HESSELØ OFFSHORE WIND FARM

Certification Report
Concept
Metocean and ice conditions

Energinet Eltransmission A/S

Report No.: CR-C-DNV-SE-0190-08736-0
Date: 2022-05-10

Project name:	Hesselø Offshore Wind farm	DNV Energy Systems
Report title:	Certification Report	Renewables Certification
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Date of issue:	2022-05-10	
Project No.:	10332313 / 644383	
Report No.:	CR-C-DNV-SE-0190-08736-0	

Applicable contract(s) governing the provision of this Report: 226250-SFA-20211222, PO nb. IO 4500071457 0010

Objective:

To confirm the successful evaluation of the conceptual metocean site conditions and conceptual ice conditions for the Hesselø Offshore Wind Farm according to DNV-SE-0190:2021-09.

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Keywords:

Concept, Hesselø Offshore Wind Farm, metocean, ice

Rev. No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
0	2022-05-10	First issue, for Statement of Feasibility	IPL	JSIMON	PR

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1 EXECUTIVE SUMMARY

This report confirms that DNV, as accredited Certification Body, has verified the conceptual meteorological and marine (metocean) site conditions documentation and the conceptual ice conditions documentation for the Hesselø Offshore Wind Farm (OWF) according to the service description in DNV-SE-0190:2021-09 for Project Certification Phase 0: Concept, for Energinet Eltransmission A/S (Energinet), the Danish national transmission system operator. The conceptual metocean site conditions and the conceptual ice conditions evaluation can be taken as background for subsequent DNV-SE-0190:2021-09 and IECRE OD-502:2018-10 certification phases.

The aim of the Concept phase according to the service description in DNV-SE-0190:2021-09 is to provide an overview of design parameters and design methods intended for the project, for an early identification of critical items, if any. The conceptual metocean site conditions assessment and the conceptual ice conditions assessment for Hesselø OWF is part of the Concept certification phase and produces preliminary metocean and ice design parameters to be applied for preparing a tender for the Hesselø OWF concession.

The 247 km^2 Hesselø OWF will be established within Hesselø Bugt in Kattegat, approximately 30 km north of Zealand and 20 km from the island of Hesselø as indicated in figure 1 below. The Hesselø OWF is planned to have a capacity of minimum 800 MW and maximum 1200 MW and to be in full operation no later than ultimo 2027.

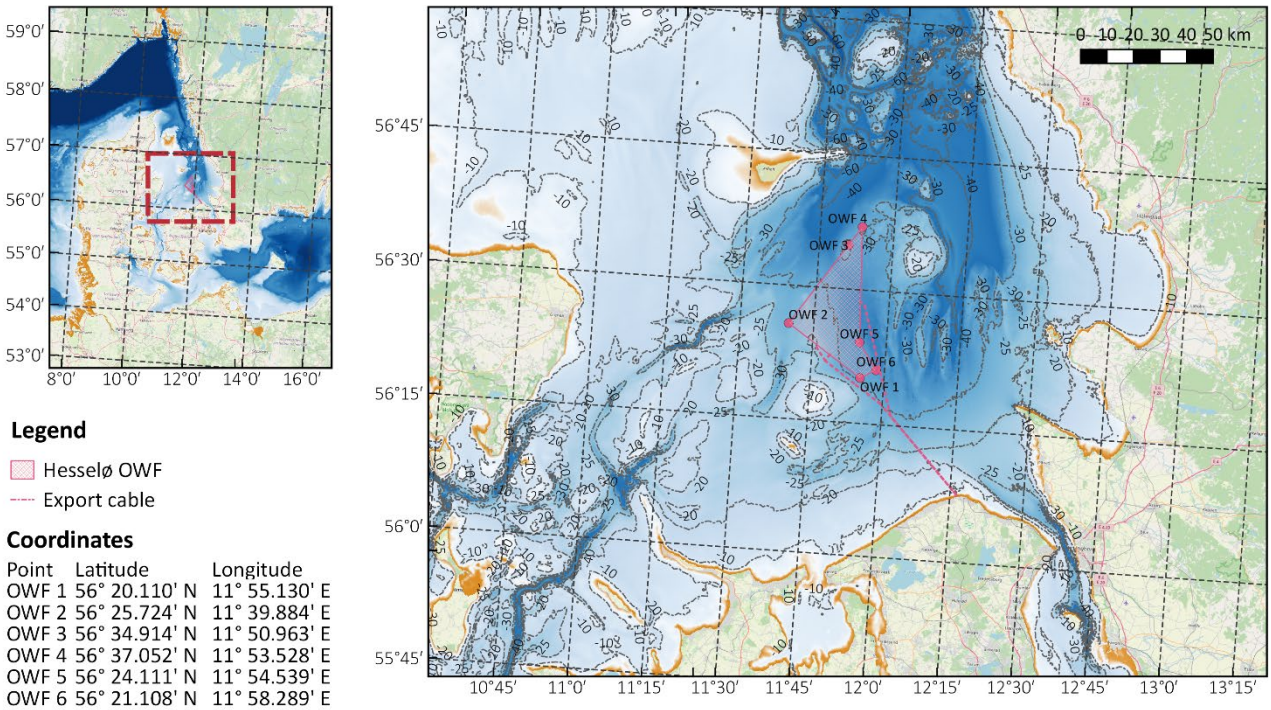

Figure 1: Map showing the gross area (pink polygon) and cable route of the Hesselø OWF

As expected for a Tender phase, the data is not as complete as for a Design Basis phase, and the DNV evaluation does not provide a general approval of metocean and ice design parameters or methods for the subsequent Design Basis certification phase according to DNV-SE-0190:2021-09, for which more detailed documentation and review is required.

The DNV verification of plausibility for the conceptual metocean and ice design parameters is based on document reviews described in the appendices to this report, see section 3. A summary of conditions and outstanding issues, if any, is listed in section 5 and section 6.

The technical plausibility check performed by DNV confirms that the documentation from Energinet related to the Hesselø OWF tender process as listed in Appendix A section A4 and Appendix B section B4 fulfils the relevant demands set up in the applied Certification scheme listed in section 2 below.

2 CERTIFICATION SCHEME

Document No.	Title
DNV-SE-0190:2021-09	Project certification of wind power plants

3 SCOPE OF EVALUATION

The scope and interface of the evaluation covered by the report is the

- conceptual metocean site conditions assessment and
- conceptual ice conditions assessment

as part of the Concept certification phase and produces preliminary metocean and ice design parameters applicable for preparing a tender for the Hesselø OWF concession.

The Appendices to this report comprise the detailed DNV evaluation which include references to standards, list of documentation and the conclusion of the DNV evaluation.

4 CONDITIONS

DNV has evaluated the documentation referenced in Appendices A and B for conceptual design data and the design parameters presented are suitable for conceptual design only. For a Design Basis certification generally, further details for determination of metocean and ice design parameters shall be given.

Conditions based on the documentation referenced in Appendices A and B are:

- an update of the report /1/ once the full floating LIDAR data set is available shall be undertaken
- validated local marine hindcast model setups should be applied to obtain more accurate hindcast results at the site
- further details pertaining to e.g., the applied bathymetry and the applied calibration shall be included
- the water level rise due to climate change shall be included and added to the high-water levels for design
- the applicable current profile shall be investigated further, for example using a validated 3D current model
- correlation analysis for the extreme water levels with extreme wave heights and extreme current with extreme wave parameters should be performed
- a detailed wave breaking analysis shall be included
- consistency between wind forcing of the models and design wind shall be analysed
- the 1-year ice crushing strength coefficient (C_R) shall be further analysed
- ice thickness shall be further analysed
- validation of air temperature records from hindcast data vs. observed air temperature shall be included for determination of ice design parameters.

5 OUTSTANDING ISSUES

Outstanding issues represent deviations from the specified standard(s) and shall be resolved for final compliance with the applied standard(s).

No outstanding issues have been identified.

6 CONCLUSION

Under consideration of the conditions listed in Section 4, the technical plausibility check performed by DNV confirms that the documentation from Energinet related to the Hesselø OWF tender process as listed in Appendix A section A4 and Appendix B section B4 fulfils the relevant demands of the Concept Certification Phase of the Certification scheme specified in Section 2 for the metocean and ice site conditions.

A summary of key approved conceptual metocean and ice data is given in Appendix C.

APPENDIX A
Conceptual metocean site conditions

EVALUATION OF CONCEPTUAL METOCEAN SITE CONDITIONS FOR HESSELØ OFFSHORE WIND FARM

A1 DESCRIPTION OF VERIFIED COMPONENT, SYSTEM OR ITEM

This appendix describes the DNV evaluation of the conceptual meteorological and marine (metocean) site conditions for the Hesselø Offshore Wind Farm (OWF) according to DNV-SE-0190:2021-09.

The conceptual metocean site conditions assessment (SCA) produces preliminary metocean design parameters to be applied for preparing a tender for the Hesselø OWF concession.

As expected for a tender phase, the data is not complete as for a design basis phase, and the DNV evaluation does not provide a general approval of design parameters or methods for the subsequent Design Basis certification phase according to DNV-SE-0190:2021-09, for which more detailed documentation and review is required.

The conceptual metocean SCA for Hesselø OWF is developed by the project organization Energinet Eltransmission A/S (Energinet) with contributions from EMD International A/S and DHI; the conceptual metocean SCA documentation is defined in section A4 below.

A2 INTERFACE TO OTHER COMPONENTS/SYSTEMS

The conceptual metocean SCA evaluation is part of the Concept certification phase of the Project Certification Scheme specified in DNV-SE-0190:2021-09 and is background for subsequent DNV-SE-0190:2021-09 and IECRE OD-502:2018-10 certification phases.

A3 BASIS FOR THE EVALUATION

The applied codes and standards used in combination with the Certification Scheme DNV-SE-0190:2021-09 are listed below:

Doc. No.	Rev.	Title
DNV-ST-0126	2021-12	Support structures for wind turbines
DNV-ST-0437	2021-11	Loads and site conditions for wind turbines
IEC 61400-1	2019-02	Wind energy generation systems – Part 1: Design requirements
IEC 61400-3-1	2019-04	Wind energy generation systems – Part 3-1: Design requirements for fixed offshore wind turbines
DNV-RP-C205	2021-09	Environmental conditions and environmental loads

A4 DOCUMENTATION FROM CUSTOMER

The conceptual metocean SCA documents for the Hesselø OWF are defined as the following documents:

Ref.	Doc. No.	Rev.	Title
/A1/	220114_21198_A_TS_1	1 / 2022-02-24	EMD International A/S for Energinet Eltransmission A/S: Hesselø Offshore Wind Farm- Site Wind Conditions Assessment
/A2/	proj. no. 11826722	Draft 0.1 / 2021-01-14	DHI: Hesselø Offshore Wind Farm - Site Metocean Conditions Assessment Report

List of documents taken for information only:

Ref.	Doc. No.	Rev.	Title
/A-A/	-	2021-02-01	EMD International A/S for Energinet Eltransmission A/S: Hesselø Offshore Wind Farm - Site Wind Conditions Assessment Doc. no. 220114_21198_A_TS_0, rev. 1, dated 14-01-2022
/A-B/			Hindcast Data for OWF1, OWF2 and OWF3 as delivered
/A-C/			Historical Measurement data as delivered
/A-D/	proj. no. 11824164	Draft 0.1, dated 18-01-2022	DHI for Energinet Eltransmission A/S: Hesselø Offshore Wind Farm - Weather Windows Analysis Technical Report

A5 EVALUATION WORK

The DNV evaluation activities are outlined in this section. To facilitate the overview of the approved conceptual metocean site specific conditions the key data are presented in tabular form in Appendix C.

The DNV verification of the conceptual metocean site conditions is primarily based on document review assisted by minor independent calculations, with focus on the technical plausibility of the conceptual metocean design parameters specified in the metocean site conditions documents (Section A4). DNV's communication with the customer during the verification process has been through Verification Comment Sheets (VCS) where Technical Queries, Non-Conformances and Advices to the documents that constitute the verified conceptual metocean SCA may be raised.

A5.1 METEOROLOGICAL SITE CONDITIONS

The meteorological conditions for conceptual design for this project encompass the site conditions related to mainly wind, where a distinction is made between normal and extreme conditions.

The meteorological parameters for conceptual design are developed by EMD International A/S as described in /A1/ based on a floating LIDAR measurement campaign at the site combined with 22 years of EMD-WRF mesoscale data. The report /A1/ considered additional measurement sources namely Læsø met mast, Danish Meteorological Institute (DHI) stations at Anholt, Gniben and Nakkehoved Fyr and Swedish Meteorological Institute (SMHI) stations at Väderö and Halmstad Flygplats as an aid to verify the long-term wind climate.

As stated in the report /A1/ the floating LIDAR measurement campaign used in this assessment currently covers 8 months from 28/02/2021 to 28/10/2021 and therefore measurements from the winter months are currently missing. DNV's recommendation for the subsequent phases of the project is that the report /A1/ be updated once the full floating LIDAR data set is available.

Due to the limited amount of site-specific measurement, for the determination of the 50-year extreme wind condition EMD International A/S chose in /A1/ to apply EN1991-1-4 including its Danish Annex DK NA EN1991-1-4. This approach is considered acceptable by DNV.

DNV finds that the methodologies applied in /A1/ for deriving the conceptual meteorological design parameters are according to best engineering practice. DNV has evaluated the conceptual meteorological site conditions presented in /A1/ for plausibility and considers them to be in line with DNV's expectations in the area. DNV finds the conceptual meteorological site conditions suitable for conceptual design.

DNV notes that though wind parameters are given in /A2/, these are accepted for wind forcing of the marine models only, and not accepted for meteorological conceptual design parameters, for which only /A1/ is accepted.

A5.2 MARINE SITE CONDITIONS AND WIND-WAVE CORRELATION

The marine conditions for conceptual design for Hesselø OWF encompass the site conditions related to mainly water levels, waves and currents, where a distinction is made between normal and extreme conditions.

The conceptual marine parameters are developed by DHI and given in the DHI marine hindcast report /A2/, which presents results and analyses from the "DHI Danish Waters hindcast model database", obtained from the 2D hydrodynamic hindcast model MIKE21 HD (water levels and currents) and spectral wave hindcast model MIKE21 SW applied with a so-called "regional model set-up", i.e. with a rather coarse local model grid. Further to /A2/, a data package including hindcast data in the form of time-series and spectra associated with /A2/ is part of the DHI delivery for the conceptual design.

The hindcast models described in /A2/ are forced with the high-resolution reanalysis COSMO-REA6 (CREA6) dataset developed by the Hans-Ertel-Centre of the Deutscher Wetterdienst and the University of Bonn in Germany. The wind and wave correlations are thus obtained with the CREA6 wind, which may be different from the conceptual design wind /A1/. Consistency between the CREA6 wind and the conceptual design wind /A1/ has not been investigated, however, the verification of CREA6 wind with local wind measurements gives confidence that the wind used for wind-and-wave correlations is acceptable for conceptual design.

In the data package associated with /A2/, the waves are divided into wind-sea and swell-wave components, so that the designers may choose to apply these in the design, or to apply the total wave component. Further, data are extracted at 3 locations covering the site, so that the designers may choose a design based on the most conservative marine conditions of the three locations, i.e. covering the whole site, or alternatively a design based on the marine parameters at specific locations within the site. The extreme values are based on extreme value analysis of the background data as described in /A2/. It is concluded that depth induced wave breaking is not expected at the site, however, detailed wave breaking analysis including steepness related breaking is not performed for conceptual design.

DNV finds that the applied hindcast models are state of the art, that the model results are acceptably validated against measurements for conceptual design and that the methodologies applied in the extreme value analysis and for deriving the conceptual marine design parameters in /A2/ are according to best engineering practice. DNV has evaluated the conceptual marine design parameters presented in /A2/ for plausibility and found them to agree with DNV's expectations in the area.

It is noted in /A2/, to which DNV agrees, that application of local model set-ups, i.e. with a local refined model grid, is recommended for obtaining results of higher accuracy, and that the current at the site should be further investigated for example by a validated 3D model, as the current at the site may not be well represented by a 2D model due to stratification, characterized by layers of salty water from the north Sea close to the seabed and brackish waters from the Baltic Sea at the surface. These recommendations should be analysed for the subsequent Design Basis module.

A6 CONDITIONS TO BE CONSIDERED IN OTHER CERTIFICATION PHASES/MODULES

DNV has evaluated the documentation /A1/ and /A2/ for conceptual design data and the design parameters presented are suitable for conceptual design only.

For a Design Basis certification module the metocean conditions must be further analysed, including but not limited to:

- an update of the report /1/ once the full floating LIDAR data set is available shall be undertaken

- it is recommended to apply validated local marine hindcast model setups to obtain more accurate hindcast results at the site
- further details pertaining to e.g. the applied bathymetry and the applied calibration must be included
- the water level rise due to climate change shall be included and added to the high-water levels
- the applicable current profile shall be investigated further, for example using a validated 3D current model
- it is recommended (not required) by DNV to perform correlation analysis for the extreme water levels with extreme wave heights and extreme current with extreme wave parameters
- a detailed wave breaking analysis shall be included
- consistency between wind forcing of the models and design wind shall be analysed.

A7 OUTSTANDING ISSUES

There are no outstanding issues for the conceptual metocean site conditions part of the Concept Certification Phase.

A8 CONCLUSION

The technical plausibility check performed by DNV confirms that the metocean SCA documentation from the customer related to the Hesselø OWF tender process as listed under Section A4 fulfils the requirements according to the Concept Certification Phase described in DNV-SE-0190:2021-09 and the standards listed in section A3.

Summary of key approved conceptual metocean data is given in Appendix C.

APPENDIX B
Conceptual ice conditions

EVALUATION OF CONCEPTUAL ICE CONDITIONS FOR HESSELØ OFFSHORE WIND FARM

B1 DESCRIPTION OF VERIFIED COMPONENT, SYSTEM OR ITEM

This appendix describes the DNV evaluation of the conceptual ice assessment for the Hesselø Offshore Wind Farm (OWF) according to DNV-SE-0190:2021-09.

The conceptual ice assessment produces preliminary sea ice site condition design parameters to be applied for preparing a tender for the Hesselø OWF concession.

As expected for a tender phase, the data is not complete as for a design basis phase, and the DNV evaluation does not provide a general approval of design parameters or methods for the subsequent Design Basis certification phase according to DNV-SE-0190:2021-09, for which more detailed documentation and review is required. The present review focuses on specification of ice conditions (level ice and ice ridge physical and mechanical properties) and icing.

The conceptual ice assessment for Hesselø OWF is developed by the project organization Energinet Eltransmission A/S (Energinet) with contributions from Sweco; the conceptual ice assessment documentation is defined in section B4 below.

B2 INTERFACE TO OTHER COMPONENTS/SYSTEMS

The conceptual ice assessment evaluation is part of the Concept certification phase of the Project Certification Scheme specified in DNV-SE-0190:2021-09 and is background for subsequent DNV-SE-0190:2021-09 and IECRE OD-502:2018-10 certification phases.

B3 BASIS FOR THE EVALUATION

The applied codes and standards used in combination with the Certification Scheme DNV-SE-0190:2021-09 are listed below:

Doc. No.	Rev.	Title
IEC 61400-3-1	2019-04	Wind energy generation systems – Part 3-1: Design requirements for fixed offshore wind turbines

B4 DOCUMENTATION FROM CUSTOMER

The conceptual ice documents for the Hesselø OWF are defined as the following documents:

Ref.	Doc. No.	Rev.	Title
/B1/	23.1511.01	00 / 2021-12-03	SWECO: Ice Assessment, Hesselø OWF p:\tm\23.1511.01_hesselø_owf,_ice_assessment\04_output\ice assessment hesselø owf draft_211202.docx

List of documents taken for information only:

Ref.	Doc. No.	Rev.	Title
/B-A/	-	2021-01-14	Site Metocean Conditions Assessment, DHI Report.

B5 EVALUATION WORK

The present review focuses on specification of ice conditions (level ice and ice ridge physical and mechanical properties) and icing. Information regarding climate change, loads and other non-ice related properties such as water level has not been reviewed.

To facilitate the overview of the approved conceptual ice conditions the key data are presented in tabular form in Appendix C

B5.1 Sea Ice Condition

Ice thickness

The calculation of the ice thickness is based on an empirical expression between ice thickness and annual freezing degree days. The expression is similar to that in IEC 61400 but slightly modified for the conditions in the southern Baltic. The temperature used as input for the thermal growth is taken from the reanalysis dataset ERA5 with data from 1979 to 2019. The annual freezing degree days are fitted with a probability distribution and the 50-year annual freezing degree days is obtained from the fit.

The ice thicknesses associated with 50-year and 100-year occurrence period are 35 cm and 39 cm, respectively. These values are found plausible by DNV and are accepted at this phase. Due to inherent variations in ice condition reports, future detailing may result in greater ice thickness than accepted here.

Ice distribution

The ice distribution in the section 4.3 of the report /B1/ is found reasonable and is accepted.

Ice ridges

The thicknesses of the consolidated layer were obtained multiplying the level ice thickness associated with a specific return period with a factor of 1.6. This is found reasonable and is accepted by DNV.

Further, below mentioned design values of the ice ridges are found reasonable and are accepted by DNV.

- draught of ridge keel: 8.45 m.
- thickness of the consolidated layer for 50-year and 100-year recurrence periods respectively: 56 cm and 62 cm.
- keel porosity: 35%.
- internal friction: 30 degrees.
- keel cohesion: 3 kPa.

Ice crushing strength

The crushing strength with 1-year return period is established based on a publication and adjusted for southern Baltic conditions. A range is suggested varying from 0.85 – 1 MPa which is accepted.

B6 CONDITIONS TO BE CONSIDERED IN OTHER CERTIFICATION PHASES/MODULES

DNV has evaluated the documentation /B1/ for conceptual design data and the design parameters presented are suitable for conceptual design only.

For a Design Basis certification module the ice conditions must be further analysed, including but not limited to:

- the 1-year crushing strength coefficient (C_R)
- ice thickness
- validation of air temperature records from hindcast data vs. observed air temperature.

B7 OUTSTANDING ISSUES

There are no outstanding issues for the conceptual sea ice site conditions part of the Concept Certification Phase.

B8 CONCLUSION

The technical plausibility check performed by DNV confirms that the ice assessment documentation from the customer related to the Hesselø OWF tender process as listed under Section B4 fulfils the requirements according to the Concept Certification Phase described in DNV-SE-0190:2021-09 and the standards listed in section B3.

A summary of key approved conceptual ice data is given in Appendix C.

APPENDIX C
Summary of key approved conceptual metocean and ice site conditions

Wind conditions – Normal	
Annual average wind speed (at proposed hub height 140.0 m MSL)	9.64 m/s
Weibull A-parameter	10.89 m/s
Weibull k-parameter	2.22
Wind shear for operational conditions	0.088
Ambient turbulence / characteristic turbulence at 15 m/s (NTM)	6.0% / 8.2%
Air density	1.23 kg/m^3
Wind conditions – Extreme	
Wind speed 50-year recurrence period, 10 min. (at proposed hub height)	40.50 m/s
Wind shear for EWM	0.095
Turbulence intensity for use with EWM	12.9%
Air density	1.23 kg/m^3

Most conservative of the position specific marine design conditions	
Highest astronomical tide (HAT)	+0.33 m MSL
Lowest astronomical tide (LAT)	-0.37 m MSL
Significant wave height for 50-year recurrence period, $H_{m0,50\text{-}yr}$	5.0 m
Significant wave height for 1-year recurrence period, $H_{m0,1\text{-}yr}$	3.6 m
Peak wave period T_p for extreme for 50-year recurrence wave $H_{m0,50\text{-}yr}$	8.2 s
Peak wave period T_p for extreme for 1-year recurrence wave $H_{m0,1\text{-}yr}$	7.3 s
Extreme deterministic wave height for 50-year recurrence period, $H_{max,50\text{-}yr}$	9.3 m
Extreme deterministic wave height for 1-year recurrence period, $H_{max,1\text{-}yr}$	6.6 m
Wave period interval (10%-90% quantile) associated with $H_{max,50\text{-}yr}$	7.0-8.3 s
Wave period interval (10%-90% quantile) associated with $H_{max,1\text{-}yr}$	5.9-7.1 s
Extreme wave crest elevation* for 50-year recurrence period	7.1 m MSL
Extreme wave crest elevation* for 1-year recurrence period	4.8 m MSL
Extreme positive surge water level* for 50-year recurrence period	1.6 m MSL
Extreme positive surge water level* for 1-year recurrence period	1.0 m MSL
Extreme negative surge water level* for 50-year recurrence period	-0.9 m MSL
Extreme negative surge water level* for 1-year recurrence period	-0.6 m MSL
Extreme depth averaged current speed for 50-year recurrence period	1.1 m/s
Extreme depth averaged current speed for 1-year recurrence period	0.6 m/s

*excluding sea level rise and vertical land movement, which have not been decided for FEED

Sea ice parameters including return period	
Frost index 1/50 years	292 deg-days
Ice thickness 1/50 years	0.35 m
Ice crushing strength coefficient 1 years	0.85 - 1 MPa
Ice crushing strength coefficient – average ridges 1 years	0.66 MPa
Ice ridge consolidated layer thickness 1/50 years	0.56 m
Ice ridge keel depth 1/50 years	8.45 m

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