Recommended design practice

for offshore & nearshore

Seaweed growing systems

Version 1.0 2023

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Marine ingenuity

Contents

1. Version control

Document version	Date	Changes	Remarks
0.1	18-11-2022	-	-
0.2	13-01-2023	Included: - Definition limit states - Load factors and material factors for ALS, SLS and FLS - Corrosion allowance table - Conditions water level, ice, soil - Load cases description - Global and local analyses description - Ch 9 Construction - Ch 11 Documentation	- Updated based on feedback DNV on version 0.1 from 22-12-2022. - DNV project reference 10392311
1.0	30-03-2023	- Change regulatory framework to recommended design practice - Textual changes	- For release

1.1. Disclaimer

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2. Introduction

2.1. Background

This document is an initiative of North Sea Farmers (NSF) supported by Invest-NL. Together with Aqitec and following a permit application process in 2022, NSF identified the need of the seaweed industry to setup a design standard for seaweed farms. To support the industry with a standardised design approach that can be certified by independent parties. This in turn will enable successful permit applications, getting the assets insured and attracting investments into the industry. This document is only a first step in developing this industry wide standard. Therefore, it is titled as “Recommended Design Practice”. NSF encourages all seaweed growing system designers to use this guideline and give feedback in terms of measurement data and suggestions for improvements. This will help developing this practice into a standard and improve the safety and cost-effectiveness in the industry.

2.2. Acknowledgements

This document has been established in a collaboration between Aqitec, Van Oord and DNV, based on an initiative of North Sea Farmers with financial support from Invest-NL.

2.3. Purpose and scope

This document aims to provide guidance for the industry on which technical criteria to use when designing an offshore or nearshore seaweed growing system, thereby aiding the process of obtaining permits for these systems. For this reason the document is not aimed at a specific design, but provides generic criteria that apply to a number of designs.

This document strives to include relevant aspects for design of offshore and nearshore seaweed growing systems; whether it is applicable to a specific design should be assessed by the designer. This document does not take into consideration local regulations and permit requirements.

This document provides the designer criteria to ensure an adequately safe design of the system itself. Handling operations (installation, seeding, harvesting, maintenance and decommissioning) are only in the scope of this document if they affect the design criteria of the system itself. E.g. a limit state for the system can be defined during installation, however requirements for the installation equipment and procedures itself are beyond the scope.

Future versions of this document may expand on the topics covered and provide more detailed guidance on installation, alternative materials, part degradation, inspection intervals, monitoring, operation, maintenance, life extension, and decommissioning.

2.4. References

Throughout this document references are made to other codes and standards. The primary used codes are:

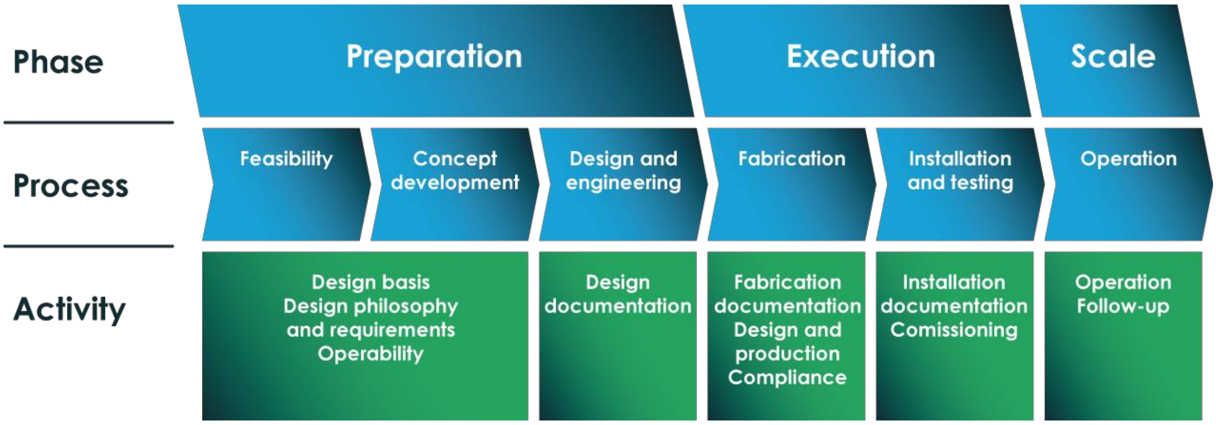
- NS 9415:2021 – Floating aquaculture farms – Site survey, design, execution and use
- DNVGL-OS-E301 – Position mooring
- DNV-RP-C205 – Environmental conditions and environmental loads

Each topic will be introduced with a list of used codes:

	Code	Year latest release	Chapter
Applicable codes	DNV-OS-E301	2021	Ch.
	NS9415	2021	Ch.

2.5. Process

This document has been developed by Aqitec at the request of Invest-NL. The document is reviewed by DNV twice, after each review feedback was implemented. The latest version is distributed with approval from all involved parties (Aqitec, DNV, Van Oord Offshore, North Sea Farmers).



Feasibility study - This step involves evaluating the feasibility of a project, taking into account factors such as technical feasibility, financial feasibility, and market feasibility. Concept development - This step involves developing a detailed plan for the project, including goals, objectives, and a detailed scope of work. Engineering - This step involves designing and specifying all of the components, subsystems, and systems required for the project. Fabrication - This step involves building and assembling the components, subsystems, and systems according to the engineering plans. Installation - This step involves installing and integrating the components, subsystems, and systems at the project site. Testing - This step involves testing the system to ensure that it meets all of the requirements and specifications. Operation - This step involves running and maintaining the project once it is operational.

The recommended design practice will be instrumental for the preparation phase. In this phase it is required to capture relevant information and prepare for the execution and scale phases. The recommended design practice can be used in this process to develop a project specific design basis. To some extent the process is iterative; the design basis and resulting design may be updated with new insights from the execution and scale phase.

The recommended design practice must also be seen in this light. New insights may require extending or refining of the proposed rules and guidelines.

2.6. Approach

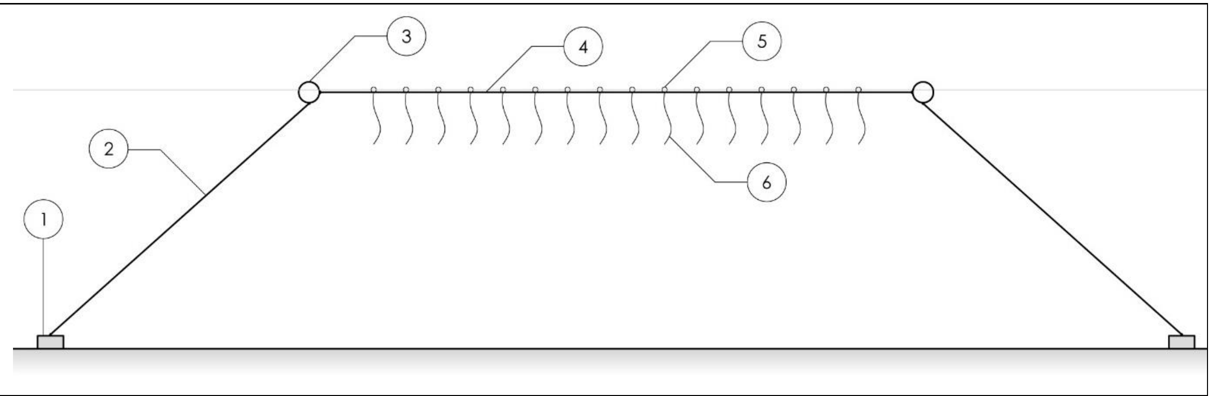
Due to the similarity of the system described by NS9415:2021 to an offshore seaweed system, this standard will be used as primary guideline. NS9415:2021 is evaluated and when applicable it is used within this framework. Missing elements in this recommended design practice will be identified subsequently and references to other applicable standard and/or new guidelines are formed. For offshore position mooring the DNV-OS-E301 code will be used. DNV-RP-C205 is a recommended practice that gives guidance for modelling, analysis and prediction of environmental conditions as well guidance for calculating environmental loads acting on structures.

3. Terms and definitions

Applicable codes	NS9415	2021	Ch 3

3.1. Typical offshore seaweed system

A seaweed system is an artificial structure designed to cultivate seaweed. Typically these are seaweeds growing in the top layers of the water column. When located at a site at sea, with significant water depth (i.e. more than 20m) and exposed to the elements, a system is considered to be offshore. Offshore as opposed to nearshore or onshore.



1 Anchor (pile, fluke, gravity, other)
2 Anchor line (chain, rope, cable)
3 Anchor buoy
4 Head rope or main structural line
5 Buoyancy parts (pipe, buoys, floats)
6 Substrate

A lay-out of a typical offshore seaweed system is shown, together with the nomenclature of typical components. Alternative system lay-outs include 1) systems with interconnecting lines and multiple anchors, 2) systems with controllable buoyancy 3) systems with rigid rafts, rings and spreader frames 4) systems with 2D or 3D substrates and 5) systems with single point anchoring.

3.2. Offshore seaweed system components

A typical offshore seaweed system can consist of the following components:

Anchoring system
System of lines and bottom attachments with the main function of keeping the aquaculture farm in position.

Anchor line
Line in anchoring system.

Anchor
Bottom attachment in anchoring system.

Buoy
Floating device to provide buoyancy for marking or anchoring a system.

Clump weights
Structure in the anchor line, typically on the seabed, limiting the movement of the anchor by friction with the seabed.

Sinker
Structure whose main function is to provide an enclosure with negative buoyancy.

Float
Rotation symmetric buoy typically with a hole through the centerline for threading a rope.

Floater
Structure whose main function is to provide an enclosure with buoyancy and/or stiffness.

Substrate
Structure on which the seaweed is attached and grows. Note: This structure can have multiple shapes, typically 1D (long-line or dropper line) or 2D structures (sheet, net, ribbons) are used.

Main component
Part of an aquaculture farm that holds one or more of the installation's load-bearing main functions.

Head rope or main structural line
Line in the aquaculture farm that holds on one or more of the installation’s load-bearing main functions.

Weak link
Element in the installation that fails on purpose when extreme conditions cause high loads on the system, thereby reducing the loads on the system.

Joint
Point at which two or more structural elements meet or are connected.

4. General requirements for design

4.1. Limit states definitions

Applicable codes	DNV-OS-C101 DNV-OS-E301 NS9415	2021 2021 2021	Ch2 Ch2 Ch9

"Limit state" refers to a level of severity or a condition beyond which a structure or component is no longer designed to fulfill its intended function. Limit states are used to ensure that a structure or component is designed and built to be safe and fit for its intended purpose. Limit state design is used in the referenced codes.

Ultimate limit state (ULS): The ultimate limit state is the maximum load or stress that the structure can withstand before it potentially fails. This limit state is also known as the "failure limit state." The most severe ULS cases are considered to be the most severe waves, current and wind in combination with tidal level, wear, corrosion and severe fouling.

Accidental limit state (ALS): The accidental limit state is the maximum load or stress that a damaged structure can withstand. Damage may occur due to accidental or extraordinary loading, such as a rogue wave or a collision. The most severe ALS cases are considered to be severe waves, current and wind in combination with reduced buoyancy or broken (mooring) lines.

Serviceability limit state (SLS): The serviceability limit state is the load or stress that the structure can withstand in case of service. Cases include the handling of the system during inspection, maintenance and repairs. Severe SLS cases include the loading of the system during seeding and harvesting of the seaweed. To some extend a vessel may transfer loads to the mooring construction.

Fatigue limit state (FLS): The fatigue limit state is the maximum load or stress that a structure or component can withstand over a given a load spectrum (wind, current, wave) without failing due to fatigue. The FLS is expected to be continuous loading caused by wave motion during the life of the components.

4.2. Load combinations

Applicable codes	DNV-OS-C101 DNV-OS-E301 NS9415	2021 2021 2021	Ch2 Ch2 Ch9

4.2.1. Ultimate Limit State (ULS)

Table 1: Combination #1 – Return period (in years) of combined load case – ULS high wind and waves

	Wind	Waves	Current	Ice	Sea level
DNV-OS-C101 (Ch2s2 6.1.)	100	100	10		100
DNV-OS-E301 (Ch2s1 1.2.5.)	100	100	10		-
NS9415 (9.3.1.)	50	50	10		-
Recommended design practice	**50**	**50**	**10**		**-**

Table 2: Combination #2 – Return period (in years) of combined load case - ULS high current

	Wind	Waves	Current	Ice	Sea level
DNV-OS-C101 (Ch2s2 6.1)	10	10	100		100
NS9415 (9.3.1.)	10	10	50		-

Recommended design practice	**10**	**10**	**50**		**-**

Table 3: Combination #3 - Return period (in years) of combined load case - ULS ice

	Wind	Waves	Current	Ice	Sea level
DNV-OS-C101 (Ch2s2 6.1.)	10	10	10	100	Mean
NS9415 (9.3.1.)	10	10	10	50	-
Recommended design practice	**10**	**10**	**10**	**50**	**-**

4.2.2. Accidental Limit State (ALS)

Table 4: Return period (in years) of combined load case - ALS

	Wind	Waves	Current	Ice	Sea level
DNV-OS-C101 (Ch2s2 6.1.)	>1	>1	>1		>1
NS9415 (9.3.1.)	According ULS				
Recommended design practice	**>1**	**>1**	**>1**		**>1**

Note: NS9415 states a reduction of load factor (1,0) and material factors for ALS. A reduced return periods (1 year or higher) can be used in case of ALS. ALS should be seen in conjunction with the accidental loads and scenarios defined.

4.3. Load factors

Applicable codes	DNV-OS-C101 DNV-OS-E301 NS9415	2021 2021 2021	Ch2 Ch2 Ch9

4.3.1. Ultimate Limit State (ULS)

- Permanent loads (G)
  - Permanent loads are loads that will not vary in magnitude, position or direction during the period considered.
- Variable loads (Q)
  - Variable functional loads are loads which may vary in magnitude, position and direction during the period under consideration, and which are related to operations and normal use of the installation.
- Environmental loads (E)
  - Environmental loads are loads which may vary in magnitude, position and direction during the period under consideration, and which are related to operations and normal use of the installation.
- Accidental loads (A)
  - Loads related to abnormal operations or technical failure.
- Deformation loads (D)
  - Deformation loads are loads caused by inflicted deformations.

Table 5: ULS Load factor

Source Document	Permanent (G)	Variable (Q)	Environmental (E)	Deformation (D)
DNV-OS-C101 (Ch2s1 4.4) ULS #1	1.3	1.3	0.7	1

DNV-OS-C101 (Ch2s1 4.4) ULS #2	1	1	1.3*	1
NS9415 (9.2)*** Floaters, anchoring, enclosure and extra equipment	1.15**			
NS9415 (9.2)*** rafts	1	1	1.3	1
Recommended design practice dynamic analysis	**1**	**1**	**1.3***	**1**
Recommended design practice quasi-static analysis	**>1.1**	**>1.1**	**1.43 (1.1x1.3)**	**>1.1**

* May be reduced to 1.15. DNV-OS-C101 states: “Based on a safety assessment considering the risk for both human life and the environment, the loadfactor γ for environmental loads may be reduced to 1.15 in combination b) if the structure is unmanned during extreme environmental conditions.”
**Not stated for which loads this load factor applies.
*** In the case of quasi-static analysis, the load factors shall be multiplied by a dynamic amplification factor greater than or equal to 1.1. The selected dynamic amplification factors shall be justified and documented.

4.3.2. Accidental Limit State (ALS)

Table 6: ALS Load factor

Source Document	
DNV-OS-C101 (Ch2s1 4.7)	1
NS9415 (9.2) * Floaters, anchoring, enclosure and extra equipment	1
NS9415 (9.2) * Rafts	1
Recommended design practice dynamic analysis	**1**
Recommended design practice quasi-static analysis*	**>1.1**

* In the case of quasi-static analysis, the load factors shall be multiplied by a dynamic amplification factor greater than or equal to 1.1. The selected dynamic amplification factors shall be justified and documented.

4.3.3. Fatigue Limit State (FLS)

Table 7: FLS Load factor

Source Document	
DNV-OS-C101 (Ch2s1 4.5)	1
NS9415 (9.2)	≥ 1
Recommended design practice	**1**

Serviceability limit state (SLS)

Table 8: SLS Load factor

Source Document	
DNV-OS-C101 (Ch2s1 4.6)	1
NS9415 (9.2)	1
Recommended design practice	**1**

4.4. Design fatigue factors

Applicable codes	DNV-OS-C101 NS9415	2021 2021	Ch2s5 Ch9

Table 9: Design fatigue factors

<table>
<tr><td>Source Document</td><td>Source</td><td colspan="3">Design fatigue factor DFF</td></tr>
<tr><td>NS9415 (9.4.5.3.)</td><td>The fatigue life shall be equal to or longer than the design working life specified in the product documentation.</td><td colspan="3">≥1</td></tr>
<tr><td rowspan="5">DNV-OS-C101 (Ch2s5 1.2)</td><td rowspan="5">Table 1 Design fatigue factors (DFF)</td><td colspan="3">DFF related to survey cycle</td></tr>
<tr><td></td><td>5-year inspection interval carried out in dry dock</td><td>5-year inspection interval carried out afloat</td></tr>
<tr><td>External structure repair in dry conditions</td><td>1</td><td>1</td></tr>
<tr><td>External structure not accessible for repair in dry conditions</td><td>1</td><td>2 (below splash zone)
3 (in splash zone)</td></tr>
<tr><td>Non-accessible areas, not planned to be accessible for inspection and repairs during operation</td><td>3</td><td>3</td></tr>
<tr><td>Recommended design practice</td><td colspan="4">Steel components according DNV-OS-C101 (Ch2s1 1.2).
Non-steel components according NS9415 (9.4.5.3.).</td></tr>
</table>

4.5. Material Factors

Applicable codes	DNV-OS-C101 NS9415	2021 2021	Ch2 Ch10, Ch13

DNV-OS-C101 only discusses steel components. NS9415 proposes material factors for multiple materials and makes a distinction between amongst others anchoring (structural) and enclosure.

Table 10: Material factors according NS9415

<table>
<tr><td></td><td>NS9415:2021 Ch13 Anchoring</td><td>NS9415:2021 Ch10 Structural elements, enclosures</td><td>NS9415:2021 Ch10 Non-structural elements, enclosures</td></tr>
<tr><td>Synthetic rope and fibre straps</td><td>2.5</td><td rowspan="8">2*</td><td rowspan="8">1.25*</td></tr>
<tr><td>Synthetic rope with knots</td><td>5</td></tr>
<tr><td>Chains and chain components</td><td>2</td></tr>
<tr><td>Used chains</td><td>5</td></tr>
<tr><td>Coupling discs and other connecting points of steel</td><td>2</td></tr>
<tr><td>Steel wires</td><td>3</td></tr>
<tr><td>Shackles</td><td>2</td></tr>
<tr><td>Rock bolts and drag anchors</td><td>3</td></tr>
</table>

*no distinction is made based on material in NS9415.

Table 11: Material factors ULS– Recommended design practice

ULS	Recommended design practice Structural elements, Main structure	Recommended design practice Structural elements of substrate	Recommended design practice Non-structural elements of substrate
Synthetic rope and fibre straps	2.5	2	1.25
Synthetic rope with knots	5		
Chains and chain components	2		
Used chains	5		
Coupling discs and other connecting points of steel	2		
Steel wires	3		
Shackles	2		
Rock bolts and drag anchors	3		
Pile anchor	3*		
Fluke anchor	3*		
Gravity anchor	3*		
*Proposed material factor for anchors, lower factors are allowed if justified and documented. Factors for loading capacity of soil and anchor combination are not included in this recommended design practice and should be assessed using appropriate codes.			
Material factor for items not included in the table above should be selected according EN-1990.			

NS9415:2021 Ch9.1.6.3: "Anchoring analyses for accidental situations shall be carried out with a material factor for different structural parts from Table 10 divided by 1.5."

NS9415:2021 Ch10.3.5.5: For accidental situations and in the serviceability limit state, the highest value of the following shall be used as a material factor for enclosures (structural and non-structural elements):

- 1; or
- material factor from table 10 divided by 1.5.

Table 12: Material factors ALS and SLS– Recommended design practice

ALS and SLS	Recommended design practice Structural elements, Main structure	Recommended design practice Structural elements of substrate	Recommended design practice Non-structural elements of substrate
Synthetic rope and fiber straps	2.5/1.5=1.67	2/1.5=1.34	1.25
Synthetic rope with knots	5/1.5=3.34		
Chains and chain components	2/1.5=1.34		
Used chains	5/1.5=3.34		
Coupling discs and other connecting points of steel	2/1.5=1.34		
Steel wires	3/1.5=2		
Shackles	2/1.5=1.34		
Rock bolts and drag anchors	3/1.5=2		
Pile anchor	3/1.5=2*		
Fluke anchor	3/1.5=2*		
Gravity anchor	3/1.5=2*		
*Proposed material factor for anchors, lower factors are allowed if justified and documented.			
Material factor for items not included in the table above should be selected according EN-1990.			

Material factors for FLS are not given, since these are not relevant for determination of fatigue limits. The safety is part of the design fatigue factor (DFF).

4.6. Corrosion allowance

Applicable codes	DNV-OS-E301 NS9415	2021 2021	Ch.2 S.2 Ch13

Table 13: Minimum corrosion allowance for chain and connection elements in millimetre on diameter

		Recommended design practice		
Part of mooring line	NS9415 (13.3.2.4.)	DNV-OS-E301 (Ch2S2 5.2)		
		Regular inspection*	**Regular inspection****	**Tropical waters**
Splash zone	0.4	**0.4**	**0.2**	**1.0**
Catenary	0.2	**0.3**	**0.2**	**0.3**
Bottom	0.2	**0.4**	**0.3**	**0.4**
* Recommended minimum corrosion allowance when the regular inspection is carried out by ROV according to DNV-RU-OU-0300 Ch.3 Sec.4 [4.10] or according to operators own inspection programme approved by the national authorities if necessary. ** Recommended minimum corrosion allowance when the regular inspection is carried out according to DNV-RU-OU-0300 Ch.3 Sec.4 [4.9] or according to operators own inspection programme approved by the national authorities if necessary.				

Corrosion allowance according to DNV-OS-E301 is dependent on location and inspection scheme. Corrosion allowance should be evaluated according to the inspection scheme chosen and the conservatism of the chosen corrosion allowance.

4.7. Marine growth

Applicable codes	DNV-OS-E301	2021	Ch.2 S.2

Marine growth should be taken into account on the full system and should be estimated for each component based on the location. DNV-OS-E301 states marine growth properties from NORSOK N-003 for latitudes between 56°N to 72°N. Local data should be obtained taking into account cleaning intervals and depth within the water column.

5. Risk assessment

Applicable codes	NS9415 ISO 31010 ISO 31000	2021 2019 2018	Ch. 5.2

5.1. Purpose and Scope

The goal of performing a risk assessment is to identify potential risk factors early in the design in order to guide the design process. Thus the outcome of the risk assessment will bear on design and engineering choices.

The negative consequences considered in the assessment analysis are the harm to human lives, natural habitat and property of third parties stemming from the loss of equipment. Economic risks can be included.

5.2. Methodology

Both NS9415 and DNV-OS-E301 state the need of a risk assessment. NS9415 relates the assessment with the escape of fish and provides an assessment technique. DNV-OS-E301 states the use of a risk assessment to estimate the risk of collision for consequence class 1. NS9415 refers to NS5814 (Norwegian only). More general guidelines for risk assessments are provided by ISO 31000 and assessment techniques by ISO 31010.

To identify the risks techniques are recommended in ISO 31010. For example brainstorming (ISO 31010:2009-B.1.2) and Failure Modes And Effects Analysis (FMEA) (ISO31010:2009-B.2.3). The risks associated with each component are recorded in a risk table with the following elements:

- Identifier
- Undesirable event
- Causes
- Underlying causes
- Consequences
- Severity class
- Likelihood class
- Proposed measures

In order to report the risks identified and analysed a risk map can be used (ISO31010:2009-B.10.3). In subsequent stages it is recommended that the most critical risks are analysed further, for instance using a 'bow-tie' analysis (ISO31010:2009-B.4.2).

5.3. Scoring criteria

A risk assessment is proposed to identify the risk of loss of equipment and identify required mitigating measures.

Table 14: Risk Severity Scores

Severity	**Effect**	
	Loss of redundancy on:	*Release of:*
1	Medium floating object with beacon / Small submerged object	
2	Medium floating object without beacon / Large floating object with beacon	Small floating object
3	Large floating object without beacon Medium submerged object /	Medium floating object with beacon / Small submerged object
4	Large submerged object / object able to plough seabed	Medium floating object without beacon / Large floating object with beacon
5		Large floating object without beacon Medium submerged object /
6		Large submerged object / object able to plough seabed
Small < 50kg and 5 meter length, medium <500kg and 25m length, large >500kg and 25m length		

Consequences of loss-of-equipment are harm to ships (lines in propeller, collision), harm to infrastructure (pipelines, cables) and ecological damage (habitat destruction, entanglement of wildlife, pollution with non-degradable materials).

Table 15: Risk Probability Scores

Probability	Likelihood
6	Very likely
5	Likely
4	Somewhat likely
3	Unlikely
2	Very unlikely
1	Extremely unlikely

Using these scoring metrics each identified risk can be placed in a risk matrix.

5.4. Risk tolerance

It is not possible to exclude all risks from a project. It is therefore necessary to define a level of risk that is accepted as tolerable. For each risk, it needs to be decided if the risk is acceptable, whether mitigation strategies need to be considered or whether a risk is deemed so high that mitigation strategies become requirements. Consequently, risks that are deemed intolerable provide direct input for design decisions.

Table 16: Risk Acceptance Matrix

Probability	**Likelihood**	**Consequence**					
Class		**1**	**2**	**3**	**4**	**5**	**6**
6	Very likely						
5	Likely						
4	Somewhat likely						
3	unlikely						
2	Very unlikely						
1	Extremely unlikely						

Key

- High risk (unacceptable, measures shall be implemented)
- Medium risk (measures shall be considered)
- Low risk (no measures necessary)

6. Environmental conditions

6.1. General

Applicable codes	NS9415 DNV-OS-301 DNV-RP-H103 API RP 2A	2021 2021 2011 superseded by DNV-RP-N103	Ch. 8 Ch.2 S. 1

Environmental data should be obtained and assessed according to NS9415. All relevant environmental conditions should be assessed. For a submerged offshore seaweed system tides, waves and current are dominant effects. Marine growth is to be assessed. Other effects (may) include wind, ice, earthquakes, tsunamis and temperature. Other effects may be relevant in special locations and should be evaluated.

6.2. Wind

Applicable codes	NS9415 EN 1991-1-4	2021	Ch. 8

NS9415 states requirements for determination of wind conditions. Conditions can be determined using the EN 1991-1-4 standard for wind actions on structures.

NS9415 Annex A includes background for site survey.

Quality, accuracy and applicability of data should be assessed.

6.3. Waves

Applicable codes	NS9415 ISO 19901-1 WMO-No.8	2021	Ch. 8

Wave conditions shall be determined by numerical analyses as per NS9415. Numerical analyses (wave modelling) can be supported by wave measurements.

NS9415 states that the measurements shall be in accordance with recognized international oceanographic standards. For example ISO 19901-1 or WMO-No.8.

NS9415 Annex A includes background for site survey.

Design wave conditions shall be described by:
- wave spectra (frequency spectrum and directional spectrum);
- Hs;
- Tp;
- direction.

Relevant wave conditions with the same return period shall be covered, for example by specifying the Hs-Tp contour or Tp interval. The level of detail shall be assessed based on the type of structure and the location being planned.

Quality, accuracy and applicability of data should be assessed.

6.4. Current

Applicable codes	NS9415 ISO 19901-1 WMO-No.8	2021	Ch. 8

NS9415 includes requirements for current measurements and refers to SINTEF 01257, NS94125-1 and NS9415-2 (Norwegian only). NS9415 Annex A includes background for site survey.

For offshore current measurements it is recommended that the measurements shall be in accordance with recognized international oceanographic standards. For example ISO 19901-1 or WMO-No.8.

ADCP current measurements should be corrected to obtain 10 year and 50 year return period velocities. Quality, accuracy and applicability of data should be assessed.

6.5. Water level

Applicable codes	NS9415	2021	Ch. 8

The following values for local water level shall be documented:

- tidal level (mean sea level, highest and lowest astronomical tides);
- extreme high water level and low water level with a return period of 50 years.

As an estimate of the extreme high water level with a return period of 50 years, the highest astronomical tide (HAT) plus 1 m may be used. As an estimate of extreme low water level with a return period of 50 years, the lowest astronomical tide (LAT) minus 1 m may be used.

6.6. Ice conditions

Applicable codes	NS9415	2021	Ch. 8

Icing shall be determined based on the following combined meteorological data for the site. Floating elements may accumulate ice; the impact should be evaluated.

The danger of drift ice at the site shall be assessed and documented.

The danger of the site freezing over shall be assessed and documented, with a statement of when during the year this can occur.

6.7. Soil (Geotechnical data)

Applicable codes	NS9415 API RP 2A DNV-OS-301	2021 2007 2021	Ch. 8 Ch.2 S. 1

The site's relevant geologic processes, geomorphology and soil characteristics should be investigated in accordance with relevant anchor engineering properties:

- Information may be collected through a review of available geophysical data and soil boring data available in engineering files, literature, or government files.
- On-site soil investigations may be performed to define the soil properties
- Experiences and on-site tests of anchorage may be used to support determination of the load capacity of the soil/anchor combination.

According to NS9415

Bottom topography and bottom type shall be mapped for the entire site, including the extent of the anchoring. The resolution of the bottom mapping shall be at least 10 m × 10 m. Major irregularities, such as large rocks, ridges, fissures or large objects shall be especially noted. The measurement method used shall be specified.

According to DNV-OS-E301 Ch.2 S.1

For long term mooring, sea bed soil conditions shall be determined for the intended site to provide data for the anchor design. Soil data should be based on soil borings at location to a depth representative of anchor penetration.

According to API RP 2A

In many offshore areas, geologic processes associated with movement of the near-surface sediments occur within time periods that are relevant to fixed platform design. The nature, magnitude, and return intervals of potential seafloor movements should be evaluated by site investigations and judicious analytical modelling to provide input for determination of the resulting effects on structures and foundations.

If practical, the soil sampling and testing program should be defined after a review of the geophysical results. On-site soil investigation should include one or more soil borings to provide samples suitable for engineering property testing, and a means to perform in-situ testing, if required. The number and depth of borings will depend on the soil variability in the vicinity of the site and the platform configuration. Likewise, the degree of sophistication of soil sampling and preservation techniques, required laboratory testing, and the need for in-situ property testing are a function of the platform design requirements and the adopted design philosophy.

7. Load cases

Applicable codes	NS9415 DNV-OS-301 DNV-RP-H103 DNV-RP-C205	2021 2021 2011 superseded by DNV-RP-N103	Ch.5 Ch.9 Ch.2 S. 1

NS9415 provides requirements for load cases. The system shall be designed to withstand permanent, variable, functional, deformation, environmental and accidental loads.

7.1. ULS cases

The main components shall be dimensioned in accordance with calculations with waves, wind and current in at least 8 directional sectors. The directional combination of current and wave should be assessed for at least 8 directional sectors.

Combinations of current, waves and wind with the highest expected loads on the system should be identified, documented and used as load case.

Effects to be included are:

1) Marine growth. The marine growth is accounted for by increasing the weight of the line segments, increasing the drag coefficients and increased inertial forces (volume). The thickness and density of the marine growth shall be in accordance with the specification for the actual location. Differentiation is allowed between permanent, temporary, regularly cleaned and self-cleaning or growth resistant elements.
2) Extreme tidal levels
3) Wear and corrosion

7.2. ALS cases

The main components shall be dimensioned in accordance with calculations with waves, wind and current in at least 8 directional sectors. The directional combination of current and wave should be assessed for at least 8 directional sectors.

Combinations of current, waves and wind with the 1 year condition expected loads on the system should be identified, documented and used as load case.

Effects to be included are:

1) Loss of buoyancy elements
2) Broken mooring line
3) Marine growth
4) Tidal levels
5) Wear and corrosion

7.3. SLS cases

The loads being transferred by vessel operations to the system should be evaluated. Combinations of current, waves and wind that are operational limits for performing service to the system should be identified, documented and used as load case.

Effects to be included are:

1) Operations during inspection
2) Operations during seeding and harvesting
3) Operations during installation or repairs

7.4. FLS cases

Components will be subjected to cyclic loading during the working life. The effect of the loads induced by incoming waves shall be evaluated. The case may be based on a Weibull distribution for incoming waves. The Weibull factor shall then be set to 1.0.

Unless substantiated otherwise, effects are to be included:

1) Seaweed yield
2) Marine growth
3) Wear and corrosion

8. Analysis

Applicable codes	NS9415 DNV-OS-301 DNV-RP-H103 DNV-RP-C205	2021 2021 2011 superseded by DNV-RP-N103	Ch.9 Ch.2 S. 2 Ch.2 S.5

8.1. Goal

NS9415 states that the aim of the analysis is to determine the combination of waves, current and wind that will result in design loads on components in the aquaculture system. It can, for example, be in the form of stresses, forces, deformations or unacceptable overtopping that can lead to the escape of fish.

For offshore seaweed systems the aim of the analysis is to determine the combination of simultaneous waves, current and wind that will result in design loads on components in the system.

The calculations should be according to NS9415 Chapter 9.4.

8.2. Global analyses

Global analysis shall be performed for the offshore seaweed system. Global analysis provides the input for local analysis of components. A global analysis is normally performed without load factors. Load factors are then applied to the load effect in the form of forces and stresses during the design.

A method should be selected that is suitable for assessing the seaweed cultivation system. Requirements for analysis include:

- The method should accurately model the structural and mechanical properties of the system and loads
- The method is able to obtain the response of the system to loads stated in chapter 4.3 (permanent, variable, environmental, accidental and deformation):
    - Stresses and strains in structural elements
    - Deflections of elements
    - Buoyancy
    - Identifying potential failure points
- Realistic specific weights, drag values and added mass coefficients (preferably empirically obtained) of seaweed are used

Static methods involve analyzing the behavior of a system under a constant, unchanging load. Static analysis is useful for static elements (such as gravity or pile anchor) but is generally not well-suited for studying the behavior of flexible moored offshore systems subjected to wave, wind, and current loads, as these loads are typically highly variable and changing.

Alternative methods can be used for global analyses of response of a system. These include:

- Quasi-static and quasi-dynamic methods. This involves analyzing the response of a system under changing loads. Elements may be simplified and behavior can be modelled using (empirical) formulas.
- Dynamic numerical methods. These include computational fluid dynamics (CFD) and lumped mass mathematical modelling techniques. Both are known methods for mooring calculations. Boundary element methods (BEM) are to a lesser extend practical for modelling the dynamics of responsive flexible systems. Since the accuracy of dynamic methods strongly depend on the assumptions made in the model, it is recommended to validate results by comparing them to field data.

Recommended tools are:

- Lumped mass models that are able to model the systems response in time domain. This method provides a good approximation of the behavior of the seaweed system.

- Commercially available CFD software that is able to model the (highly) flexible systems response in time (or frequency) domain. CFD can provide very accurate predictions of the behavior of systems.

8.3. Local analyses

Loads obtained from the global analysis are to be investigated at a local scale. At this point the load factors are added to the internal forces and the material factor is used to evaluate the capacity of the components. Minimum breaking load of all components needs to be above stresses caused by the loads with material and load factors applied. Custom connections need to be reviewed and structurally analysed.

A local analysis shall be performed of all critical connecting points with verification of resistance including fatigue. If the lifetime based on fatigue calculations for relevant environmental loads is shorter than the design working life according to the product documentation, the design working life shall be set to the calculated fatigue life.

Fatigue analysis shall generally be based on an S-N curve based on tests for relevant detail and using linear damage theory (Palmgren-Miner). Dynamic load effect analysis shall be used for calculating stress ranges, and all contributions to damage shall be included. Simplified fatigue analysis based on a Weibull distribution for incoming waves may be used where justified. The Weibull factor shall then be set to 1.0.

9. Construction

9.1. Anchors

9.1.1. Pile anchor

Applicable codes	DNV-OS-E301 DNV-OS-C101 API RP 2A	2021 2021	Ch.2 S.4 Ch.2 S.10

Pile anchors can be installed using vibratory hammers, screwing systems or rotation drives.

DNV-OS-E301 refers to DNV-OS-C101 Ch.2 Sec.10. The latter includes a chapter for design of pile foundations; the load capacity of the pile design should be based on the requirements. According to DNV-OS-E301 the load capacity can be modelled using soil resistance-deflection (p-y) curves method described in API RP 2A.

9.1.2. Fluke anchor

Applicable codes	DNV-OS-E301 DNV-OS-C101 DNV-RP-E301	2021 2021	Ch.2 S.4 Ch.2 S.10

DNV-OS-E301 refers to DNV-OS-C101 and DNV-RP-E301 for further information on design and installation of fluke anchors for long term mooring.

9.1.3. Gravity anchor

Applicable codes	DNV-OS-E301 DNV-OS-C101 API RP 2A	2021 2021	Ch.2 S.4 Ch.2 S.10

DNV-OS-E301 refers to DNV-OS-C101 Ch.2 Sec.10 for design of gravity foundations.

9.1.4. Other anchor systems

Other anchors such as plate anchors, suction anchors, are not included in this recommended design practice and should be assessed using appropriate codes.

9.2. Chain

Applicable codes	NS9415 DNV-OS-E301 DNV-OS-E302	2021 2021 2022	Ch.13 Ch.2 S.4

NS9415 states that chain shall have an average breaking stress of <u>less than or equal to 700 MPa</u> and an internal link length not exceeding 6.58 x the chain diameter.

DNV-OS-E301 states that the chain qualities K1, K2 and K3 intended for temporary mooring of ships shall not be used by offshore units for position mooring. Offshore mooring chain grades are R3, R3S, R4, R4S, R5.

Table 17: Properties of chain grades

	Offshore mooring grade chain					Anchor chain
	R5 [1]	R4S [1]	R4 [1] (VL R4)	R3S [1] (VL R3S)	R3 [12] (VL R3)	K3/ U3 / Grade 3 [2]
Ultimate tensile strength (MPa)	1000	960	860	770	690	690
Yield strength	760	690	580	490	410	-
[1] Acceptable according to DNV-OS-E301 [2] Acceptable according to NS9415						

R3, R3S or R4 chains are recommended chain for use mooring of an offshore seaweed farm.

9.3. Rope

Applicable codes	NS9415 DNV-OS-E301 DNV-OS-E303	2021 2021 2022	Ch.13 Ch.2 S.4

The choice of fibre ropes and straps shall be based on the characteristics that they shall have in the seaweed system.

9.4. Buoy

Applicable codes	NS9415 DNV-OS-E301 IALA 1066 IALA 1099 IALA G1006	2021 2021 2010 2013 2018	Ch.13 Annex D Ch.2 S.4

The choice or dimensioning of buoys shall be based on the characteristics that they shall have in the seaweed system.

- Buoys shall be dimensioned to withstand the maximum pressure from submersion and waves at the design load on the anchor lines.
- Buoys and attachments shall be dimensioned to withstand the loads from submersion, wave and current loads, icing, drift ice, flotsam and boats.
- It shall be documented through testing that no structural failure or reduction in buoyancy will occur when the buoy is subjected to 1.3 times the specified compressive resistance for at least 20 minutes.
- Buoys shall be dimensioned for lifting operations and resistance, and limitations on this shall be specified.
- If buoys are used in lifting operations, the buoys shall be approved as lifting equipment, and they shall thus be certified and recertified in the same way as other lifting equipment.
- Buoys, including connections, used in lifting operations, shall also be designed as lifting equipment in accordance with NS-EN 1677 (all parts).
- The movement characteristics of buoys shall be assessed, and the lifetime of buoys and attachments shall be documented based on an assessment of the load effect of the anchoring with buoys.
- In addition, it shall be documented that the buoy is dimensioned for the dynamic loads that occur when exposed to waves and the line to the buoy alternates between slack and taut. Fatigue and wear shall be assessed during the design process.
- It shall be documented that steel details are protected against corrosion during the design working life of the buoy.
- The main component of the buoy's mountings shall be capable of withstanding a failure load of 10 times the buoyancy.

9.5. Shackle

Applicable codes	NS9415 DNV-OS-E301 IALA 1066	2021 2021 2010	Ch.13 Ch.2 S.2

Within an offshore seaweed farm shackles can be used for different purposes:

- Connection of permanent anchor lines and buoys. Use of LTM shackles is recommended.
- Connection of anchors. Use of anchor shackles is recommended.
- Connection of non-permanent and/or non-structural elements such as temporary buoys or floaters and substrates. Use of aquaculture shackles is recommended.

9.6. LTM Shackle

Applicable codes	DNV-OS-E301	2021	Ch.2 S.2 Ch.2 S.4

DNV-OS-301 8.1.6: Recommended connection elements in long term mooring systems are purpose made elements such as triplates, LTM D-shackles and H-shackles.

Long term mooring D-shackles and H-shackles are designed to have superior fatigue strength compared to the chain. The types with oval pin are recommended for connecting chains to ropes, floaters or buoys.

9.7. Anchor shackle

Applicable codes	DNV-OS-E301 DNV-OS-E302	2021 2022	Ch.2 S.4

The shackle connecting the anchor needs special consideration. Dimensions according to DNV-OS-E301. Anchor shackles to be applied in long term mooring systems shall be of quality R3, R3S, R4, R4S or R5 and they shall be manufactured and tested according to DNV-OS-E302.

9.8. Aquaculture shackle

Applicable codes	NS9415	2021	Ch.13

NS9415 includes requirements for aquaculture shackles. The requirements include:

- Shackles shall be tested and marked in accordance with EN 13889. Marked with minimum breaking load.
- Shackle bolts shall be provided with double securing at all times. The double securing shall be made from a material that is corrosion-resistant in the relevant environments.

Note: Aquaculture shackles are available with DNV certification according to NS9415. The offshore application of aquaculture shackles needs special attention. It is recommended that the shackles are only used for attachment of non-permanent or non-structural elements in taut or pretensioned arrangements.

9.9. AtoN and monitoring

Applicable codes	IALA R0139 (O-139) IALA G1082 IALA R0101 (R-101) IALA G1162	2021 2016 2021	Ch.13 Ch. 2.6

NS9415 and DNV-OS-E301 do not include requirements for Aid to Navigation (AtoN) and monitoring.

IALA R0139 recognizes:

- That the number and types of man-made structures being placed in the maritime environment are increasing.
- The need to provide consistency in marking different types of man-made structures which may be a danger to navigation.
- That it is a matter for a national authority to decide on whether a man-made structure needs to be marked, depending on the risk involved and the level of traffic.
- That marking is to improve the safety of navigation, protect the structures themselves, and safeguard the environment.

IALA recommends: That members (including Dutch ministry of infrastructure and water management) ensure that the marking of man-made structures conforms to the standards and practices specified in the relevant sections of the guidelines.

AIS system is to be considered. See IALA R1082 guideline on the application of AIS systems on AtoN.

Radar beacon is to be considered. See IALA guideline for Marine Radar Beacons (Racons).

Monitoring using camera, GNSS and/or sensor systems enable remote condition monitoring. A risk assessment should be performed to identify need for condition monitoring.

IALA G1162 provides a guideline for marking of aquaculture sites. A supplement is provided below. IALA G1162 includes more general rules and examples for marking of aquaculture sites.

Offshore aquaculture farms should be marked as follows:

1. Aquaculture farms are normally marked by Special marks.
2. If there is a requirement for vessel to transit between aquaculture farms, then such channels are normally marked as defined in IALA Guideline G1078.
3. If the prevailing situation warrants, Cardinal marks alone may be used to direct vessel traffic away from the aquaculture farm(s).
4. It is recommended that areas of aquaculture farms are marked by appropriate AtoN. In addition radar reflectors, retro reflecting material, racons and AIS AtoN may be considered.
5. To improve the effectiveness of marking and taking into account any background lighting, synchronization of the lights is recommended. The results of a risk assessment will dictate the appropriate nominal range;
6. The AtoN described herein should comply with IALA guidance and have an appropriate availability, normally not less than 99.0% (IALA Category 2).

9.10. Substrate

Applicable codes	NS9415	2021	Ch.13

The seaweed substrate is considered to be a non-structural element. Design according to NS9415.

9.11. Custom fabricated components

Applicable codes	NS9415	2021	Ch.13

Table 18: List of relevant codes

EN 1990	Eurocode: Basis of structural design
EN 1993	Eurocode 3: Design of steel structures
ISO 12944	Protective paint systems
ISO 12473	General principles of cathodic protection in seawater
EN 1999	Eurocode 9: Design of aluminium structures
EN 1992	Eurocode 2: Design of concrete structures
ISO 19903	Concrete offshore structures
EN 12201	PE Pipes
ISO 527	Plastics - Determination of tensile properties
EN 13121	Glass fibre reinforced plastic
EN 16245	Glass fibre reinforced plastic
ISO 15607	Welding metals
NS 416	Plastic welding
NS 470	Welded steel structures
EN 10204	Metallic products - Types of inspection documents

10. Installation

Applicable codes	NS9415	2021	Ch.13

Anchoring shall be laid out in such a way that none of the anchoring components are damaged during the installation process.

The testing of holding power may be derogated from if a documented geotechnical investigation has been carried out which include a documentation of the resistance of the bottom attachment.

Following tensile testing, anchor lines shall be adjusted so that the level of pre-tensioning falls within the tolerances specified in the anchoring analysis

Following the anchoring installation, the way in which the anchoring was laid out shall be documented.

Loads during installation should be assessed for all components and evaluated if these are leading. Measures should be taken to reduce the risk of damage and wear during installation

11. Documentation

11.1. Documentation of design

Applicable codes	NS9415	2021	Ch.5.10

Calculations and analyses in the design shall be documented in reports with prerequisites, assumptions, model setup, methods, investigated limit states, results and conclusions. The design working life used as a basis for the calculations shall be stated. Calculations shall be clear, unambiguous and in such a form that design control can be performed.

11.2. Documentation of execution

Applicable codes	NS9415	2021	Ch.5.11

Documentation of execution of the main components shall be included:

- as-built arrangement drawing of system
- as-built detailed drawings of components
- as-built drawing including location and relative positions of main components; anchors, buoys and (submerged) lines
- documentation of materials:
  - product and material properties;
  - material certificate specifying resistance, e.g. ultimate and yield strength, and fatigue properties;
  - any other properties;
- documentation that joints have been carried out in accordance with the execution specification:
  - welding and heat treatment;
  - tightening of screws and bolts;
  - assembly, sewing, stitching, splicing and knotting of knots;
- photo material of assembly
- maintenance and inspection logbook;
  - Installation date, inspection interval, inspection method and condition/age for main components.

11.3. Certificates

Certificates for certified parts shall be traceable. Certification shall be obtained to verify the quality and performance of mooring components. It is recommended to check with the manufacturer or supplier which certifications can be provided. In general it is recommended to obtain documentation for the construction parts that include the following elements:

- Compliancy, inspection or test certificates relevant to prove acceptance by IASC Societies (DNV, LRQA ABS or equivalent)
- Material certificates
- Traceability certificates

Table 19: Recommended certificates for construction parts

	Recommended certification
All components	Applicable codes should be used for the type of part
Anchor – standard type	Type approval certificate (approved according to DNV, LRQA, ABS or equivalent) Inspection certificate (approved according to DNV, LRQA, ABS or equivalent)
Anchor – custom type	Design and testing in accordance with Eurocode EN 1990 3.1 and 3.2 material certificate according to EN 10204

		Welding procedure approval according to EN-ISO 15607 (general rules) and EN ISO 15614 1 to 13 (welding procedures)
Chain		Type approved in accordance with *DNV-OS-E302 Offshore Mooring Chain* or equivalent R3, R3S or R4 grade certificate (approved according to IACS, DNV, LRQA, ABS or equivalent). Traceability certificate
Rope and rope termination hardware		All fibre ropes shall be tested, documented and marked as specified in NS-EN ISO 9554 and supplied with a certificate in accordance with the same standard Fibre ropes should satisfy the requirements of EN ISO 10572, EN ISO 1346, EN ISO 1140, EN ISO 1141 or EN ISO 10556 for mixed polyolefin, polypropylene (PP), nylon (PA), polyester and polyester/polyolefin respectively. Fibre rope tests shall be performed in accordance with NS-EN ISO 2307 , and requirements related to reporting shall be in accordance with NS-EN ISO 2307. Fibre rope shall be supplied with a self declaration from the manufacturer or supplier, which specifies the technical characteristics of the product (see certificate type 3.1 in accordance with EN 10204). The self declaration should contain at least the following: ○ information that identifies type, material, treatment, consignment, etc.: ○ how the rope is protected against UV radiation; ○ reference to information on documentation of the product and test results in accordance with EN ISO 2307; ○ declaration by a responsible representative of the manufacturer or supplier; ○ place and date NS9415 states additional requirements for the self declaration: ○ weight (mass) per metre in air and weight per metre in water; ○ loading and unloading curve within the working area of the rope to MBL; ○ MBL
Shackles	LTM	Type approved in accordance with DNV-OS-E302 Offshore Mooring Chain or equivalent R3, R3S or R4 grade certificate (approved according to IACS, DNV, LRQA, ABS or equivalent). Traceability certificate
	Anchor	Type approved in accordance with DNV-OS-E302 Offshore Mooring Chain or equivalent R3, R3S or R4 grade certificate (approved according to IACS, DNV, LRQA, ABS or equivalent). Traceability certificate
	Aquaculture	NS9415, EN 13889
Custom metal parts		Design and testing in accordance with Eurocode EN 1990 3.1 and 3.2 material certificate according to EN 10204 Welding procedure approval according to EN-ISO 15607 (general rules) and EN ISO 15614 1 to 13 (welding procedures)

12. Inspection and maintenance

Applicable codes	NS9415	2021	Ch.15.7

Inspection, maintenance, repairs and replacements shall be described.

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DNV

VERIFICATION STATEMENT

Doc. No.: 2023-5413
Rev.: 1

This is to verify that the

Recommended design practice

For

Seaweed growing systems

Issued to

North Sea Farmers (NSF)

Is found to comply with specified requirements, which will give acceptable safety level with focus on personnel, asset and external environment.
Compliance is with basis of standard:

NS 9415:2021

See additional referred standards below

Particulars of Report

Report name:	Recommended design practice for offshore & nearshore Seaweed growing systems
Revision:	Version 1.0 2023
Purpose of document:	This document aims to provide guidance for the industry on which technical criteria to use when designing an offshore or nearshore seaweed growing system
Status:	For release

Particulars of Supplier

Supplier:	Aqitec Projects BV
Supplier project:	NSF#1

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Verification Extent

Verification Summary:
In accordance with the agreement signed 2022-12-13 DNV has performed review and verification of the Recommended design practice for offshore & nearshore Seaweed growing systems

The verification includes review of the following reports, and verification comment sheets has been issued and all comments has been closed.

The Recommended design practice has been found to comply with the codes/standards given below.

Reports:

Document Title	Rev.	Project No.
Recommended design practice for offshore & nearshore Seaweed growing systems	1.0	NSF#1

Verification Comment Sheets (VCS):

Document name	Rev.	Title
VCS-01	0.11	10392311_VCS 01 Regulatory Framework
VCS-01	0.2	10392311_VCS 01_v0.2 Regulatory Framework

Codes/standard used as reference:
NS-EN 9415:2021
DNV-OS-C101
DNV-OS-E301
DNV-OS-E302
DNV-OS-E303
DNV-RP-C205
NS 5814:2021