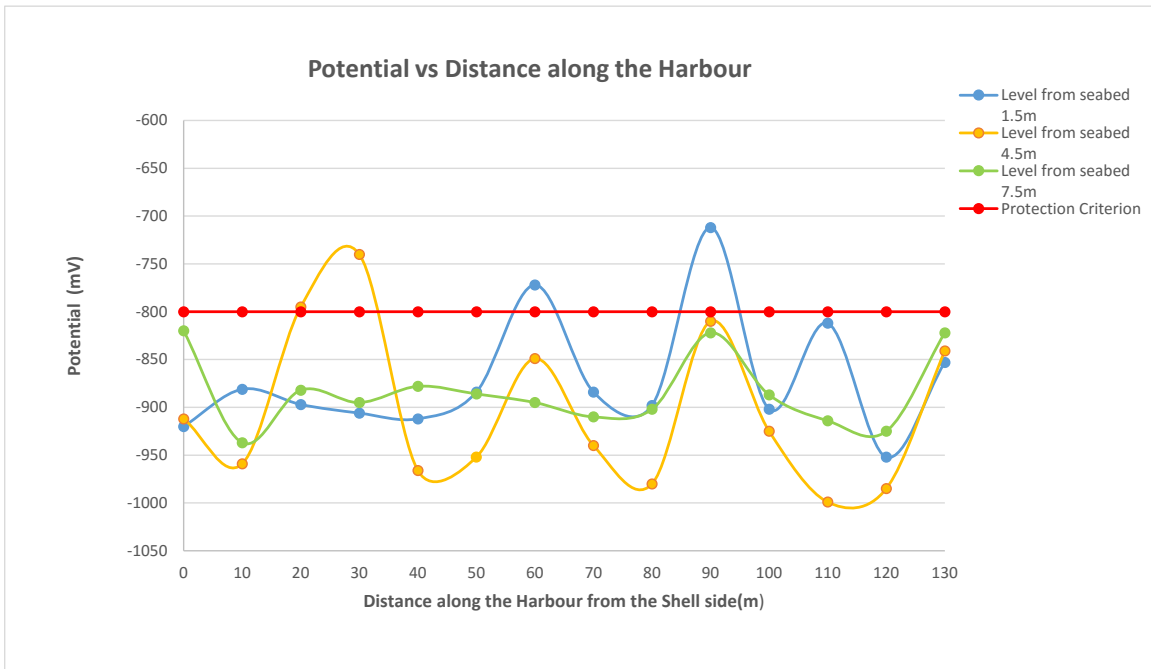
### 6.3 Sheet piles

Direct contact potential readings with an ROV II probe was carried out on 42 locations along the structure's length, started from the three cell sheet piles side. **Table 6-3** and **Figure 6-5** below show the contact measurements. Appendix II shows the locations on the map. Toward the end of the pile sheets (section C-C), some of the anodes were submerged in mud.

### 6.3.1 Contact Readings- Shell and Sheet Piles

**Table 6-3: Direct contact potential readings on the Structures**

Section	Distance from Shell side. (m)	Depth 1.5 m reference from seabed (mV)	Depth 4.5 m reference from seabed (mV)	Depth 7.5 m reference from seabed (mV)
Cell Shell piles	0	-920	-912	-820
	10	-881	-959	-937
	20	-897	-795	-882
Section A -A along the port side	30	-906	-740	-895
	40	-912	-966	-878
	50	-884	-952	-886
	60	-772	-849	-895
	70	-884	-940	-910
Section B – B along the port side	80	-898	-980	-902
	90	-712	-810	-822
	100	-902	-925	-887
Section C – C along the port side	110	-812	-999	-914
	120	-952	-985	-925
	130	-853	-841	-822



**Figure 6-5: Graph showing structure potential readings along the harbour.**

From the forty two (42) contact measurements, four (4) show potential more positive than the -800 mV protection criterion. These may be a result of poor contact between the probe contact tip and the steel due to marine growth, some passivation tendency of nearest anodes or tidal flow increasing during inspection.

All measurements outside the protection criterion are from -712 mV as the most positive to -795 mV as the most negative. None of the four potential values gives a risk of corrosion, but will be monitored closely during the next inspection.

## 7. Remaining life of the CP system

The prediction of remaining life of the CP system is based on 40% anode consumption as defined in section 6.2.2 and structure description in /3/.

- Total installed anode mass in 2007: 7 918 Kg
- 40% anode consumption: 3 167 Kg
- Total surface area including structure in sediment and sea: 2 380 m<sup>2</sup>

Then the average current during 9 years can be calculated with following formula /1/:

$$I = \frac{M \times \theta}{L \times 8760} \tag{eq 1}$$

Where:

I = Current in Ampere

M = net anode mass in Kg

Θ = Electro chemical capacity in Ah/year

L = Exposed life in years

8760 = hours per year

With (eq 1) the average current demand since 2007 then becomes

$$I = \frac{7\,918\text{ Kg} \times 2585\text{ Ah/kg}}{9\text{ years} \times 8760\frac{\text{hours}}{\text{year}}} = 104\text{ Ampere}$$

Then average current density becomes 104 Ampere / 2 380 m<sup>2</sup> = 44 mA/m<sup>2</sup>

**Note:** The 2585 Ah/kg used in the design /3/ is higher than recommended by DNV /1/

Based on the above calculated current density the remaining life can be calculated with the following formula (1)

$$L = \frac{M \times u \times \varepsilon}{I \times 8760} \tag{eq 2}$$

Where

L = remaining life in years

M = remaining anode mass in Kg

u = utility factor (0,85 for long flush anodes /1/)

ε = electro chemical capacity in Ah/kg

I = current demand in Ampere

8760 = hours per year

With (eq 2) the calculated lifetime then becomes:

$$L = \frac{4\,750\text{ Kg} \times 0,85 \times 2000\frac{\text{Ah}}{\text{Kg}}}{104,72\text{ A} \times 8760\frac{\text{hour}}{\text{year}}} = 8,8\text{ Years}$$

Note: In the equation above 2000 Ah/kg capacity is used as recommended by DNV /1/.

See summary in **Table 7-1**

**Table 7-1 Current and lifetime calculations**

<b>Calculating current demand since 2007</b>	
Total anode mass installed in 2007 (Kg) (106 anoder @ 74,7 Kg)	7 918
40% Consumption of 7 918 Kg	3167
Total surface area in sediment and seawater (m2)	2 380
Calculating average current since 2007 (Ampere)	104
Calculating average current density since 2007 (mA/m2)	44
<b>Calculating theoretical remaining lifetime (years)</b>	
Remaining anode mass (Kg)	4 751
Calculated remaining life (years)	8,8

It should be noted that the above calculated anode lifetime is based on the average current drain to structure surfaces exposed to seawater and structure surfaces exposed to sediments. To benefit from maintenance current demand the CP system should be retrofitted well in time before 2024 rather than allowing the structure to de-polarise as a result of consumed anodes which will require higher polarisation current and larger quantity of anodes.

## 8. Data Discussion

The harbor area covered in this inspection is considered as sufficiently protected for the time being. The four structure potential readings showing more positive potential than the defined protection criterion in /1/ will not cause any significant corrosion. The free corroding potential of carbon steel in seawater is around -600 mV. At this potential the corrosion rate will be in order of 0,1-0,3 mm/year. If the steel is polarised around 100 mV from it's native (free corrosion) potential the cathodic current will decrease with one decade such that the corrosion rate is reduced to around 10%, so in order of 0,01 – 0,03 mm/year.

As this was the first inspection since installation, the results will be stored as base line for future inspections. The next inspection should be carried out in 2018 to determine whether structure and anode potentials are changing in positive direction and to give a better basis for a retrofit CP design.

The hard marine growth on the anodes may be a source of error when evaluating anode consumption. Hence, one should evaluate to brush the anodes before next measurement.

## 9. Conclusions and Recommendations

- The harbour is considered to be sufficiently protected against corrosion
- The estimated anode consumption after 9 years is 40% with a calculated remaining life of 8 years. The true remaining life may be somewhat shorter because the anodes will lose capacity when approaching 80% utilization. Hence, one should take into account a CP retrofit in 5-6 years' time.
- The anode potentials are generally found sufficient with exception of one anode. This will be further inspected during next survey.
- Next inspection should be carried out in 2018 with the same program defined for this 2016 inspection, with some additional cleaning of sheet piles for visual inspection of the integrity.

## 10. References

/1/: DNV RP-B401-2010: Cathodic Protection Design

/2/: Document "Anoder på Verdal Havn 2007"

/3/: Skarpenord prosjektbeskrivelse

/4/: Deepwater Norway AS Document no 3-P1040-101-WIS-001 Inspection Procedure Verdal Havn



## 12. Appendix II: Layout showing structure markings for direct contact potential measurement.

