List of suction bucket drawings **(0011347-SPT-00FEB1-ENG-DG-)**:

Document No.	Revision	Date	Title
004-01	C2	2017-08-08	Diameter 9.5m Structural Drawing
005-01	C2	2017-08-08	Diameter 9.5m Top plate, Girders, Stiffeners
006-01	C4	2017-08-08	Diameter 9.5m Welding Details
007-01	C3	2017-08-23	Diameter 9.5m Lifting Padeyes
008-01	C4	2017-08-23	Diameter 9.5m Details Pump Skid Interface
031-01	C1	2017-08-08	Diameter 9.5m Grout In/Outlets and Stub Flooding Inlet
022-01	C2	2017-08-08	Diameter 10.5m Structural Drawing
023-01	C2	2017-08-08	Diameter 10.5m Top plate, Girders, Stiffeners
024-01	C6	2017-11-24	Diameter 10.5m Welding Details
015-01	C3	2017-08-23	Diameter 10.5m Lifting Padeyes
016-01	C4	2017-08-23	Diameter 10.5m Details Pump Skid Interface
032-01	C1	2017-08-08	Diameter 10.5m Grout In/Outlets and Stub Flooding Inlet

List of suction bucket drawings taken for information only **(0011347-SPT-00FEB1-ENG-DG-)**:

Document No.	Revision	Date	Title
003-01	C2	2017-08-08	GA – Suction Bucket, Diameter 9.5 m and 10.5 m
025-01	C2	2017-08-08	Diameter 9.5m Details Docking Frame
009-01	C3	2017-08-08	Diameter 9.5m Details.Anodes
026-01	C3	2017-08-08	Diameter 9.5m Paint Marks
027-01	C3	2017-08-08	Diameter 9.5m Safety Bar
035-01	B4	2017-08-08	Diameter 9.5m and 10.5m Protection plate Roxtec Protrusion
042-01	C1	2017-08-08	Diameter 9.5m Supports Grouting System
043-01	C1	2017-08-08	Diameter 9.5m Grouting Outlet Systems
039-01	C1	2017-08-08	Diameter 9.5m Operation Panel Grouting System
040-01	C1	2017-08-08	Diameter 9.5m Grouting Inlet System
041-01	C1	2017-08-08	Diameter 9.5m Flooding/Grouting Inlet Stub
017-01	C2	2017-08-08	Diameter 10.5m Details Docking Frame
018-01	C2	2017-08-08	Diameter 10.5m Details Anodes
019-01	C3	2017-08-08	Diameter 10.5m Paint Marks
029-01	C3	2017-08-08	Diameter 10.5m Safety Bar
-	C1	2017-08-08	Diameter 10.5m Supports Grouting System
037-01	C1	2017-08-08	Diameter 10.5m Grouting Outlet Systems
046-01	C1	2017-08-08	Diameter 10.5m Operation Panel Grouting System
048-01	C1	2017-08-08	Diameter 10.5m Grout Inlet System
047-01	C1	2017-08-08	Diameter 10.5m Flooding/Grouting Inlet Stub

A4 EVALUATION WORK

The structural design is verified based on a combination of documentation review and spot check hand calculations. The design review has been concentrated on primary structural elements of jacket with the bucket suction and details which are important for the overall stability and safety of the structure. The verification includes an appraisal and evaluation of the structural design under relevant load combinations that are expected to occur during extreme condition, operational phases and installation condition.

For the analysis, detailed models and methods have been applied by Designer, particularly for the design of structural joints and other details where requirements to fatigue resistance govern the design. Based on a general consideration of jacket joint flexibilities, the assessment and documentation of the primary structure's fatigue properties has widely been based on a systematic handling of the fatigue accumulation in hot spots in tubular joints, connections across assembly plates and details of complex stress conditions in the TP and suction buckets, all by means of influence matrices whose coefficients have been determined in separate finite element models of the details.

The very nature of the supports structure's predominant and highly dynamic wind loading differs significantly from that of a traditional gravity- and wave-loaded offshore installation seen in the Oil & Gas industry. In combination with the cases of complex geometry seen in all three main parts of the SBJ design, a general implication of this loading characteristic has been that both modelling and analysis by means of the Finite Element Method has called for an extraordinarily careful and meticulous planning.

These aspects of the design and analysis have required a more detailed approach in DNV GL's verification activities than typical for verifications of jacket structure designs in the Oil and Gas industry.

Designer's documentation of the integrity and safety of the primary structures in the SBJ include analyses of the ultimate limit state (ULS), accidental limit state (ALS), fatigue limit state (FLS) and serviceability limit state (SLS, i.e. eigenfrequency analysis) for the primary steel structure.

DNV GL's verification of the design and analyses has been based solely on comprehensive document reviews.

A5 VERIFICATION OF DESIGN DRAWINGS

Along with the process of verifying the design reports and performing independent analyses, DNV GL has commented on and verified the primary steel design drawings. The verification of the drawings has been performed as a review particularly checking that dimensions, welding, notes and other specifications stated in the individual drawings entirely and consistently correspond to the design basis.

Particularly, checks have been performed to verify the one-to-one correspondence between the design drawings and the specifications made therein on the one hand and the design analyses made on the other.

Much attention has been paid to the General Notes, which among definitions of symbols and basic conventions summarize the general and highly important specifications of material qualities, fabrication requirements, inspection requirements and corrosion protection.

Also, logistics of fabrication, sequence of assembly and installation have been considered in the review.

A5.1 Design drawings of Jacket and Transition Piece

The review of the jacket and transition piece design drawings has paid specific attention to the corrosion protection system planned and specified for the structures, this also including all preparatory treatments of surfaces, both before initial painting and before repair of painted surfaces.

Certain discrepancies between the painting systems specified in designer's General Note to the project and the painting systems specified by Vattenfall in their project specifications have been identified, yet also become settled in consequence of Vattenfall's expressed acceptance of Designer's design drawings and specifications.

Thus, all issues raised in concern of the jacket and transition piece design drawings have been settled.

A5.2 Design drawings of Jacket and Transition

It is particularly relevant for mention that the review of the suction bucket design drawings has verified the specification of fabrication and installation tolerances. Thus, special attention has been directed towards the tolerances pertaining to buckles, out-of-roundness and out-of-straightness, including the control and documentation of same. The final product's compliance with these tolerances shall be considered of high importance for the installation to be accomplished with least possible complications and for the required safety of the buckets' in-place function to be achieved.

All issues raised in concern of the suction bucket design drawings have been settled.

A6 CORROSION AND CATHODIC PROTECTION

A6.1 Corrosion and Cathodic Protection of jacket support structure:

The corrosion protection of the jacket support structure is ensured with a combination of coating and cathodic protection (GACP). The technical design life time of the jacket support structure is taken as 26 years (25 years of production + 1 year including periods of commissioning and de-commissioning of the turbine). The design life of the cathodic protection system is assumed to be 30 years.

It is observed that the maximum soluble salt level is deviating between the specification considering corrosion protection and the general notes included in the drawing PS-00-005. It is recommended to update the drawing PS-00-005 so that it is clearly seen that the Employer accepts the deviation mentioned above.

It is also observed that deviations between the coating systems provided in the corrosion protection specification and in PS-00-006 are present. Employer has at the 17-11-2017 accepted these deviations.

In addition, it is observed that deviations between the specified total dry film thicknesses for System A and B in the corrosion protection specification and in PS-00-006 are present. Employer has at the 17-11-2017 accepted these deviations.

The following assumptions have been made during the assessment of the corrosion protection system:

- Specified coating systems are based on Employer's specification and subject to a condition of maintenance throughout the design life time.
- Inspection and maintenance of the corrosion protection system in general must be performed. This include cathodic protection survey and coating inspections and repair.
- Properly functioning earthing/electrical connections connecting all parts to be protected by the cathodic protection system, must be confirmed by testing during manufacturing/installation to ensure full electrical continuity with due consideration of the connection resistance and potential voltage drop across electrical continuity cables. However, this is also considered common practice. Please e.g. refer to DNV-RP-B401, Sec. 7.12.

A6.1 Corrosion and Cathodic Protection of suction bucket support structure:

The corrosion protection of the suction bucket support structure is ensured with a combination of coating with coating category III and cathodic protection (GACP). The design life of the cathodic protection system is assumed to be 30 years.

The Operation & Maintenance manual is not reviewed and thereby not verified during this assessment. During the verification of the Operation & Maintenance manual, it must be checked if the requirements for inspection survey of the cathodic protection system are considered to be in accordance with the ones specified in DNV-OS-J101:2014.

The following assumptions have been made during the assessment of the corrosion protection system:

- Specified coating systems are based on Employer's specification and subject to a condition of maintenance throughout the design life time.
- Inspection and maintenance of the corrosion protection system in general must be performed. This include cathodic protection survey and coating inspections and repair.
- Properly functioning earthing/electrical connections connecting all parts to be protected by the cathodic protection system must be confirmed by testing during manufacturing/installation to ensure full electrical continuity with due consideration of the connection resistance and potential voltage drop across electrical continuity cables. However, this is also considered common practice. Please e.g. refer to DNV-RP-B401, Sec. 7.12.

A7 ULS IN-PLACE ANALYSIS

A7.1 ULS In-place analyses of Jacket and Transition Piece

The ULS in-place conditions have been analysed using the finite element method on a global model representing the entire support structure. The documentation /ABE-BOS-0263/ of said model has been reviewed and found to be fit for the assessment of the relevant limit states when support by additional local finite element models as documented in /ABE-BOS-0092/ for the transition piece super element model and in /ABE-BOS-1505/ for the suction bucket super element.

The in-place performance of the jacket and transition piece is documented in /ABE-BOS-0263/ and /ABE-BOS-0092/ has been reviewed. Based on said review it is concluded that the performance of the jacket and transition piece is acceptable and in compliance with the ultimate limit state requirements of the governing standard DNV-OS-J101.

A7.2 ULS In-place analyses of Suction Buckets

The ULS in-place conditions have been analysed using the finite element method as documented in /ABE-BOS-1505/. This documentation has been reviewed whereby the focus has solely been on the ULS performance of the bucket lid structure, i.e. it excludes the documented performance of the bucket skirt. Said skirt is due to its interaction with the surrounding soil assessed as part of the geotechnical review, please see Appendix B. From this review, it is concluded that the ultimate limit state requirements of the governing standard DNV-OS-J101 are fulfilled for the lid by the bucket design.

A8 FLS IN-PLACE ANALYSIS

A8.1 FLS IN-PLACE ANALYSES OF JACKET AND TRANSITION PIECE

The fatigue performance of the jacket and transition piece is documented in /ABE-BOS-0256/ and /AOWF-514-019/.

Jacket- and TP-Designer's widely used approach of influence matrices as a tool for computation of the accumulation of fatigue in and around the welds – in particular in the joints of rather complex geometry and stress condition – has required a rather detailed examination of the FEA-models applied in the computations of the influence numbers.

This examination has focussed on the types of elements applied, the meshing, the identification of hot spots and associated read-out points for stress extrapolation – as well as on the principles applied in order to compensate for the FE-method's shortcomings in correctly showing the stress concentrations at welds in T- and cruciform joints between plates and shells.

Regarding the verification of the Time Domain Fatigue Analysis report, this has to a considerable extent been complicated (and for some details simply hindered) by the report essentially being a summary of results, not offering all information needed for a verification be based solely on document review.

Furthermore, along with the verification activities a discussion between DNVGL and Designer has evolved regarding the multiaxial nature of the stress response in the support structure being an inevitable consequence of the highly dynamic and multidirectional loading of the support structure. The consequences of said general characteristic of the stress ranges needs be accounted for, since it is known to have a reducing influence on fatigue lives computed based on assumptions normally made and methods normally used in fatigue analyses of jacket support structures for structures in oil and gas producing facilities.

This discussion has primarily been focused on the fatigue analysis of jacket tubular joints and been concerned about principles for appropriate computation of the damage in hot spots. Examples of fatigue analysis of selected hot spots on chord- and brace-sides of the Y- and K- type of tubular joints in the upper part of the jacket structure have been made, all based on a reduced number of time series (load seeds) and an attempt at realistically weighing the influence of same on the total damage accumulation.

Regrettably, this discussion and the examples analysed have not brought the clarity needed to put DNV GL in a position where the key issues pertaining to load misalignment and stress directionality / non-proportionality can be verified with the confidence needed to declare compliance with the design requirements of governing DNV GL standards.

However open to pursuing a technical solution to the problems remaining on the fatigue performance verification, considering the current status of the project and its documentation, DNV GL has proposed the pragmatic approach moving forward which consists in the preparation of a Conformity Statement conditional on inspection and monitoring.

A8.2 FLS IN-PLACE ANALYSES OF SUCTION BUCKETS

The fatigue performance of the suction buckets is documented in /ABE-BOS-1506/.

Suction bucket designer's approach has been one of ensuring that the design of the buckets in general and of the design and dressing of the welds in the buckets in particular is such that the details of the weld in the interface between jacket leg and bucket lid (diamond plate) becomes decisive for the conclusions about the fatigue capacity of the suction buckets. This approach, and the results reported in its consequence, has been thoroughly reviewed and commented by DNV GL, concluding in an acceptable settlement of all issues raised along the process.

After the review and commentary of Designer's fatigue analysis report, all issues raised in the process of its verification have been settled.

A9 ALS IN-PLACE ANALYSIS

Vessel impact scenarios have been defined and analysed as documented in /ABE-BOS-0258/. This documentation has been reviewed and found to comply with the requirements of the governing standard DNV-OS-J101.

A10 SLS IN-PLACE ANALYSIS

For the SLS, two functional requirements have been addressed: Vortex shedding and eigenfrequencies.

The exclusion of vortex induced vibrations has been documented in /ABE-BOS-0959/. Said documentation have been reviewed and found to comply with the requirements of the governing standard DNV-OS-J101.

The documentation for the natural vibration characteristics of the foundation /AOWF-513-003/ have been reviewed. Based on said review the documentation have been found to comply with the requirements of the governing standard DNV-OS-J101.

A11 INTERFACE BETWEEN TRANSITION PIECE AND TOWER

The flange connection between transition piece and tower has been checked by comparing the transition piece flange geometry on drawing PS-02-301 with the tower flange geometry on MVOW drawing 0063-8655 rev.1. It is found that the following measures are the same:

- Outer flange diameter
- Inner flange diameter
- Bolt circle diameter
- Flange thickness
- Bolt hole diameter
- Number of bolt holes

Based on this, it is considered verified that the transition piece and tower can be fitted together.

A12 INSTALLATION ANALYSIS

The installation of the foundation is documented in /ABE-BOS-0265/ for the jacket and in /ABE-BOS-1505/ for the suction buckets. The suction bucket skirt has been reviewed as reported Appendix B.

The Jacket installation analyses design report covers the phases of lifting, lowering and on-bottom stability (sliding and overturning) with focus on the structural safety of jacket structure as such. The analyses of the jacket structure during said phases is based on the methodologies, design codes and specifications specified in jacket designer's Design Brief, Installation Analysis. The safety of the structural components during sea transportation has not been verified by DNV GL; still, the documentation of same has been taken for information.

Verification of the safety of the crane and lifting equipment is not covered under present contract.

In general, DNV GL's verification has been based on document review, supplemented with hand calculations. Systematic independent analyses of the jacket structure per se during lift, lowering and on-bottom stability have not been performed.

Regarding the design and analysis of the suction buckets please see Appendix B.

For the phases of lift, lowering and on-bottom stability, the limiting environmental loads have been specified in order to ensure that no component in the integrated sub-structure will be over-utilized.

All issues raised in concern of the structural safety during the stages of transition from fabrication to complete installation of the substructure have been settled.

Still, see also the below made summary of conditions to be considered in the certification phases after subject Design Evaluation Phase.

A13 CONDITIONS TO BE CONSIDERED IN OTHER CERTIFICATION PHASES/MODULES

The conditions identified during the technical evaluation are listed in the following. The conditions are assigned to the certification phases in which they need to be considered and evaluated.

Transport and Installation phase:

The following conditions shall be complied with to ensure the structural safety:

- The sea-state during lift from barge and subsequent lowering shall be one in which peak periods of the waves do not exceed Tp,max = 7.0 sec. Significant wave heights Hs during same phase of lift and lowering shall be limited to Hs,max = 1.5 m for the deep-water positions (bucket diameter 10.5 m) and Hs,max = 3.0 m for the shallow-water positions (bucket diameter 9.5 m).
- During on-bottom stability, particularly against sliding of the structure, the significant wave height shall be limited to Hs,max = 1.5 m.
- Structure shall remain hooked by crane after the lowering procedure has been accomplished and while both self-weight penetration of the bucket skirts and initial stages of suction are ongoing, until a skirt penetration of 2 m or more has been achieved for all three buckets in the structure's foundation.
- Suction in buckets during skirt penetration shall be limited to 3.78 kPa and 4.21 kPa for the Ø9.5 m and Ø10.5 m buckets respectively.
- While suction operation is ongoing and at its termination, mutual differences in bucket penetrations shall be limited to 250 mm. The jacket rotation relative to perpendicular shall also be less than 1.0°.
- Properly functioning earthing/electrical connections connecting all parts to be protected by the cathodic protection system must be confirmed by testing during manufacturing/installation to ensure full electrical continuity with due consideration of the connection resistance and potential voltage drop across electrical continuity cables. However, this is also considered common practice. Please e.g. refer to DNV-RP-B401, Sec. 7.12.

Operation & maintenance phase:

- Based on the findings from the verification of the fatigue design; inspection and monitoring of the welded connections of the jacket structures shall be performed. The inspection and monitoring plan shall be developed in such a manner that remedial action can be taken should cracks in the welded connections develop.
- Specified coating systems are based on Employer's specification and subject to a condition of maintenance throughout the design life time.
- Inspection and maintenance of the corrosion protection system in general must be performed. This include cathodic protection survey and coating inspections and repair.

A14 OUTSTANDING ISSUES

There are no outstanding issues.

A15 CONCLUSION

DNV GL has verified the primary structural steel design of Transition Piece, Jacket and Suction Bucket based on document review. The verification work performed by DNV GL confirms that the customer documentation listed above fulfils the relevant requirements in the IEC 61400-22:2010 and the related governing codes and standards in the present report. The fatigue design is accepted on the condition of inspection and monitoring of the welded connections of the jacket structures.

APPENDIX B
Design Evaluation - WTG Support Structure Geotechnical Design

Evaluation of Geotechnical Design for Aberdeen Offshore Windfarm (AOWF)

B1 DESCRIPTION OF VERIFIED COMPONENT, SYSTEM OR ITEM

This appendix describes the Site-Specific Design Evaluation for the 11 wind turbines on suction bucket jacket foundations of the Aberdeen offshore wind farm (AOWF) according to the Basis for the Evaluation seen in section A2. The foundation system of the three legged jacket structure consist of suction buckets with diameter varying from 9.5 m to 10.5 m. The skirt height varies from 7.5 m to 13.0 m with a target skirt penetration depth between 7.0 and 12.5 meters below seabed. This approach leaves room in the design for soil upheaval and seabed inclination.

This appendix and covers the geotechnical capacity and the soil-structure interaction of the foundation in ULS, SLS and FLS conditions as well as the suction bucket installation process.

B2 INTERFACE TO OTHER COMPONENTS/SYSTEMS

The geotechnical design is the basis for the load evaluation and structural design whose details depend on the soil-structure interaction.

B3 BASIS FOR THE EVALUATION

Applied codes and standards:

Document No.	Revision	Title
IEC 61400-1	2005-08 / AMD1:2010	Wind turbines – Part 1: Design requirements incl. Amendment 1
DNV-OS-J101	2014-05	Design of Offshore Wind Turbine Structures.
DNV-CN 30.4	February 1992	DNV Classification Notes No. 30.4, Foundations.

The evaluation has been based on the following loads, design basis as well as other specific criteria:

Document No.	Revision	Title
20153051.DOC.102	B2	Suction Bucket Design Brief
ABE-BOS-0259	03	Design Report – Load Exchange Setup & Validation
301000327/AOWF-514-010	03	Engineering report – Loads for geotechnical design – Cluster 1, doc. no.
301000327/AOWF-514-011	05	Engineering report – Loads for geotechnical design – Cluster 2, doc. no.
301000327/AOWF-514-009	04	Engineering report – Loads for geotechnical design – Cluster 3, doc. no.
301000327/AOWF-514-005	04	Engineering report – Loads for geotechnical design – Cluster 4, doc. no.
20153051.DOC.103	C1	Suction Bucket Design Basis
20153051.DOC.900	B1	Shell buckling in layered soil

B4 Documentation from customer

List of reports:

Document No.	Revision	Title
ABE-BOS-0037	Rev. C 25-07-2017	Design Report – Suction Bucket Foundation – Detailed Geotechnical Design
20153051.TN.002.B2	B4	AOWF – Foundation Stiffness Matrices from Load-Displacement Curves
20153051.TN.003.B1	B1	AOWF – Suction Bucket Stiffness Properties
0011347-SPT-00FEB1-STR-ER-001-01	C1	Detailed Structural Design – In-place Conditions
ABE-BOS-1126	B2	SPT - Technical Note Soil Structure Interaction During Installation
ABE-BOS-0918	B	Engineering Report Scour Protection
0011347-DLT-00FEI6-00FEI6-DES-ER-004-00	02	Physical Model Tests AOWF-Test Report
0011347-DLT-00FEI6-DES-ER-003-01	02	Material Specification Scour Protection
0011347-DLT-00FEI6-DES-ER-003-00	01	Outcome Physical Model Tests AOWF
0011347-DLT-00FEI6-DES-ER-002-00	02	Design Report – Test Specification AOWF Physical model tests of SBJ scour protection

List of Scour Protection drawings (**0011347-BOS-00FEI6-DES-DG**):

Document No.	Revision	Title
001-01	E	Jacket A01 – Scour Protection Design
002-01	E	Jacket A02 – Scour Protection Design
003-01	E	Jacket A03 – Scour Protection Design
004-01	E	Jacket A04 – Scour Protection Design
005-01	D	Jacket A05 – Scour Protection Design
006-01	E	Jacket B01 – Scour Protection Design
007-01	D	Jacket B02 – Scour Protection Design
008-01	E	Jacket B03 – Scour Protection Design
009-01	D	Jacket B04 – Scour Protection Design
010-01	D	Jacket B05 – Scour Protection Design
011-01	D	Jacket B06 – Scour Protection Design
012-01	B	General arrangement scour protection- Phase 1
013-01	B	Cross sections scour protection- Phase 1
014-01	D	General Arrangements Scour Protection Phase II – Post Installation
015-01	C	Cross sections scour protection- Phase2

List of specifications/manuals/instructions:

Document No.	Revision	Title
N/A		

List of documents taken for information only:

Document No.	Revision	Title
20153051.TN.0006	B1	Back Analysis SSB Trial Installations
20153051.DOC.101	C1	Geotechnical Ground Model and Design Parameters for information only
0011347-RAM-00FEC3-GEO-ER-001-00	16-02-2017	Engineering Report – Clustering Study
0011347-SPT-00FEI5-GEO-CN-002-00	10.01.2017	SPT Offshore: Foundation Stiffness Matrices from Load-Displacement Curves, Technical Note
20153051.TN.006.B1	23-12-2016	SPT Offshore: Back Analysis SSB Trial Installations
20153051.DOC.101	C1	Geotechnical Ground Model and Design Parameters
ER-DE-IEC61400-22-02360-0	2017-12-21	DNV GL Evaluation Report. Integrated Load Analysis. Aberdeen Offshore Wind Farm Limited
ER-DE-IEC61400-22-02359-0	2017-12-21	DNV GL Evaluation Report. Design Basis Evaluation. Aberdeen Offshore Wind Farm Limited
ER-SC-IEC61400-22-01569-1	2017-12-21	DNV GL Site Conditions Assessment Evaluation Report for Rotor-Nacelle Assembly and Support Structure. Aberdeen Offshore Wind Farm Limited.

B5 EVALUATION WORK

For the suction bucket, the calculation methods were previously confirmed in the DNV GL Design Basis Evaluation report. DNV GL's verification is primarily based on parallel independent calculations, taking consideration of the calculation methods assessed during the Design Basis Evaluation phase.

The foundation system is designed in ULS, SLS and FLS accounting for relevant load cases, including installation effects and cyclic loading. The foundations will be equipped with scour protection, and the void between the lid and the soil will be grouted to ensure full contact and avoid potential differential settlements.

SPT has carried out the geotechnical part of the foundation design while Rambøll has the responsibility for the structural design of the foundation buckets and the jacket structure.

B5.1 General Soil Parameters

The design parameters for use in the geotechnical design of the suction bucket foundations are derived from the results of the numerous geotechnical investigations carried out at the Aberdeen wind farm site. The investigations have been assessed in the DNV GL Site Conditions Assessment Evaluation Report.

The soil present at the Aberdeen Offshore Wind Farm consists of 20-25m of Quaternary sediments, both sand and clay, overlying the bedrock. The formation layers (units) are gradually sloped onwards towards the sea; the angle of slope roughly parallels the slope of the seabed.

A summary of the soil characteristics is presented in the following:

Soil Property	Value
Effective unit weight	γ' = 7.8 / 8.8 kN/m3 (sand unit Ia / Ib), 8.8 / 10.0 kN/ m3 (clay unit II / III
Cone resistance	q_c = 10 MPa to 80 MPa, usually increasing with depth

Soil Property	Value
Angle of internal friction	φ' = 36° / 33° (sand unit Ia / Ib)
Undrained shear strength	c_u = 45 kPa to 75 kPa, increasing with depth from 0 m to 25 m below seabed for clay units II and III.

The assessment and evaluation is diligently executed, with different methods looking at one topic from different points of view before determining the design parameters.

Thus, DNV GL confirms that the relevant requirements of standard DNV-OS-J101 are fulfilled.

B5.2 Degradation due to cyclic loading

The approach and results of the cyclic degradation evaluation are in accordance with industry practice and previous DNV GL experience from similar design conditions, and fulfils the requirements of DNV-OS-J101.

The foundation capacity was checked for two ULS load conditions:

- 35-hour design storm event according to NORSOK N-003.
- Normal operating conditions with prolonged tension

The result of the cyclic degradation was included in the geotechnical design for both strength and stiffness assessment.

B6 GEOTECHNICAL DESIGN

B6.1 Suction Bucket Installation

The bucket foundations intended for the Aberdeen jacket structure foundation will be installed using under-base suction. The soil resistance during this installation is governed by the side friction on the foundation skirts and the skirt tip resistance. The limiting suction that can be applied is the least of the soil capacity, cavitation limit and structural capacity against buckling of the foundation bucket structure.

The penetration resistance is calculated using the CPT-method, where the soil resistance is calculated by using the qc-profiles from the individual CPT-tests and empirical correlation coefficients (skirt friction factor kf, and skirt tip resistance kp). This is supported by trial installations carried out on similar structures in layered soils similar to the site soil data.

High estimate and best estimate resistance factors are derived based of in-situ trial penetration tests, where specific values of kf and kp have been established for each soil unit based on back-calculations of the penetration tests. This calculation model is also in agreement with DNV-CN 30.4.

The back-analyses from the trial installations have been reviewed by DNV GL, and were found to give a good basis for the proposed calculation methods.

In the calculations, water flow around the skirt will be relied on, thus reducing the tip resistance during installation.

The foundation was assessed to be within the requirements regarding:

- Soil capacity against upheaval failure
- Cavitation limitation for water depth 19 m to 32 m
- Buckling capacity of the steel structure

The foundation will be installed by introducing underbase suction. The suction installation capacity for WTG B04 and B05 were found to be on the limit to be able to reach the minimum target penetration of 12.3 m with a maximum underbase suction of 350 kPa.

The designer intents to use pressure cycling to mitigate an unexpected higher installation resistance. This may change the mechanical properties of the soil, and these effects have not been considered in the design. Thus, the design has been approved with the condition of avoiding pressure cycling.

If pressure cycling is applied nevertheless, the design strength of the foundation must be re-evaluated again.

Although the skirt is supported by the soil, its buckling is an issue. The relevant FE-calculation involves a combination of geotechnical and steel characteristics. A physical (soil springs) and geometrically (pre-deformation) non-linear FE-calculation is required to determine the critical load due to suction pressure.

The determination of the most critical pre-deformation usually runs into some difficulties, as the standard method of using an appropriate scale of the first Eigenform is often not sufficiently conservative. It has been revealed that there are more conservative pre-deformations, only to be determined by trial and error. The skirt was verified by a parallel FE-calculation, coupling soil and steel structure behaviour, confirming the design assumptions.

B6.2 Geotechnical Capacity Analysis (ULS)

The foundation bucket capacity shall be checked for all relevant ULS load cases. This includes normal operational conditions and the 35-hours storm case. Both tension and compression loads shall be applied to the capacity checks.

The design soil bearing capacity including cyclic soil degradation have been verified by a parallel FE-calculation in Plaxis 3D.

For the 35-hours storm loading, the effect of cyclic degradation and subsequent regain of strength was established based on the methodology reviewed as part of the design basis evaluation documented.

If the time of action of the differential pressure is too long, the suction bucket will move upwards and rotate too much. Hence, the following premises must be ensured:

- that a single stroke of upward movement is small enough not to provoke a permanent change of soil state and
- that one time span of "prolonged tension" is balanced by a time span of prolonged compression of equal or higher duration, so that the bucket does not fail in the long term.

This means, if for some seconds, the skirt's skin friction is not enough to carry the outer tension load and a negative differential pressure develops inside the bucket. But this negative pressure able to develop is large and its duration short enough to be able to carry the outer loads safely without problems. The next peak tension loads are smaller and do not activate the negative pressure as much. The main topic is, that the near zero average load is maintained throughout the whole 35 hour storm, as the wind turbine's power production with its resulting rotor thrust is switched of.

Prolonged tension loading was assessed for the normal operating condition. The tension loads from the ULS storm conditions is higher than for this condition, but the short load peaks with a near zero average load are less critical than high average tension loads found for normal operating conditions. The highest average tension loads acting on the suction buckets has been found for the case when the wind turbine is operating with full design power, i.e. between ~10 to 15 m/s.