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MORAY FIRTH REPAIR DETAILED DESIGN

DESIGN BRIEF

RAMBØLL

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Revisions are indicated by outlined border

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CONTENTS

1. INTRODUCTION

The scope of the project is to reinforce the main shaft of the foundation for the offshore meteorological mast at Moray Firth Offshore Wind Farm, located off the eastern coast of Scotland. The met mast is supported by a Gravity Based Structure (GBS) and the structure is composed of five main elements (from sea bed): Bedding layer, a concrete caisson, a main shaft, a steel platform and a steel lattice tower.

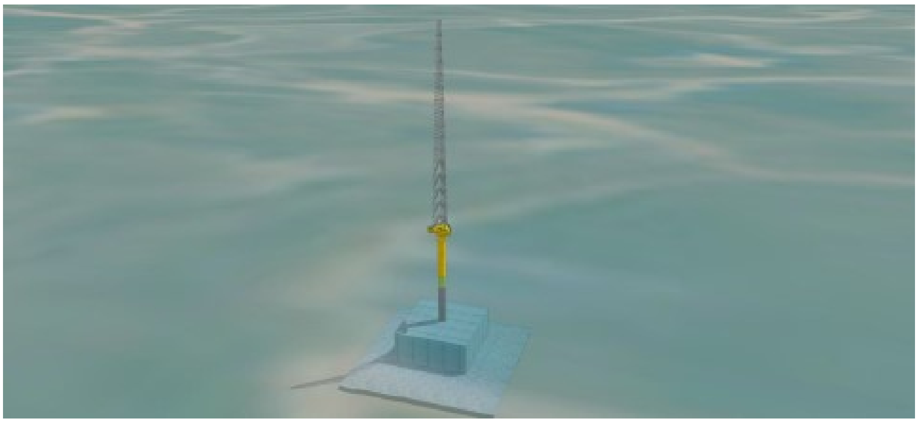

Figure 1. Met Mast, General Arrangement (before repair)

1.1 Background

In October 2014 a pontoon collided with the met mast, which resulted in damage. The extent of the damage included the joint between the main shaft and the concrete caisson whose lifetime was significantly reduced. The damage at the joint resulted in, among other things, a permanent inclination of the main shaft. The damaged joint requires a repairing system to transfer the loads from the main shaft to the concrete caisson. The repairing system consists of a gravity based steel bucket outlined in Section 2.

1.2 Objective

The present design brief describes the repairing solution, a GBS steel bucket and the necessary operations for its installation, to return the foundation structure to its original service life.

2. DESCRIPTION OF REPAIR CONCEPT

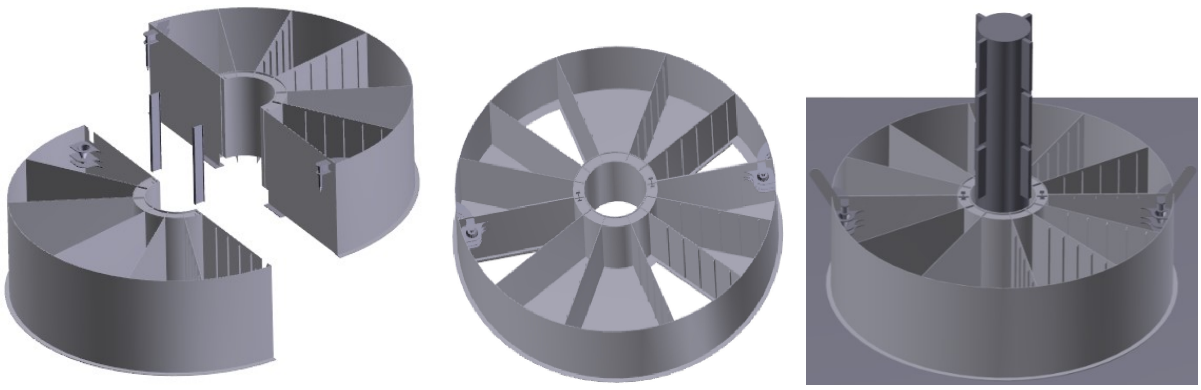

Figure 2. 3D sketch of repair concept

The repair concept is designed to replace the existing connection between the main shaft and the concrete caisson with a gravity base solution as showed on Figure 2. A steel bucket, installed in two halves will act as a gravity base for the main shaft, transferring moment and shear to the caisson top slab. The two halves will be grouted together subsea and connected to the main shaft, also using a grouted connection. The steel bucket will then be ballasted to provide the necessary weight for stability. The bucket will have a height of 5,0 m and a diameter of 16,0 m.

2.1 Preliminary Quantities

Table 1, Table 2 and Table 3 states the preliminary quantities of steel, grout and anodes respectively. The design in still under development and the stated quantities can vary from the final quantities. Two options for ballast material are presented referring to option A with high density quarry stones (Table 4) and option B with concrete blocks (Table 5). Material properties are stated in Section 8.

Steel quality	Thickness interval	Dry weight
S355K2, S355N or S355M	20-80 mm	400 ton
Total	**20-80 mm**	**400 ton**

Table 1. Steel, preliminary quantities

The grouting operations are divided into 3 main operations as stated in Table 2.

Grouting operation	Volume	Dry weight
1. Full underbase grouting	35 m^3	90 ton
2. Grouting of shear locks and space between bucket halves	14 m^3	35 ton
3. Grouting between main shaft and bucket inner rim	17 m^3	42 ton
Total	**66 m^3**	**167 ton**

Table 2. Grout, preliminary quantities

Anodes	Dry weight
Ballast option A Indium activated aluminium anodes	Estimated to **12 Tons** evenly distributed in- and outside the bucket.
Ballast option B Indium activated aluminium anodes	Estimated to **18 Tons** evenly distributed in- and outside the bucket.

Table 3. Anodes, preliminary quantities

Ballast: Option A High density quarry stones	Final submerged bulk density (including buoyancy) when placed in GBS	Submerged weight	Volume
High density quarry stones suitable for application in net.	1050 kg/m^3	920 ton	880 m^3
Total	**1050 kg/m^3**	**920 ton**	**880 m^3**

Table 4. Ballast: Option A, preliminary quantities

Ballast: Option B Concrete blocks	**Final submerged density (including buoyancy) when placed in GBS**	**Submerged weight**	**Volume**
Concrete	1380 kg/m^3	938 ton	680 m^3
Total	**1380 kg/m^3**	**938 ton**	**680 m^3**

Table 5. Ballast: Option B, preliminary quantities

3. INSTALLATION

3.1 Existing Conditions

Since the project concerns a repair, the existing conditions need to be considered during installation. The existing conditions, which could have an impact on the installation is listed below:

Met Mast: The lattice met mast is fitted with protruding wind measurement booms. The two top sections of the lattice tower broke off during the collision and will have to be remounted before or after installing the bucket.

Steel platform: The platform is supported by the main shaft and acts as a TP supporting the met mast together with different equipment.

Main shaft: The permanent inclination of the main shaft can have an impact on the installation. The inclination of the main shaft have been measured to 2° according to the technical report *Moray Offshore Met Mast. Inclinometer Rev.0.3*.

Anodes on the main shaft: 12 anodes are placed along the existing main shaft in 3 different levels. The lowest levels of anodes have to be moved before installation of the bucket. The anodes shall be welded to original brackets after bucket installation. Welding on existing main shaft is not allowed.

Holes in concrete caisson top slab: Any open holes in the concrete caisson needs to be extended/protected to prevent any unintentional grout spilling or leaks from cloaking up the holes and equipment connected to these. The existing manholes in the concrete caisson are covered by sealed hatches and it must be possible to open these after grout spill or leaks without further effort. The function of existing holes must remain intact in case of grout spill or leaks.

Concrete plinth: The concrete plinth is located around the main shaft on top of the concrete caisson. It prevents corrosion and protects the main shaft anchors. Steps casted to the plinth have to be removed (not indicated on as built drawings) if the buckets are to be formed in the simplest possible manner. According to EDPR tubes for anchor bolt grouting operations have been casted into the steps, as indicated on Figure 3. EDPR shall approve removal of the steps.

Figure 3. Steps casted to plinth

3.2 Preinstallation Survey

A preinstallation survey has been performed the 2016-02-27. The preinstallation report, *Moray Firth Met Mast Survey*, has been prepared by contractor SubC. The main findings of the survey are the following:

- The inclination of the main shaft is measured to be 2°.
- The extent of the marine growth is reasonable.
- The anodes are located as stated on the as built drawings.
- 6 concrete steps were detected around the concrete plinth and has to be removed prior to installation.
- The alignment of the caisson, based on the ROV depth, is measured to be within +/- 10 mm.

3.3 Installation Survey

An installation survey needs to be performed prior to the bucket installation. The installation survey will consist of the following operations:

1. Cleaning of the concrete caisson
2. Establishment of the surface roughness
3. Measuring of irregularities on the concrete caisson for adjusting bucket leveling

The existing concrete caisson is to an unknown extent covered by foreign objects such as marine growth. The bucket needs to be placed on top and the area beneath the bucket has to be cleaned. Further, the surface roughness must be achieved by mild jetting.

The irregularities on the concrete caisson are estimated in the preinstallation survey. Original tolerances are as well stated on project drawing no.: 2123-220.727-DRW-DSG-1100(5-5)-V05, see Figure 4.

SLABS	
TYPE OF IRREGULARITY	
DEVIATION FROM INTENDED ELEVATION FOR CENTRE PLANE	±12 mm
DEVIATION FROM INTENDED PLANENESS MEASURED OVER GIVEN LENGHTS:	
2 m	±12 mm
5 m	±25 mm

Figure 4. Original tolerances, drawing no.: 2123-220.727-DRW-DSG-1100(5-5)-V05

3.4 Installation Process

Installation trials are conducted by SubC on the quayside to test the installation process and the guiding system of the bucket halves as stated in Section 7.5. The installation subsea will make use of a jack-up vessel. Taglines and lifting locks are needed and can be placed on the outer edge of the bucket halves.

Shimming or adjustable bolts, are provided underneath the supporting flange of the bucket. These have to be adjusted before unloading the bucket from the vessel to accommodate any unevenness of the caisson slab, observed from the installation survey.

The preparation of the bucket installation can be divided into the following processes, specified by contractor SubC:

1. ROV drill
2. Dive drill
3. Recovery dropped objects
4. Cutting off lowest main shaft anodes (4 nos.)
5. Cutting of steps on plinth (5 nos.)
6. Water jetting the top of the caisson
7. Protection of manholes and other protrusions from grouting operations
8. Pre installation check

The subsea installation of the bucket can be divided into the following processes, specified by contractor SubC:

1. Install the first bucket section
2. Install the second bucket section
3. Install the locking beams (2 nos.)
4. First grouting operation: full underbase grouting
5. Install ballast in bucket compartments
6. Second grouting operation: grouting of shear locks and space between buckets
7. Install wedges for restraining main shaft during grouting
8. Last grouting operation: Grouting between main shaft and bucket inner rim.
9. Refitting anodes on main shaft (4 nos.)
10. Recover manholes protection
11. As-left survey and documentation

Works related to topside is not described in this document.

The bucket halves are placed on the concrete caisson in two operations. The first bucket half is lowered until contact with the concrete caisson and moved to the concrete plinth, where bumpers are mounted to secure correct position of the first bucket half. The second half will be guided by a guiding system from the two halves to secure a proper location of the second bucket half.

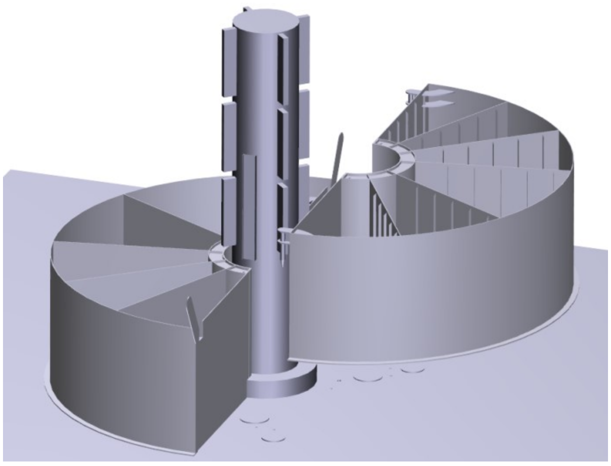

Figure 5. Guiding system

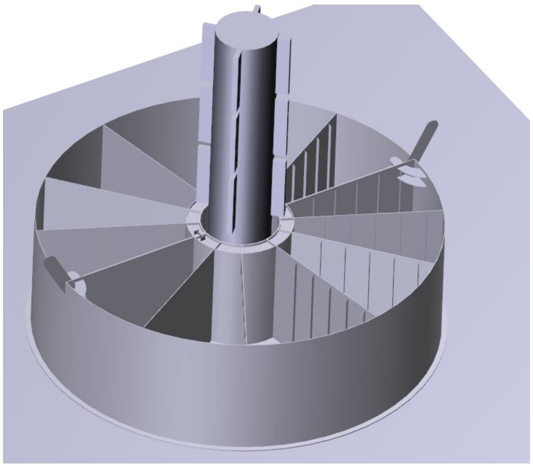

Figure 6. Assembly of bucket halves

Figure 5 and Figure 7 shows the overall principle for the guiding system with guiding tools on both the first and the second bucket half. In the top of the circumference on the second half stabbing pins are mounted. Together with the conical hole in the first bucket, this will locate the second bucket half in the right position. The vertical movement will be controlled by the two ears on the first bucket half, which also guides the stabbing pins to the conical hole.

The main locking system of the two bucket halves, which consist of a grouted locking system are located near the center of the bucket. Figure 6 and Figure 8 shows the overall principle of the two jointed bucket halves in which profiles will secure fastening. The joint will be grouted after placing of the profiles.

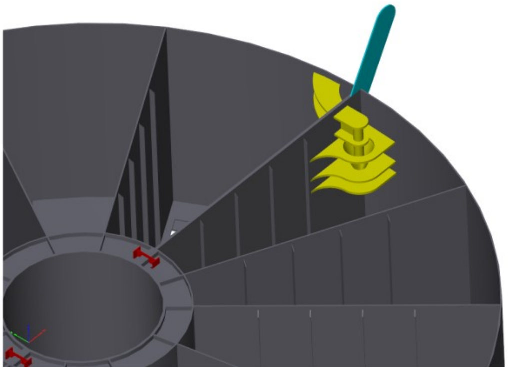

Figure 7. Guiding system on bucket

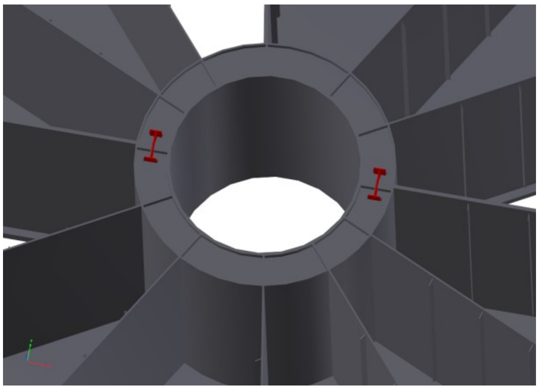

Figure 8. Grouted locking system

The bucket is grouted to the existing concrete caisson. Structurally, circumferential grouting is required, however for practical issues full underbase grouting is an option. Essential for the underbase grouting is that very soft plate/filler material fitted underneath the ballast deck is required. Choice of seals to control the grout will be based on inquiries with suppliers. If only circumferential grouting is performed, seals will control the sealing on the inside.

The volumes of grout required will be minimised as far as possible through the design process. Grout will be mixed using fresh water on board the installation vessel and stored in grout silos ready for use. Grout is pumped using a high pressure system through high pressure grout delivery hoses. Grout loss will be minimised by the monitoring and control of grout volumes being injected. The grout will set after 24 hours of curing.

Manholes and other holes need to be covered to protect from grout as stated in Section 3.1.

3.5 Installation tolerances

The installation tolerances will be maintained by guides with additional tolerances coming from manufacturing.

3.6 De-commissioning of foundation structure

De-commissioning strategy will be communicated by TYPSA. Strategy must not be compromised by the repair solution.

4. MARINE GROWTH

Any existing marine growth on the parts of the concrete caisson and main shaft covered by the bucket needs to be removed according to the installation survey described in Section 3.3.

5. CORROSION PROTECTION

The protection zone of the steel bucket is only located in the submerged zone. The bucket is made from black steel without additional surface treatment. For the submerged external surfaces of the steel bucket a cathodic protection system based on galvanic anodes will be established.

5.1 Cathodic Protection

Cathodic protection shall be applied to all external surfaces in the submerged zone according to DNV-OS-J101, ref. /1/.

External surface areas to be included in the cathodic protection system are primary and secondary steel of the bucket.

The galvanic anode cathodic protection will be designed in accordance with DNV-RP-B401, ref. /2/ and DNV-OS-J101, ref. /1/.

The external cathodic protection system consists of indium activated aluminium anodes. The anodes are welded directly to the steel bucket and will be evenly distributed on the outer ring and in the empty compartments of the bucket which facilitates access to caisson manholes.

Inspection and maintenance of the system will be required over the lifetime of the structure.

The existing structure will be protected by its own cathodic protection system. The systems for the bucket and main shaft are considered to be isolated from each other except for possible stray currents.

6. TRANSPORT

The installation will be carried out from jack-up vessel. The vessel transports both bucket and nets with ballast to the construction site.

Sea fastening is required.

7. FABRICATION

7.1 Execution class

The execution of the steel and the manufacturer qualification shall fulfill EXC3.

7.2 Non destructive testing (NDT)

All welds shall be 100% visually inspected and accepted prior to carrying out NDT.
NDT shall be performed on all welds connecting primary components.

7.3 Welds

Most welds in the bucket primary structure are full penetration welds. Welds must conform to quality level B according to ISO 5817.

7.4 Tolerances

General tolerances must be in compliance with DNV-OS-C401 and EN1090-2.

7.5 Installation trials

Installation trials are conducted by the contractor on the quayside to test the installation process and the guiding system of the bucket halves. Especially the guiding system needs to be verified, tested and adjusted to secure a proper installation of the bucket subsea.

8. MATERIALS

8.1 Grout

A high strength grout with properties as Densit S5 mean has to be used.

8.2 Steel

The bucket shall be produced with S355K2, S355N or S355M steel grade in accordance with EN 10025-2, EN 10025-3 and EN 10025-4 respectively. Common steel properties are stated in Table 6.

Property	Value	Unit
Modulus of elasticity	210×10^3	MPa
Shear modulus	81×10^3	MPa
Poisson’s ratio	0,3	-
Density	7850	kg/m^3

Table 6. General material properties

8.3 Ballast

8.3.1 Option A: High density quarry stones

For option A, the main ballasting of the bucket is considered to be achieved from rock material. The final minimum submerged density (incl. buoyancy) of ballast once placed in the bucket shall be 1050 kg/m^3. The sizing of the ballast material shall be suitable for placing in ballast nets.

Ballast is considered to be secured against wash-out and erosion as they are placed in ballast nets which are durable for the entire service life, refer to 8.3.1.1.
If the net durability cannot be ensured the ballast may be secured by 0.5m armor layer of 10inch rocks in the top of all ballast compartments.

The ballast will be placed in all bucket compartments. A removable steel plate will be placed in the bottom of the bucket compartments, where access to caisson hatches is needed. The nets with ballast and the removable steel plate in the bottom of the 4 compartments with hatches have to be removed during decommissioning.

8.3.1.1 Ballast net

The nets must be durable so that ballast may be lifted out for de-commissioning of the foundation after 30 years service life. In addition, it is required that the nets are placed evenly in the buckets and further, that the nets can provide an even distribution of the ballast in the compartments in the bucket.

8.3.2 Option B: Concrete blocks

For option B, the main ballasting of the bucket is considered to be achieved from concrete blocks. The final minimum submerged density (incl. buoyancy) of ballast once placed in the bucket shall be 1380 kg/m^3.

The concrete may contain blast furnace slag and fly ashes.

9. LOADS

All loads on the repair solution will be provided by TYPSA.

10. ENVIRONMENTAL APPROVALS

All approvals from authorities except from health and safety will be handled by EDPR.

11. REFERENCES

/1/ DNV-OS-J101, Design of Offshore Wind Turbine Structures, Det Norske Veritas, May 2014.

/2/ DNV-RP-B401, Recommended Practice 'Cathodic Protection Design', October 2010.