Statens vegvesen

Ferry free E39 –Fjord crossings Bjørnafjorden | 304624

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# Preferred solution, K12 – Appendix O

# Material technology and steel in marine environment

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CONCEPT DEVELOPMENT, FLOATING BRIDGE E39 BJØRNAFJORDEN

# Preferred solution, K12

## Appendix O – Material technology and steel in marine environment

CLIENT

Statens vegvesen

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AAS-JAKOBSEN COWI Multiconsult

JOHS HOLT AkerSolutions entail NGI DISSING+WEITLING architecture a|s mossmaritime

**REPORT**

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| CONTACT | Øyvind Kongsvik Nedrebø | PREPARED BY | Guri Elisabeth Nustad<br>Tor Johansen<br>Ane Kristin Haraldsen |
| | | RESPONSIBLE UNIT | AMC |


**SUMMARY**

The bridge design life is 100 years and this document discusses material selection and means of providing corrosion protection to limit the need for future inspections, maintenance, and replacements. The recommended solutions are summarised in the table below.

The most severe exposure conditions are in the splash zone and in this area carbon steel will be replaced by a corrosion resistant alloy, 25Cr DSS. Welding of carbon steel to 25Cr DSS is fully manageable provided properly qualified procedures and suitable materials are used.

High level cathodic protection (CP) calculations have been performed. The anode weight requirements vary dependent on the selected CP design life and extent of coating on the 25Cr DSS plates. Detailed calculations should be performed in next phase.

Corrosion allowances (CA) for the mooring chains have been evaluated based on standards and requirements included in the SVV design basis. Since the top chain is situated below the splash zone, the same CA as for the bottom chain is proposed (0.2 mm/year).

Recommendations for further work is included in a separate section at the end of the document.


| Bridge section | Generic material selection | Proposed corrosion protection |
|---|---|---|
| Upper section: Underside of road structure, columns and pontoon above splash zone | Carbon steel | SVV system 2 |
| Pontoon, splash zone and submerged section | Carbon steel with solid 25 Cr duplex stainless steel in splash zone | NORSOK System 7B + aluminium based sacrificial anodes |
| Ballast water tank, active tank | Carbon steel | NORSOK system 7B + zinc based sacrificial anodes |
| Ballast water tank, passive tank | Carbon steel | NORSOK system 1 |
| Empty sections / voids in the pontoon with active dehumidification | Carbon steel | NORSOK system 3G |
| Empty sections / voids in the pontoon *without* active dehumidification | Carbon steel | NORSOK system 1 |



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| 0 | 15.08.2019 | Final issue | Guri E. Nustad | Tor Johansen | S. E. Jakobsen |
| REV. | DATE | DESCRIPTION | PREPARED BY | CHECKED BY | APPROVED BY |

# TABLE OF CONTENTS

# 1 Scope

This document is a further development of the material selection and means of providing corrosion protection proposed in the phase 3 concept study for Bjørnafjorden floating bridge.

The bridge design life is 100 years and the scope related to material selection, and corrosion protection is to propose solutions that will limit the need for future inspections, maintenance, repairs and replacements.

Different methods for protection are required, depending on the exposure to the elements. The exposure conditions for the following zones are discussed in separate sections of this document:

- The upper external section consisting of the pontoon section above splash zone and the above bridge structure
- The splash zone of the pontoons defined as a height of 4 m between the upper and submerged parts of the construction
- The submerged external sections of the pontoons
- The ballast water tanks inside the pontoons
- Voids/empty sections

In the earlier study, duplex stainless steel with 25 %Cr (25Cr DSS) was recommended as a suitable corrosion resistant alloy (CRA) for the splash zone. In this phase, only the option with solid 25Cr DSS as replacement for carbon steel in the splash zone is further evaluated.

# 2 Abbreviations and Explanation

| | |
|---|---|
| 25Cr DSS | Duplex Stainless Steel with 25 % Cr |
| 22Cr DSS | Duplex Stainless Steel with 22 % Cr |
| SS 316 | Austenitic Stainless Steel type AISI 316 |
| CP | Cathodic Protection |
| CRA | Corrosion Resistant Alloy |
| DFT | Dry Film Thickness |
| FMECA | Failure Mode, Effect and Criticality Analysis |
| GRP | Glass Fibre Reinforced Plastic |
| HAZ | Heat Affected Zone |
| HISC | Hydrogen Induced Stress Cracking |
| MIC | Micro Biological Corrosion |
| RH | Relative Humidity |
| SVV | Statens Vegvesen |
| TSA | Thermally Sprayed Aluminium |
| TSZ | Thermally Sprayed Zinc |

# 3 General

## 3.1 Methods of providing corrosion protection

In principle, the following methods are available to avoid corrosion:

- Select corrosion resistant materials
- Reduce corrosivity of the environment by e.g. dehumidification
- Introduce a protective barrier against the corrosive environment by e.g. coating application
- Make the steel immune to the corrosive environment by cathodic protection (CP)

Selecting corrosion resistant materials is theoretically an option for all parts of the bridge, but is cost effective only for parts exposed to very corrosive conditions combined with poor access for later maintenance and repairs. Herein, this option is therefore only evaluated for the splash zone.

For voids and empty compartments, corrosion can be limited by reducing the relative humidity (RH). Below 60% RH corrosivity is strongly reduced, below 40%RH corrosion will not occur.

A corrosion barrier in the form of a coating system is a common way of protecting steel structures and is recommended for carbon steel parts exposed to marine environment. For carbon steel submerged in seawater coating combined with cathodic protection is recommended.

Selection of coating systems shall be based on an expectancy to provide corrosion protection for minimum 20 to 30 years prior to first maintenance. First maintenance should be carried out when coating degradation reaches Ri3, i.e. European rust scale Re3 that equals 1 % of the surface area being affected as advised in ISO 4628 /Ref. 1/ and ISO 12944 /Ref. 2/ Performing the first repair at this stage is generally regarded as cost effective regardless of type of coating system.

The following parameters are of utmost importance to achieve durable corrosion protection:

- A coating friendly design is required. This means a design with slope to avoid water trapping, limiting corners and edges, avoiding narrow gaps, etc. To ensure that such points are captured and minimised, a design review meeting should be arranged prior to finalising the bridge design.
- Ensure proper surface preparation and coating application. This is related to:
    - Rounding of edges;
    - Surface cleanliness;
    - Surface roughness;
    - Remaining chloride content on the steel surface;
    - Conditions during application: temperature, dew point, relative humidity;
    - Workmanship: Operator knowledge and experience, equipment and QC inspection.

Focus on these parameters represents the key to success. Hence, prior to selecting a paint shop, their facilities, knowledge and experience need to be verified.

It should be noted that the cost of the coating products is low compared to the total application costs when including surface preparation, application, and quality control. Hence, it is recommended that the actual coating products are selected based on technical suitability and pre-qualification only.

CP is required for carbon steel structures submerged in seawater. CP can be provided by installation of sacrificial anodes or by application of an impressed current cathodic protection system. Herein, CP by sacrificial anodes is recommended both externally and internally.

Coating system references are based on NORSOK M-501 /Ref. 15/.

## 3.2 Material Requirements – Structural Steel

Håndbok R762 Prosesskode 2, prosess 85, /Ref. 3/ specifies requirements to structural materials for bridges. Steel structures shall be CE-marked in accordance with NS-EN 1090, /Ref. 4/and as such, steel materials according to NS-EN 1090-2 /Ref. 24/ and R762 shall be used.

For 25Cr DSS materials, proposed material requirements are included herein.

### *3.2.1 Carbon Steel*

Structural steel shall be delivered according to the standards and additional requirements specified by R762, Section 85.1.

The proposed design is based on use of plates, sections made from plate (welded girders and tubulars), and bulb profiles in grade S420.

For grade S420, SVV specifies delivery condition normalized (N / NL) or TMCP (M / ML). Normalized steel according to EN 10025-3 allows relatively high content of vanadium. This may increase risk of precipitates (vanadium carbonitrides), e.g. during stress relieving / annealing. It is proposed to evaluate whether TCMP (M / ML) should be specified as the only alternative in the next phase. See section 10.1.

### *3.2.2 25Cr DSS*

It is proposed to replace carbon steel with 25Cr DSS plates in the splash zone of the pontoons. Stringers may remain in carbon steel.

Structural design of stainless steels will be based on EN 1993-1-4 /Ref. 5/. This standard refers to the EN 10088-series for material requirements. The technical requirements for sourcing 25Cr DSS plates should therefore be based on EN 10088-2 /Ref. 6/, alternatively EN 10028-7 /Ref. 7/ which is typically used for pressure vessels.

In the oil and gas sector, NORSOK M-650 qualified manufacturers are normally required for special materials, including 25Cr DSS. However, for structural purposes, such as on the Bjørnafjorden Bridge, it is proposed not to include this as an absolute requirement.

Further, to save cost, requirements additional to the chosen material standard should be kept to a minimum. Typical additional or clarifying requirements to ensure quality materials would, however, typically include requirements to:

- steel making process,
- chemical composition
- heat treatment,
- impact testing (typically -46degC, 46/35 J),
- corrosion testing (typically ASTM G48 method A, 50 °C /Ref. 9/)

It is recommended to establish a Material Data Sheet(s) (MDS) for 25Cr DSS materials based on NORSOK M-630 /Ref. 10/. Summarizing the material requirements in such a format facilitates procurement, reduces the risk of mistakes, and is transparent and user friendly.

If the above initiatives are found not to decrease cost, NORSOK M-630 MDS D55 may be used as is, including the NORSOK M-650 qualification requirement. See section 10.1.

### *3.2.3 Bolting*

Requirements to bolting materials are specified in R762, Section 85.13. No critical bolted connections have been identified for the Bjørnafjorden bridge. Therefore, no particular evaluations are deemed necessary in this phase.

It is recommended that stainless steel bolting (type A4 / 316 SS) is used irrespective of bolt size for fixing stainless steel equipment and outfitting.

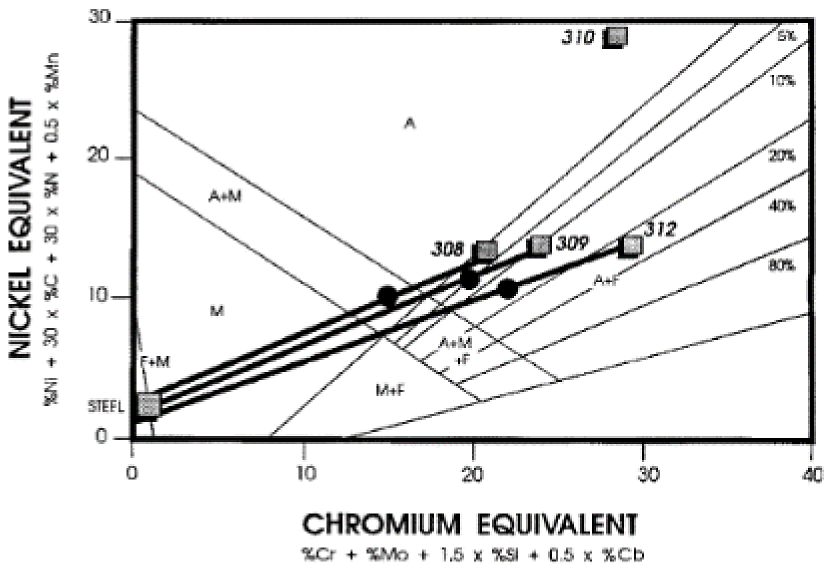
# 4 Fabrication

Håndbok R762 Prosesskode 2, prosess 85, refers to NS-EN 1090-2 for fabrication of structures. In addition to the requirements in R762, fabrication shall be based on execution class 3 (EXC3).

## 4.1 Welding of 25Cr DSS and carbon steel

Welding of dissimilar welds between 25Cr DSS and carbon steel shall be according to NS-EN 1090 and NS-EN 1993-1-4. In a dissimilar metal weld both parent metals (A and B), and the welding consumable must be considered to produce sound joints. Risk of martensite formation is primarily governed by carbon content of the base material (carbon steel side), dilution ratio, and the selected welding consumable.

Constitution (Schaeffler) diagrams can be used to predict the composition of the weld metal. A typical example showing the resulting microstructure of the weld *on the carbon steel side* (i.e. mix of a typical consumable (309) and carbon steel, identified by round marker) is given below:




As can be seen from the diagram, a carbon steel dilution of 25% results in a weld metal microstructure consisting of austenite and ferrite. Martensite is avoided. As the position of 25Cr SDSS in the diagram is to the right of the typical consumable (309), a dilution/mix with 25Cr SDSS parent material will not increase the risk of martensite formation. Risk of martensite formation is further reduced by specifying carbon steel with a limit on carbon content (typically < 0.18%). Such a limitation is not uncommon and is not believed to increase cost.

Welding of carbon steel to corrosion resistant alloys (CRA) is an established practice and various welding consumables have been used over the years. 309LMo is commonly used for welding carbon steel to CRAs (incl. 25Cr SDSS). If welds of matching strength are required, type 2509 weld consumable may be considered.

Based on the above, Contractor considers welding carbon steel to 25Cr SDSS to be fully manageable provided properly qualified procedures are used and restrictions on carbon content is specified.

# 5 Upper sections

The upper sections are to be understood as the underside of road structure, columns and pontoon above splash zone. In these sections, access allows for regular inspection and maintenance. Still, a high quality coating system is recommended to limit the need for future maintenance. Based on the experience from Statens Vegvesen (SVV) their system 2, Thermally Sprayed Zinc (TSZ) covered with a tie coat and a 3- coat system has proven very durable as outlined in a presentation at Teknologidagene in 2015 /Ref. 13/. This is in line with experience from the North Sea although the major operator in the Norwegian sector specifies Thermally Sprayed Aluminium (TSA, e.g. NORSOK system 2A) as the default system for structures and pressure retaining equipment that are highly exposed and/or hard to maintain /Ref. 14/ and /Ref. 15/. Both TSA and SVV system 2 are active systems that will provide local cathodic protection in case of coating damage.

The high quality coating systems discussed in the previous phase have been evaluated further. Their pros and cons are summarised in Table 5-1 below along with a recommendation. In addition, a corrosion allowance may be added depending on maintenance philosophy. See section 10.2.

*Table 5-1 Candidate coating systems for upper external bridge sections*

| Coating system | Generic products | Good experience reported from | Pros | Cons | Recommendation |
|---|---|---|---|---|---|
| High build glass flake | High build glass flake epoxy or polyester | Splash zone, underside of platform decks, and platform substructures (jackets) where access for maintenance is poor. | Its high DFT provides a very robust barrier both against corrosion and mechanical wear. | Passive system - no protection of any exposed steel.<br>Poor UV properties, will need a top coat to maintain gloss and colour. | Not recommended for further evaluation |
| TSA | Metallic aluminium and epoxy sealer | Splash zone, underside of platform decks, topside structures and equipment where access for maintenance is poor or exposure temperature is high. | Active system (TSA).<br>By increasing the DFT service life can be extended. Robust barrier both against corrosion and mechanical wear. | Can only be over coated with a sealer. Surface will be greyish with a matt appearance. Removal of dirt may be challenging. Difficult to combine with other coating systems. Application is time consuming, noisy and dusty. Application with spray gun only. Expensive. | Can be evaluated since upper sections may be matt metallic, i.e. no specific colour requirement. |
| SVV system 2 | Metallic zinc with sealer, two layers epoxy mastic and top coat | Bridge structures, topside structures on platforms where access for maintenance is poor. | Active system (TSZ) combined with a coating system that can provide an extend service life. SVV, and its contractors are familiar with this system. | Each coating layer requires control of surface cleanliness prior to application and control of DFTs after application.<br><br>The tie coat may need to be applied in two steps which increases cost.<br>Track record for splash zone is limited | **Recommended for upper sections.**<br>Top coat recommended to be a polyurethane |

It is recommended that only one of the above systems is selected for all external surfaces of the upper section. Although corrosion threats vary, all parts of the upper section are located in a corrosive, marine environment and is recommended protected in the same way.

## 5.1 Voids and empty compartments

For voids within the bridge girder and inside the columns corrosion can be limited by a dehumidification system. For such areas, system 3G, i.e. one coat zinc ethyl silicate is recommended. Zinc ethyl silicate is an "active", Zn rich coating that provides localized cathodic protection of the steel in case of minor coating damages (scratches, etc.) and it is often used as the primer in a coating system. However, experience has revealed that it also provides very good corrosion protection on its own (without additional coats).

During transport and construction the coated surfaces will be exposed to corrosive marine atmosphere ranging typically from category C4 to CX (ISO 12944-2). It is during these phases the worst-case exposure conditions are foreseen although the exposure period is expected to be relative short.

In the operational phase the corrosion concerns are minor, and the coating breakdown rate is expected low since it will not be exposed to sunlight / UV and hardly any mechanical wear.

To ensure robustness, it is recommended to only select among zinc ethyl silicate products having a documented durability and with good tolerance for variations in dry film thickness. This may for example being products having passed the qualification requirements in NORSOK M-501 for system 1. The need for a top coat to increase durability and/or need for specific colours to be evaluated later.

For voids/empty spaces without dehumidification NORSOK system 1 with sink ethyl silicate primer is recommended.

## 5.2 Outfitting structures

Material selection for outfitting structures such as railing, ladders, grating, gullies, etc. shall be based upon SVV experience and specified requirements. Due to bridge location and extensive design life the material selection and means of providing corrosion protection must consider marine exposure conditions.

# 6 Splash Zone

The splash zone is defined as the area between the continuously submerged areas of the pontoon and the upper section. The corrosive conditions within the splash zone are considered severe due to continuous wetting, abrasive wear, and presence of marine growth that will need to be removed by mechanical means. These conditions make corrosion protection by coating very challenging due poor access for later maintenance and repair. Moreover, cathodic protection cannot be relied upon in the splash zone.

A possible solution to prevent splash zone corrosion is to use a CRA in these areas. The splash zone of the pontoons has, as a conservative measure a height of 6.5 m in the present design. This allows the longitudinal welds between CRA and carbon steel to be located outside the actual splash zone.

To avoid galvanic corrosion the weld zone and minimum 50 mm onto the CRA shall have the full coating system and then be feathered to ensure a smooth transition to the uncoated surface. This is visualised in Figure 6-1 with coating system SVV2 and CRA (25 Cr DSS).

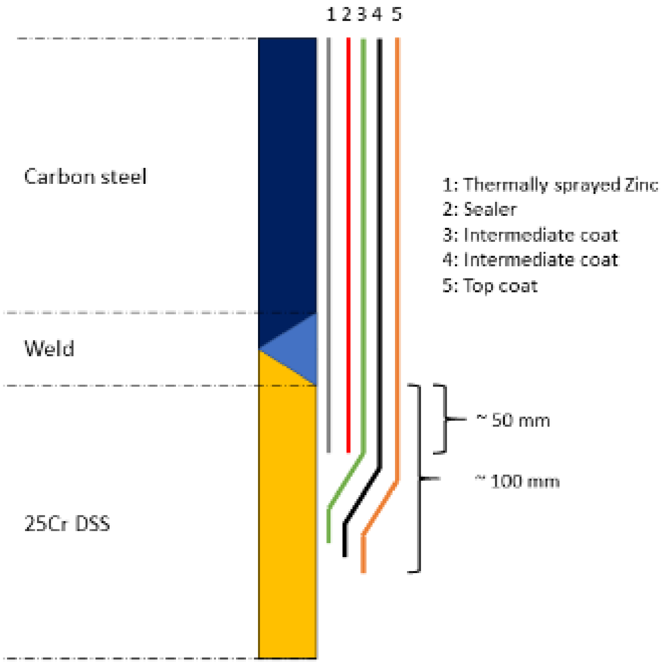



*Figure 6-1 Coating of weld zone and onto CRA to avoid galvanic corrosion*

## 6.1 Material selection

Use of a CRA as an integrated part of the steel pontoon structure was recommended for the splash zone in the earlier study. Both cladding with 25Cr DSS and use of solid 25Cr DSS were evaluated and the latter was recommended.

Based on this recommendation, SVV engaged SINTEF to do a failure mode, effect and criticality analysis (FMECA) for use of 25Cr DSS in the splash zone. In addition, SINTEF also conducted a field test.

In the FMECA report /Ref. 16/ numerous corrosion threats were evaluated and ranked. The concerns ranked with high probability or unknown probabilities combined with serious consequences are:

- Crevice corrosion due to:
    a. Crevice developed at the interface between coating and 25Cr DSS

   b. High local temperature from sun
   c. Presence of biofilm
- Pitting corrosion
   a. at welds due to too high heat input
- Micro biological corrosion (MIC)
   a. due to possible presence of sulphate reducing bacteria
- For the option with cladding with 25Cr DSS
   a. galvanic corrosion of underlying steel if a damage causes a leak in the plate

Based upon the FMECA report a field experiment was conducted to examine the corrosion risks for 25Cr DSS in the splash zone. The field test was performed using test plates in solid 25Cr DSS that were submerged from a barge located in the sea outside Sandefjord in the period 21.06.2018 to 16.11.2018. Each of the 4 test specimens had a vertical and a horizontal weld, and 3 artificial crevices were placed within the heat affected zone (HAZ). No temperature readings or inspections during the test period are reported, but 2018 was a warm summer in this region. Although the test specimens were installed to be only partly submerged, the SINTEF report concludes that these must have been completely submerged since the level of marine growth is extensive and uniform. The findings from this field test are summarised in Table 6-1 below.

*Table 6-1 Summary of findings from the field test with 25Cr DSS specimens exposed to natural seawater outside Sandefjord. Exposure period: 5 months*

| Test specimen number | Heat input during welding * | Pickling of welds | Extent of pitting corrosion along welds | Extent of crevice corrosion | Metallographic examination |
|---|---|---|---|---|---|
| 1 | Normal | Yes | none | none | No sigma-phases discovered<br>Micro structure as expected for all specimens |
| 2 | High | No | none | At 2 of 3 crevices | |
| 3 | Normal | No | none | At 1 of 3 crevices | |
| 4 | High | Yes | none | None | |

**) Actual difference in heat input was insignificant due to low plate thickness*

The above findings indicate that 25Cr DSS is corrosion resistant in natural seawater if welds are pickled. Pickling may be required after welding to restore the oxide film which is the barrier providing corrosion protection. The field results document the importance of this. For the test specimens adequately pickled after welding no corrosion were reported after 5 months exposure in seawater.

NORSOK M-001 /Ref. 17/ and ISO 21457 /Ref. 18/ give guidance on material selection for oil and gas production systems. For seawater carrying systems 25Cr DSS is recommended provided that maximum operating temperature does not exceed 20 °C and maximum residual chlorine concentration does not exceed 0.7mg/l. Hence, the 20 °C temperature limit typically referred to for 25Cr DSS is related to chlorinated seawater, not natural seawater.

The corrosivity of chlorinated seawater is considered more severe than that of natural seawater since the presence of hypochlorite increases the free corrosion potential more than biofilms do. If this potential exceeds the break down potential for the stainless steel passive film, localised corrosion can be expected.

Hence, corrosion of 25Cr DSS should not be of concern when exposed to natural seawater at ambient Norwegian temperatures provided properly qualified welding procedures are used. Although seawater temperatures may exceed 20 °C during warm summer days, this is not expected to last long enough to cause breakdown of the oxide film and initiate corrosion.

Unfortunately, only limited documentation of the corrosion resistance of 25Cr DSS in natural seawater is available. If further documentation is required, it is suggested to perform a new field test with test specimens placed in the splash zone, preferably in Bjørnafjorden. The test period should be of minimum 1 year, preferably 2 years.

It should further be noted that corrosion due to sulphate reducing bacteria should not be of concern since oxygen is always available in the splash zone. Presence of aerobic bacteria is to be expected.

# 7 Submerged structures

## 7.1 External surfaces

The seawater submerged sections are the steel surface areas from seabed to splash zone. Theses sections can be effectively protected by a coating system combined with CP, or by CP alone.

The candidate coating systems advised in the previous phase have been evaluated further. Their pros and cons are summarised in Table 7-1 below along with a recommendation.

*Table 7-1 Candidate coating systems for submerged sections*

| Coating system | Generic products | Experience | Pros | Cons | Recommendation |
|---|---|---|---|---|---|
| NORSOK System 7A | High build epoxy | Robust system that also withstands mechanical wear | Its high DFT provides a very robust barrier both against corrosion and mechanical wear. Will limit sacrificial anode requirement | The current CP design codes does not include coating breakdown factors for such high build coating systems and it is therefore not possible to utilise this in the initial CP design. More expensive than 7B | May be evaluated further |
| NORSOK System 7B | Epoxy/epoxy mastic | Used for submerged structures for decades | Will limit the need for sacrificial anodes | NA | Based case for all submerged sections combined with sacrificial anodes. |

Corrosion protection by coating only is not recommended for submerged sections. Corrosion protection by CP only is theoretically possible, but not recommended as this will have a dramatic impact on weight and increase concerns in case of ship collisions as this may jeopardize the corrosion protection if anodes are damaged.

The CP design requirements and preliminary calculations to demonstrate anode weight demands are discussed in section 7.3.

### *7.1.1 External surfaces submerged in mud*

For structural parts submerged in mud i.e. below seabed, coating for corrosion protection will only have a limited effect due to mechanical wear during installation. For such areas CP is recommended as the only source of corrosion protection.

## 7.2 Ballast water tanks

The pontoons are designed with a fixed ballast level, i.e. not requiring ballasting or de-ballasting under normal operation. When needed, due to a service condition or an extraordinary event, ballasting or de-ballasting is to be carried out with portable pumps through the manholes at the pontoon deck.

Corrosion protection of ballast tanks depends upon tank operation and ballast water quality. The present design includes active, passive and empty ballast tanks. Active tanks are for ballasting operations. During regular inspection and maintenance, the ballast water will be pumped into adjacent passive tanks. Hence, the passive tanks will be filled with seawater only during maintenance periods. After installation the empty tanks will be dried, dehumidified and sealed off.

If the ballast tanks could be completely closed, i.e. sealed off to avoid any oxygen ingress, the need for corrosion protection will be limited as corrosion will cease when oxygen is depleted provided there are no additional feed to bacteria. For such tanks addition of a corrosion inhibitor or biocide may be adequate. The present design does however not allow for completely sealed off water filled ballast tanks.

The candidate coating systems discussed in the previous phase have been evaluated further and the results are summarised in Table 7-2 below along with a recommendation. In addition, a corrosion allowance may be added depending on maintenance philosophy.

*Table 7-2 Candidate corrosion protection systems for ballast water tanks*

| Type of ballast water tank | Type of ballast *) | Candidate corrosion protective means | Comments | Recommendation |
|---|---|---|---|---|
| Active | Seawater | NORSOK system 7B + CP | Zinc is recommended as sacrificial anode | Well proven and durable solution |
| | | Rubber lining | Requires smooth internal walls, without stiffeners etc. | Not feasible with the present tank design |
| | | Tank in tank (in 25Cr DSS or glass fibre reinforced plastic (GRP)) | Large opening required to allow tank installation. Stiffeners in ballast tank bottom should be avoided. | |
| | Fresh water | High quality coating | NA | Not relevant since present design is to use seawater |
| | | Tank in tank (SS316 or GRP) | NA | |
| Passive | Seawater | Coating. | Will require regular inspections or monitoring | NORSOK system 1 |
| | Freshwater | | NA | |
| Empty **) | NA | Coating combined with dehumidification | Level of corrosion protection depends upon dehumidification. To be at least below 60%RH | NORSOK system 3G |

**) Solid ballast may also be added to the tanks.*
***) The same coating system as recommended for voids and empty spaces in the upper section is suitable for empty ballast tanks if a relative humidity <60% can be achieved. Alternatively, the same system as for passive tanks is recommended.*

## 7.3 Cathodic protection

*The CP design shall be in accordance with a recognised international code. It is to be performed when the structural design is complete and when the design basis for the sacrificial anodes has been decided. Herein, preliminary CP calculations have been carried out for the pontoons to demonstrate anode weight requirements expected to meet 25 years and 50 years exposure based on the recommendations outlined in DNVGL-RP-B401, edition 2017 /Ref. 19/. The parameters applied are summarised in*

Table 7-3 below.

*Table 7-3: CP design parameters from ref. 19 applied in the calculations.*

| Description | Design parameter | Value | Comments |
|---|---|---|---|
| Al-Zn-In anode | Anode current capacity | 2000 Ah/kg | |
| Zinc anode | Anode current capacity | 780Ah/kg | |
| Anode utilisation factor | Anode shape: Long flush | 0.85 | Factor describing extent of anode mass that can be utilised. |
| Steel current demand | Average current required per surface area unit | 0.1A/m$^2$ | Average current demand expected for the pontoons. |
| Coating breakdown factor | Average value accounting the first 25 years | 0.17 | Average coating breakdown factors as advised in the code. These values are based on NORSOK system 7B. |
| | Average value accounting the first 50 years | 0.32 | |
| | Uncoated steel | 1 | Applied for 25Cr DSS if left uncoated |
| Contingency | Factor added to account for design development. | 10% | Added to CP calculations for external surfaces. For ballast tanks the estimated surface area has a built-in conservatism |

The anode weight calculations have been carried out for the external surface area of one pontoon and for one ballast tank based upon typical dimensions as per present design. The results are summarised in Table 7-4.

*Table 7-4: Typical anode weight demands expected for a pontoon and for an active ballast water tank*

| Item | Description | Surface area (m$^2$) | Anode type | Anode weight demand if all surface areas are coated (tons) | | Anode weight demand if 25Cr DSS is uncoated (tons) | |
|---|---|---|---|---|---|---|---|
| | | | | 25 years | 50 years | 25 years | 50 years |
| Pontoon *) | Submerged section | 1092 | Aluminium based anode | 3.7 tons | 14.1 | 9.1 | 22.9 |
| | Splash zone | 458 | | | | | |
| Ballast water tank | All submerged except for the roof | 1485 | Zinc anode | 8.3 | 31.4 | NA | NA |

**) The calculations do not include any anode demand to account for current drain to chains*

As demonstrated in Table 7-4 coating of the CRA belt, although not required for corrosion protection, will have a significant impact on the required anode weight.

It must be underlined that these calculations are based on coating breakdown factors for NORSOK system 7B which is a 2-coat system resulting a DFT of minimum 350µm. By selecting a high build glass flake coating system with a DFT exceeding 1000µm, the actual coating breakdown factor is expected to be much less. However, the current CP design codes give no advice related to this. Furthermore, experience from the North Sea has revealed that coating breakdown is generally far less than anticipated in the CP design codes. Consequently, a new revision of DNVGL-RP-B401 is currently being prepared and it will allow lower coating breakdown factors when coating work is being carried out in accordance with NORSOK system 7B. This is expected to reduce the anode weight demand with some 30%.

Herein it is therefore suggested to base the initial CP design on maximum 50 years. During operation, inspections will reveal actual anode consumption and actual coating breakdown factors. Based upon these findings, the expected anode life can be adjusted, and an update of the CP design can be planned for when need be.

A conservative approach also applies for the default anode current capacities advised by the design codes. Once an anode manufacturer has been selected that actual anode current capacity (demonstrate by long term testing) can be utilised and this alone may decrease anode weight demand with some 10 to 15%.

Hence, when accounting for the above parameters in the final CP design, the actual anode demand may be reduced by up to 50% compared to the initial weight calculations given herein. The final design must also account for anode replacements and include additional brackets to allow installation of additional anodes later in life.

# 8 Mooring System

## 8.1 General

A general reference is made to Appendix M. The mooring system for concept K12 consist of the following main components:

- Fairlead chain stoppers
- Top chain
- Wire rope, including sockets
- Bottom chain
- Suction or gravity anchors

Reference is made to SBJ-31-C4-SVV-26-BA-001 Design Basis – Mooring and Anchor /Ref. 20/. The mooring equipment and components shall be manufactured according to DNVGL-OS-E301 /Ref. 21/ and other relevant/referenced DNVGL standards.

## 8.2 Corrosion protection

Corrosion protection for the various components is outlines below:

*Table 8-1 Corrosion protection for the various components*

| Component | Type of corrosion protection | Remark |
|---|---|---|
| Chain stopper / fairlead | Coating (system 7B) and cathodic protection | Anodes located on the pontoon and/or on the equipment. |
| Chain | Corrosion allowance (CA)<br><br>The chains are uncoated | - CA for top chain: 0.2 mm/year *<br>- CA for bottom chain: 0.2 mm/ year |
| Wire rope and sockets | Wire rope: Coating / sheathed<br><br>Sockets: Coating (system 7B) and cathodic protection. | According to /Ref. 20/, wire rope sockets shall be coated and cathodically protected. See section 10.2. |
| Anchors | Coating (system 7B) and cathodic protection | Coating to extend ~2 m below mudline. Anodes should be located freely exposed to seawater (not buried). |

* According to SBJ-31-C4-SVV-26-BA-001 /Ref. 20/, the corrosion allowance for the top chain shall be 0.8 mm / year. With the current mooring design, the top chain will be permanently submerged and below the splash zone, and as such, the same allowance as for bottom chain is proposed. This is also in line with ISO 19901-7 and DNVGL-OS-E301.

# 9 Design against hydrogen induced stress cracking

The splash zone is recommended to be solid 25Cr DSS. This material grade is susceptible to hydrogen induced stress cracking (HISC) when exposed to CP. How to design against HISC is advised by DNVGL-RP-F112 /Ref. 23/ and the relevant recommendations to be accounted for herein are:

- Avoid fillet welds, sharp edges and crack initiation points
- Keep the loads and stresses within the limitations advised
- Ensure material selected has fine austenite spacing

As per the present design the solid 25Cr DSS belt in the splash zone will not have any fillet welds and the smooth geometry does not have any sharp edges or other crack initiating points. The structural loads are generally very low in this area of the pontoons. In addition, residual stresses from welding and cold forming shall be considered. Since duplex materials are widely used subsea, e.g. for flowlines, etc., the loads and residual stresses should not be cause for concern. Finally, it will be fabricated from rolled plates with thickness well below 25mm and thereby fine austenite spacing is ensured.

Based upon the above, HISC is not considered to be of real concern.

# 10 Recommendations for further work

## 10.1 Material requirements and fabrication

- R762 requires material certificates type 3.2 for structural steel (type 1 and 2). The Norwegian oil and gas sector has been using NORSOK M-120 Material Datasheets /Ref. 11/ for over 25 years, and irrespective of criticality material certificates type 3.2 has never been used for general purposes. This requirement is believed to increases cost and should be evaluated.
- Evaluate the requirement for qualification of manufacturers of special materials according to NORSOK M-650 (cost-benefit).
- Establish a project MDS for plates in 25Cr DSS.
- Allowing use of structural material according to EN 10225 /Ref. 12/ (instead of EN 10025) should be evaluated.
- Evaluate whether TCMP (M/ML) shall be the specified as delivery condition for grade S420 materials, i.e. not allowing use of normalised materials.
- Suitability of EN 1090-2 as basis for fabrication and inspection of 25Cr DSS, including dissimilar welds should be evaluated. If found necessary, a project specification must be established.

## 10.2 Corrosion protection

- Evaluate need for top coat for increased durability and/or need for specific colours where NORSOK system 3G (zinc ethyl silicate) is specified.
- Develop the selected coating systems in more detail with respect to actual products and actual DFTs. This needs to be done in co-operation with the nominated/selected coating manufacturers.
- Evaluate NORSOK systems 2A and 7A, if required.
- Perform a detailed CP design once the bridge design has been completed. Liaise with anode manufacturer to select suitable anode types and sizes and to be able to utilise the actual anode current capacity.
- Feasibility of providing adequate cathodic protection to the wire rope sockets should be investigated since proper electrical isolation both to the chains and wire rope may be hard to obtain.
- If further documentation is required, it is suggested to perform a new field test with test specimens placed in the splash zone, preferably in Bjørnafjorden. The test period should be of minimum 1 year, preferably 2 years.
- Develop a plan for inspections, maintenance and repairs/replacements and advise any corresponding corrosion allowance required.

# 11 List of references

*Ref. 1 ISO 4628 Evaluation of degradation of coatings. Designation of quantity and size of defects, and of intensity of uniform changes in appearance.*

*Ref. 2 ISO 12944 Corrosion protection of steel structures by protective paint systems*

*Ref. 3 Statens Vegvesen, Håndbok R762 Prosesskode 2: Standard beskrivelse for bruer og kaier*

*Ref. 4 NS-EN 1090-1 Execution of steel structures and aluminium structures - Part 1: Requirements for conformity assessment of structural components.*

*Ref. 5 EN 1993-1-4 Eurocode 3 - Design of steel structures - Part 1-4: General rules - Supplementary rules for stainless steels*

*Ref. 6 EN 10088-2 Stainless steels - Part 2: Technical delivery conditions for sheet/plate and strip of corrosion resisting steels for general purposes*

*Ref. 7 EN 10028-7 Flat products made of steels for pressure purposes – Part 7: Stainless steels*

*Ref. 8 NORSOK M-650 Qualification of manufacturers of special materials*

*Ref. 9 ASTM G48 Standard Test Methods for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution*

*Ref. 10 NORSOK M-630 Material data sheets and element data sheets for piping*

*Ref. 11 NORSOK M-120 Material data sheets for structural steel*

*Ref. 12 EN10225 Weldable structural steels for fixed offshore structures - Technical delivery conditions*

*Ref. 13 SINTEF Korrosjonsbeskyttelse av stålbruer – hvordan oppnå lang levetid, Teknologidagene, 23.09.2015*

*Ref. 14 Equinor TR0042 Surface preparation and protective coating*

*Ref. 15 NORSOK M-501 Surface Preparation and Protective Coating*

*Ref. 16 SINTEF report No. 2018:00258 Bruk av superdupleks stål i marin plaskesone*

*Ref. 17 NORSOK M-001 Materials selection*

*Ref. 18 ISO 21457 Materials selection and corrosion control for oil and gas production systems*

*Ref. 19 DNVGL-RP-B401 Cathodic protection design*

*Ref. 20 SBJ-31-C4-SVV-26-BA-001 Design Basis – Mooring and Anchor*

*Ref. 21 DNVGL-OS-E301 Position Mooring*

*Ref. 22 ISO 19901-7 Petroleum and natural gas industries - Specific requirements for offshore structures - Part 7: Stationkeeping systems for floating offshore structures and mobile offshore units*

*Ref. 23 DNVGL-RP-F112 Duplex Stainless Steel - design against hydrogen induced stress cracking, June 2018*

*Ref. 24 EN 1090-2 Execution of steel structures and aluminium structures – Part 2: Technical requirements for steel structures*