Corrosion Protection - Robust Retrofit of a Gravity Based Production Structure in Frozen Arctic High Scour Conditions

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Agenda

• Background

• Arctic conditions

• Corrosion protection design
  • Cathodic protection design issues
  • Cathodic protection current requirement test

• Cathodic protection component layout

• Cathodic protection system components

• Fabrication and installation of anode systems

• Commissioning of cathodic protection system
  • Comparison between design and operation performance

• Conclusions
Background

• Built in 1983
• Served as drilling unit in the Beaufort Sea
• Consists of steel mudbase, concrete brick mid-section and deck barges
• Dimensions ~80 m x 80 m (250 ft x 250 ft)
• Original cathodic protection system (CP) with zinc anodes removed by ice scour
• Corrosion protection required for entire design life
• Experience proved galvanic anodes not suitably robust with ice scour
• Impressed current cathodic protection (ICCP) required for mudbase and associated subsea items.
Background
Arctic Conditions

Structure frozen in during winter months

All CP equipment has need for robustness
Steel Mud Base

- Anodes prior to initial deployment
- Anodes removed from ice scour
Design Challenges

• Long design life
• Ice scour
• Coating system deterioration and current condition unknown
• High CP current requirement due to cold conditions and unknown coating condition
• Current distribution difficult due to size of structure and limited ability to remotely place CP anodes
• Stray current on pipelines concern due proximity to ICCP system
CP Design Issues

• Need to design cathodic protection system capable of protection for entire design life of 45 years

• Robustness of CP system indicated that this is not off the shelf design

• CP system need to be robust to handle rock dump to be placed around structure for scour protection

• Original CP design basis was to use DnV RP B401 assuming no coating present on mud base underside

• CP current requirement quite large so current requirement test proposed
  • Quite complex in working shipyard
<table>
<thead>
<tr>
<th>Location</th>
<th>Current Density</th>
<th>Value, mA/m²</th>
<th>Coating Breakdown Factor, %</th>
<th>Effective Design Current Density, mA/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seawater</td>
<td>Initial</td>
<td>250</td>
<td>95</td>
<td>237.5</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>120</td>
<td>100</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>Final</td>
<td>170</td>
<td>100</td>
<td>170</td>
</tr>
<tr>
<td>Mud</td>
<td>Initial</td>
<td>20</td>
<td>95</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>20</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Final</td>
<td>20</td>
<td>100</td>
<td>20</td>
</tr>
</tbody>
</table>
## CP Current Based on Design Basis

<table>
<thead>
<tr>
<th>Location/Structure</th>
<th>Surface Area (m²)</th>
<th>Effective Current Density (mA/m²)</th>
<th>Current Demand (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Initial</td>
<td>Mean</td>
</tr>
<tr>
<td>Current drain to Brick</td>
<td>1872</td>
<td>14.4</td>
<td>14.4</td>
</tr>
<tr>
<td>Top and slope of Mud Base in seawater</td>
<td>6113</td>
<td>237.5</td>
<td>120</td>
</tr>
<tr>
<td>Sides of Mud Base in erosion protection</td>
<td>1468</td>
<td>19</td>
<td>20</td>
</tr>
<tr>
<td>Underside of Mud Base</td>
<td>16724</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Pipe Sleeve</td>
<td>144</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Current drain to 20 Wells @ 5 Amps/well</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Totals</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Structure at Ship Yard

Sheet Piling
Current Requirement Test

Current Requirement Test Schematic

Drop Cell

Potential Measurement Locations
Results of Current Requirement Test

<table>
<thead>
<tr>
<th>Current Requirement, Amps</th>
<th>Initial</th>
<th>Mean</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>DnV RP - B401</td>
<td>1942</td>
<td>1225</td>
<td>1530</td>
</tr>
<tr>
<td>Current Requirement Test with DnV RP B-401</td>
<td>389</td>
<td>1225</td>
<td>1530</td>
</tr>
</tbody>
</table>

• Current requirement test at shipyard showed current coating condition on bottom of mud base better than expected

• Initial current demand much lower than final demand (at end of 45 years)

• Although coating in better than expected shape, CP current requirement per code selected for end of life condition
Schematic of CP Installation

- **Mudbase**
- **Anode Containers**
- **Power Feed Cables**
- **Pull tubes**
- **Anode Sleds**
- **Anode Sleds are located under the erosion protection**
- **Anode Sleds** (single cable per sled)
- **Erosion Protection**
- **Anode containers are buried**
- **Several Reference electrodes to be installed**
Anode Configurations

- 4 Steel Container Sleds
- Located on North and West Sides
- Buried in net deposition predicted
- Filled with coke breeze
- 30 Tubular MMO anodes

- 6 Concrete Container Sleds
- Located on South and East Sides
- Installed under platform erosion protection – areas of net erosion
- Seawater filled (no coke breeze)
- 30 Tubular MMO anodes
Anode Sled

- 30 anodes within container
- Sled filled with coke breeze
- All electrical connections cast in place

- Final sled for shipping
- Power cable installed with bend restrictor
Anode Containers

- Concrete containers used to provide additional robustness due to rock dump
- 30 anodes installed in same fashion as sleds
- Containers will flood with seawater so no coke breeze necessary like with containers
- Final container for shipping
Installation of Anode Sled
Installation of Anode Container
Other components

Cross-Section of Power Cable

Power Cables

Reference Electrodes
## Commissioning Current

<table>
<thead>
<tr>
<th>Rectifier No.</th>
<th>Current</th>
<th>Voltage</th>
<th>Oil Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>amps</td>
<td>Volts</td>
<td>C</td>
</tr>
<tr>
<td>1</td>
<td>110</td>
<td>12</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>160</td>
<td>8</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td>148</td>
<td>9</td>
<td>23</td>
</tr>
<tr>
<td>4</td>
<td>96</td>
<td>12</td>
<td>18</td>
</tr>
</tbody>
</table>

Total current was 514 amps
## CP System Current vs. Time

<table>
<thead>
<tr>
<th>Month</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>Total</th>
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<tbody>
<tr>
<td>Nov</td>
<td>28.0</td>
<td>27.9</td>
<td>24.5</td>
<td>21.1</td>
<td>37.2</td>
<td>36.8</td>
<td>32.3</td>
<td>33.1</td>
<td>25.0</td>
<td>26.2</td>
<td>292.1</td>
</tr>
<tr>
<td>Dec</td>
<td>25.2</td>
<td>25.2</td>
<td>23.1</td>
<td>15.1</td>
<td>33.5</td>
<td>33.4</td>
<td>28.8</td>
<td>31.2</td>
<td>20.4</td>
<td>17.8</td>
<td>253.7</td>
</tr>
<tr>
<td>Jan</td>
<td>26.1</td>
<td>24.3</td>
<td>23.2</td>
<td>16.8</td>
<td>32.5</td>
<td>33.4</td>
<td>29.8</td>
<td>31.0</td>
<td>21.2</td>
<td>17.9</td>
<td>256.2</td>
</tr>
<tr>
<td>Feb</td>
<td>17.0</td>
<td>25.0</td>
<td>21.0</td>
<td>11.0</td>
<td>35.0</td>
<td>35</td>
<td>27.0</td>
<td>33.0</td>
<td>18.0</td>
<td>12.0</td>
<td>234.0</td>
</tr>
<tr>
<td>Mar</td>
<td>15.0</td>
<td>22.0</td>
<td>18.0</td>
<td>9.0</td>
<td>32.0</td>
<td>32</td>
<td>24.0</td>
<td>29.0</td>
<td>17.0</td>
<td>11.0</td>
<td>209.0</td>
</tr>
<tr>
<td>May</td>
<td>16.0</td>
<td>23.0</td>
<td>18.0</td>
<td>9.0</td>
<td>33.0</td>
<td>32</td>
<td>24.0</td>
<td>29.0</td>
<td>15.0</td>
<td>12.0</td>
<td>211.0</td>
</tr>
<tr>
<td>Jun</td>
<td>15.8</td>
<td>24.0</td>
<td>19.5</td>
<td>15.4</td>
<td>33.6</td>
<td>33.3</td>
<td>26.4</td>
<td>31.0</td>
<td>16.6</td>
<td>10.2</td>
<td>225.8</td>
</tr>
</tbody>
</table>

- CP current reducing as structure polarizes
- Current requirement test predicted 389 amps
### CP System Commissioning

<table>
<thead>
<tr>
<th>Rectifier No (side)</th>
<th>Average Drop Reference Cell Potential, mV vs Ag/AgCl</th>
<th>Average Permanent Reference Cell Under Erosion Protection Potential, mV vs Ag/AgCl</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – South</td>
<td>-1012</td>
<td>-951</td>
</tr>
<tr>
<td>2 – North</td>
<td>-1000</td>
<td>-968</td>
</tr>
<tr>
<td>3 – West</td>
<td>-1034</td>
<td>-972</td>
</tr>
<tr>
<td>4 – East</td>
<td>-1020</td>
<td>-876</td>
</tr>
</tbody>
</table>

- Data compares CP potential measurements drop cell taken from the structure and the insitu reference electrodes.
- Cathodically protected value is - 800 mV or more negative
Conclusions

- A robust cathodic protection system was successfully commissioned
- Use of purpose built sleds, concrete and steel, provided the required cathodic protection current to protect the structure from corrosion
- Shipyard current requirement test proved accurate to reduce startup current needs and was in reasonable agreement with commissioning data
- The current requirement test proved that the original coating was in better condition than would have been predicted by the design codes
- Although the offshore installation was difficult, detailed planning and coordination with other offshore activities, i.e. scour protection installation, diver reference electrode installation, etc, was essential to assure the proper installation of all cathodic protection system components
- To assure no installation problems, a trial was conducted to prove the large power cables could be installed in the space allotted
- It was proven that coordination between the design, installation and commissioning teams was essential to permit flawless execution for the cathodic protection system to function properly.
Final Thoughts!!

• Graying of Workforce

• Problem???

Thanks

For your Attention
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