Qualification of innovative floating substructures for 10MW wind turbines and water depths greater than 50m

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Definitions & Abbreviations

ABS	American Bureau of Shipping
ALS	Accidental limit state
API	American Petroleum Institute
AST	Administrative Support Team
BSH	Bundesamt für Schifffahrt und Hydrographie
Class NK	Nippon Koiji Kyokai
DDF	Deep draught floaters
DDS	Deep draught semifloaters
DFF	Domain fatigue factor
DLC	Design Load Case
DNV GL	Det Norske Veritas - Germanischer Lloyds
DTS	Draft technical specifications
ECD	Extreme coherent gust with direction change
EDC	Extreme direction change
EOG	Extreme operating gust
FLS	Fatigue limit state
FSS	Floating substructure
IEC	International Electrotechnical Commission
ISO	International Organization of Standardization
JIP	Joint Industry Project
γ_f	Load safety factor
γ_m	Material factor
FOWT	Floating offshore wind turbine
LRFD	Load and resistance factor design method
METI	Japanese Ministry of Economy, Trade and Industry
MLIT	Japanese Ministry of Land, Infrastructure, Transport & Tourism
OWT	Offshore wind turbine
PC	Project Coordinator
PM	Project Manager
RP	Recommended practice
RNA	Rotor nacelle assembly
SLS	Serviceability limit state
SOLAS	Safety-of-Life-at-Sea
TLP	Tension leg platform
ULS	Ultimate limit state
WPL	Work Package Leader
WPS	Working stress design

Executive Summary

The existing guidelines and standards addressing the design of floating offshore wind turbines (FOWT) that are already published by classification societies, including DNV GL, ABS, and Class NK, as well as the upcoming technical specification IEC 61400-3-2 are reviewed and differences will be identified and documented. Furthermore, publically available design practices and publications related to the FOWT design process are reviewed and documented to lay the groundwork for the design practice development and to avoid any duplication of work already done

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1 Introduction

The four designers involved in LIFES50+ have agreed to use the DNV-OS-J103, Design of Floating Wind Turbine Structures, as main reference standard for the design of their concepts.

It is assumed that the IEC certification scheme is followed, as described in DNVGL-SE-0073.

This report includes a brief description of the requirements included in DNV-OS-J103 and a comparison with some of the other standards available in the market. The following standards and guidelines will be compared to DNV-OS-J103:

- IEC 61400-3-2, Design requirements for floating offshore wind turbines (draft technical specification (DTS); standard to be published);
- GL Guideline IV-2, Guideline for the Certification of Offshore Wind Turbines, edition 2012;
- ABS Guideline #195, Guide for Building and Classing Floating Offshore Wind Turbine Installations, January 2013;
- Class NK, Guidelines for Offshore Floating Wind Turbine Structures, July 2012.

The guidelines will be compared guideline by guideline and topic by topic. The focus of this comparison is on technical requirements, not on certification services. The references to be used in combination with above mentioned standards and guidelines are also listed, e.g. DNV GL, ISO, API, etc.

Table 1 gives a brief overview about the technical aspects of the reviewed standards and guidelines.

Table 1: Content overview of the reviewed guidelines and standards

Topic	DNV-OS-J103	IEC 61400-3-2	GL 2012	ABS #195	Class NK
Safety Philosophy and design principles	Yes	No	Yes	Yes	Yes
Site conditions, loads and response	Yes	Yes	Yes	Yes	IEC 61400-1, IEC 61400-3
Structural design	Yes	Yes	Yes	Yes	Yes
Materials and corrosion protection	Yes	ISO 19904-1, ISO 20340	Yes	“Industry standards”	Yes
Floating stability	Yes	Yes	Yes	Yes	Yes
Station-keeping	Yes	Yes	GL Rules of Offshore Technology, GL Rules for Material and Welding	API RP 2T, API RP 2SK	API RP 2SK
Design of anchor foundations	Yes	No	GL Rules of Offshore Technology, GL Rules for Material and Welding	API RP 2T, API RP 2SK	No
Mechanical system	Yes	Yes	Yes	Yes	Rules for the Survey and Construction of Steel Ships: Part D and Part H
Cable design	Yes	No	Yes	No	No
Control system	Yes	Yes	Yes	No	No
Transport and installation	Yes	Yes	Yes	No	Yes
In-service inspection, maintenance and monitoring	Yes	Yes	Yes	No	Yes
Guidance for coupled analysis	Yes	No	No	Yes	No

2 DNV-OS-J103:2013 Design of Floating Wind Turbine Structures

DNV-OS-J103 has been developed on a JIP with industry involvement. This involvement included participation by 3 developers, and full scale data and analysis data for their respective floater concepts were used in the development. DNV-OS-J103 needs to be applied in combination with DNV-OS-J101 and DNV-RP-C205.

Structural safety is ensured by the use of a safety class methodology where the structure to be designed is classified into a safety class based on failure consequences. This classification is normally determined based on the purpose of the structure. For each safety class, a target safety level can be defined in terms of an annual probability of failure. The safety classes are considering the structural design of the floating wind turbine structure and its station-keeping system.

Three safety classes are defined:

- low safety class (annual probability of failure of 10^{-3}): low risk of human injury, minor environmental consequences, minor economic consequences and negligible risk to human life;
- normal safety class (annual probability of failure of 10^{-4}): imply some risk for human injury, some risk for environmental pollution or significant economic consequences;
- high safety class (annual probability of failure of 10^{-5}): failures imply large possibilities for human injuries or fatalities, for significant environmental pollution or major societal losses or very large economic consequences.

The different safety classes applicable for different parts of the floating units and their station-keeping systems are reflected in terms of different requirements for load factors. The requirements for material factors remain unchanged regardless of which safety class is applicable for a particular wind farm or structure in question. The DNV-OS-J103 is based on the partial safety factor method, which is based on separate assessments of the load effect in the structure due to each applied load process. The partial safety factor method is a design method by which the target safety level is obtained as closely as possible by applying load and resistance factors to characteristic values of the governing variables and subsequently fulfilling a specified design criterion expressed in terms of these factors and these characteristic values. The characteristic values of loads and resistance, or of load effects and material strengths are chosen as specific quantiles in their respective probability distributions. The requirements for the load and resistance factors are set such that possible unfavourable realisations of loads and resistance, as well as their possible simultaneous occurrences, are accounted for to an extent which ensures that a satisfactory safety level is achieved.

For the structural design DNV-OS-J103 requires design against limit states. While most renewables standards require design against ULS (ultimate limit state), FLS (fatigue limit state) and SLS (serviceability limit state), DNV-OS-J103 requires design against ALS (accidental limit state) as well. ALS defined by DNV-OS-J103 covers:

- structural damage or failure caused by accidental loads;
- maintain structural integrity after local damage or flooding;
- post-accident resistance of the structure against environmental loads when the structural resistance has become reduced by structural damage caused by the design accidental loads such as the design fire or the design collision.

DNV-OS-J103 has a requirement for a floater motion control system to minimize excitation of floater motions.

DNV-OS-J103 allows sinking of FOWT by considering damaged stability as an optional requirement.

Detailed guidance about load analysis of FOWT is provided in the appendix of DNV-OS-J103.

2.1 DNV GL-SE-0073:2014 Project Certification of Wind Farms according to IEC 61400-22

DNV GL-SE-0073 service specification specifies DNV GL’s services for project certification of onshore and offshore wind farms according to IEC 61400-22. It includes DNV GL’s interpretation and detailing of IEC 61400-22 to serve as a contractual basis for project certification. Furthermore it provides a common communication platform for describing the scope and extent of activities performed for project certification of a wind farm and its assets.

DNV GL’s project certification system details and clarifies the verification activities within IEC 61400-22 system and utilises DNV GL standards to fill gaps in the governing IEC standards.

The project certification concept for wind farms constitutes a robust means to provide, through independent verification, evidence to stakeholders (financiers, partners, utility companies, insurance companies, the public, governmental and non-governmental organisations) that a set of requirements laid down in standards are met during design and construction, and maintained during operation of a wind farm.

DNV GL-SE-0073 also describes how to maintain this certificate by periodic maintenance during the service life of the wind farm.

2.2 Technology qualification according to DNV-RP-A203:2013

Components and concepts that cannot be verified against any standard are considered a new technology. In this case a risk based approach can be used for the verification, as described in DNV-RP-A203, *Recommended Practice for Technology Qualification*.

Technology qualification is the process of providing the evidence that a technology will function within specified operational limits with an acceptable level of confidence.

The objective of the DNV-RP-A203 is to provide the industry with a systematic approach to technology qualification, ensuring that the technology functions reliably within specified limits.

The approach is applicable for components, equipment and systems, which are not already covered by a validated set of requirements (such as an applicable standard).

The result of the qualification is documentation of evidence that the technology meets the specified requirements for the intended use, implying:

- the probability density distribution for the service lifetime is determined and/or,
- the reliability is determined and/or
- sufficient margins are defined against specified failure modes or towards specified performance targets.

3 Code Comparison, DNV-OS-J103:2013 vs. IEC-61400-3-2 (draft technical specification (DTS); standard to be published)

3.1 Scope

IEC 61400-3-2 focusses on engineering integrity of structural components. Subsystems are addressed, namely control and protection mechanisms, internal electrical systems and mechanical systems. IEC 61400-3-2 can be seen as an extension of IEC 61400-1 and -3, which apply except where noted. Thus, IEC 61400-3-2 is consistent with IEC 61400-1 and IEC 61400-3. Explicit exceptions with regard to differences from fixed bottom offshore wind turbines are highlighted in IEC 61400-3-2.

IEC 61400-3-2 includes design of the RNA, tower and support structure as well as the station keeping systems. Substructures considered explicitly are Ship-based structures and barges, Semi-submersibles, Spar buoys and Tension-leg platforms. Floating structures have to be unmanned and equipped with only one single horizontal axis wind turbine.

Other platforms intended to support wind turbines are generally but not fully covered due to the great range of variability in geometry and structural form. For the design of multi-turbine units, vertical-axis wind turbines and combined wind/wave energy systems additional consideration are deemed necessary.

The major difference to the scope DNV-OS-J103 is the inclusion of the RNA, which is explicitly not included in the scope of the DNV guideline but instead reference is given to DNV-DS-J102.

Compared to IEC 61400-3-2, DNV-OS-J103 provides explicit chapters referring to Safety Philosophy and design principles, Materials and corrosion protection, Design of anchor foundations, Cable design and Guidance for coupled analysis, but misses chapters on tropical storms, tsunamis and load extrapolation. These topics are commonly addressed in the other guideline respectively, but generally not in the same level of detail.

3.2 Design principles

IEC 61400-3-2 provides a workflow of the design methodology that is based on the methodology provided in IEC 61400-3-1, but extended through inclusion of the design of the station keeping system and the consideration of floating stability. Demonstration of structural integrity of the RNA with respect to site specific conditions is also required. The possible influence of the increased dynamic response of FOWT systems on the control and safety system is also mentioned.

For Design principles both DNV-OS-J103 and IEC 61400-3-2 generally use the design by partial safety factor method. IEC 61400-3-2 additionally allows the use of the working stress design (WSD). DNV-OS-J103 also presents possibilities for design assisted by testing and probability-based design. Another fundamental difference is the mandatory inclusion of model tests in the DNV-OS-J103 to validate the numerical model. DNV-OS-J103 refers to the section 10 of DNV-RP-C205 for guidance on the setup of the model test.

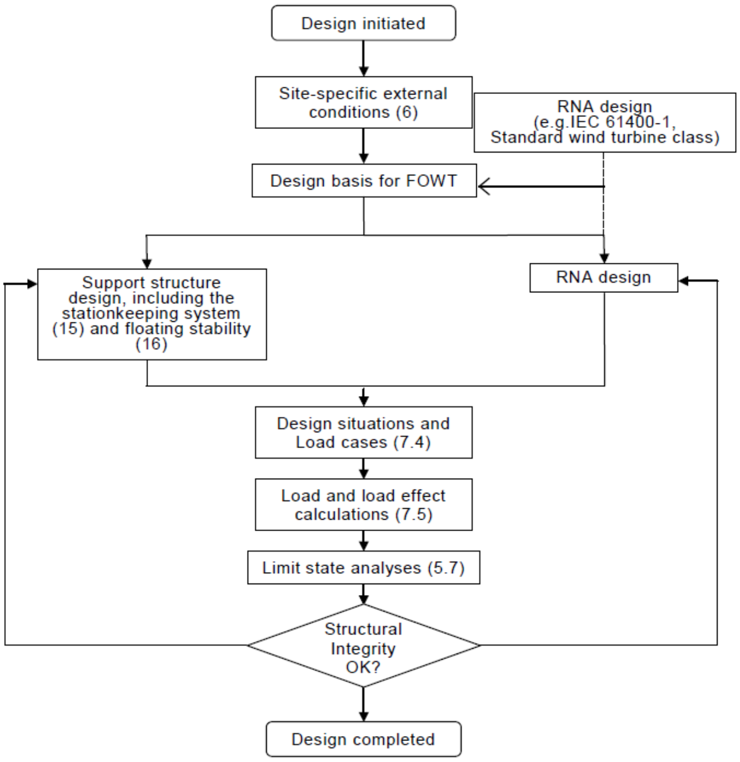

Figure 1 - IEC 61400-3-2: design process for a floating offshore wind turbine (FOWT)

3.3 External conditions

Both guidelines seem to have equal expectations of the inclusion of the environmental loads. In the IEC 61400-3-2 more detail is put into the description of on gust events to be considered for floating conditions, as well as tsunamis and ice loading. The DNV-OS-J103 provides detailed descriptions of soil conditions, analysis methods and modelling of environment and FOWT systems. For guidance on environmental conditions, DNV-OS-J103 largely refers to DNV-RP-C205, where several offshore specific issues are treated in more details than in DNV-OS-J103 or IEC 61400-3-2, e.g. adequate models for power spectral densities for waves and for wind in different frequency range, models for coherence spectra, etc.

3.3.1 Wind Conditions

Regarding wind conditions, both IEC 61400-3-2 and DNV-OS-J103 highlight the importance of including adequate representation of the wind in the low frequency range and state that **EOG** definitions of fixed bottom offshore standards need to be revised for floating systems. New formulas are given in both standards, but are not identical in definition. While DNV-OS-J103 describes qualitatively which characteristics of gusts need to be adjusted to match FOWT system sensitivities, IEC 61400-3-2 provides a more detailed description of the gust cases that need to be evaluated. In the definition of **EDC** and **ECD** cases to be analysed, the IEC 61400-3-2 is also more specific than DNV-OS-J103, linking time periods to be considered directly to yaw natural frequencies of the FSS and wind direction changes to motion natural frequencies of the FSS.

3.3.2 Marine Conditions

3.3.2.1 Waves

Both guidelines highlight the need to regard wind and waves as independent parameters and to include the influence of swell spectra additionally to known wave spectra from fixed bottom offshore structures. IEC 61400-3-2 refers to ISO 19901-1 for swell spectra. DNV-OS-J103 claims that the use of JONSWAP or other one peaked wave spectra is insufficient for FOWT in the presence of swell and two-peaked power spectrums are recommended. Considering the 50-year wave height, DNV-OS-J103 suggests that the factor to be multiplied with the 50 year significant wave height used in the IEC 61400-3-1 is non conservative and proposes values of up to 2.0 in deep waters.

3.3.2.2 Current

In general no discrepancies were found. IEC 61400-3-2 generally demands a revision of load impact of wind, wave and current misalignment in all load cases in IEC 61400-3-1. Regarding vortex effects, reference is made to ISO 19904-1, ABS and DNV-OS-J103

3.3.3 Further External Conditions

Regarding the **water level**, while DNV-OS-J103 simply asks for the inclusion of high and low water levels, IEC 61400-3 demands to take into account a variation of water levels if they are significant.

For the **soil conditions**, both guidelines demand establishment of soil conditions for each site. Additionally DNV-OS-J103 provides a table of typical ranges of soil parameters for cohesion less and cohesive soils. In DNV-OS-J103 also the effect of cyclic loading on soil conditions is addressed and consideration demanded.

With regard to **marine growth**, IEC 61400-3-2 specifically asks for the evaluation of the effect on the range of Eigen frequencies, while DNV-OS-J103 demands consideration of all effects on weight and dimensions.

The effect of **earthquakes and tsunamis** is covered with varying depth. While DNV-OS-J103 states that the size of tsunami waves is dependent on the water depth and may be very small. Only the influence for tension leg platforms (the same is expected to be true for taut mooring systems) is mentioned. There, the effects on the station keeping system design should be assessed. IEC 61400-3-2 provides a detailed Annex on the modelling of tsunamis, and also refers to ISO 19900, ISO 19901-2, ISO 19901-4 and ISO 19904-1 for soil properties during earthquakes, while stating that only tension and taut mooring systems could be influenced. Additionally, the phase of forcing at separate anchor points is asked to be considered.

3.4 Loads

Loads and load effects chapters are organized different than in DNV-OS-J103. Effects to be considered regarding gravitational and inertial loads, aerodynamic loads, hydrodynamic loads, loads through wake situations, line interaction and hydrostatic effects are generally the same. The complex interaction of FOWT with their environment demand the consideration of various new effects compared to fixed bottom turbines which are mentioned in both guidelines.

Looking at hydrodynamic loads, the **air gap** is to be considered by both DNV-OS-J103 and IEC 61400-3-2. Additionally, IEC 61400-3-2 contains requirements concerning the evaluation of air gap, i.e. more detailed inclusion of model tests and wave run-up.

The calculation of the impact of **tsunamis** is explained in detail in the annex of IEC 61400-3-2. Also IEC 61400-3-2 marks the consideration of a tsunami warning system in order to exclude additional loading from the operating turbine. DNV-OS-J103 notes the influence of the water depth on the crest height of tsunamis.

Ice loads are considered with regard to ISO 19906 in the IEC 61400-3-2, while IEC 61400-3-1 assumptions are not regarded as applicable to FOWT. Additionally to ISO 19906 loads, in the IEC 61400-3-2 ice loads shall be considered in combination with movement due to loads from ice, wind, wave or currents as well as ice loads on electrical cables. IEC 61400-3-2 also allows the usage of ice management systems to reduce ice loading. In contrast, the DNV-OS-J103 refers to DNV-OS-J101 and additionally requires consideration of drifting ice impact, if applicable.

Additional **Design load cases** are defined in IEC 61400-3-2, extending the table given in IEC 61400-3-1. Special consideration is mentioned towards misalignment of wind, wave, swell and current that need to be included if higher loading is to be expected. Faults of active control systems of the support structure shall be considered in fault conditions. In contrast, DNV-OS-J103 adds multiple chapters to the load cases defined in DNV-OS-J101 which are referred to as environmental loads. These load chapters describe qualitatively the supplement load cases to be considered which are called permanent loads, variable functional loads, abnormal wind turbine loads (loads associated with fault situations for the wind turbine), deformation loads and accidental loads. The load case table from DNV-OS-J101 as mentioned in the chapter environmental loads is highlighting the importance of gust loads on FOWT systems that use control system for stability. Wind and wave misalignment are only to be considered as part of the ULS load cases with the most unfavourable direction of wind and waves.

The simulation length is discussed in both guidelines with comparable detail. IEC 61400-3-2 provides a detailed description about simulation length and binning and states the need for longer simulation lengths for adequate representation of the hydrodynamic frequency range as well as the possibility to use periodic wind data in order to mitigate the problem of stationarity assumption of the wind field. Likewise, DNV-OS-J103 proposes longer simulation times to capture hydrodynamic effects and offers various solutions to the stationarity assumption problem of the wind field.

Modelling requirements are in general the same for both guidelines but described more detailed in DNV-OS-J103. With regard to **aerodynamics loads**, the IEC 61400-3-2 highlights the possible deficiency of Stream-tube-based induction models for FOWT. Considering **hydrodynamic loads**, IEC 61400-3-2 provides a list of relevant models for various phenomena, but also refers to ISO 19904-1, ABS, Class NK and DNV-OS-J103, where a detailed Appendix on system analysis and the modelling of various FOWT systems is given. Furthermore DNV-OS-J103 refers to DNV-RP-C205, where more detailed guidance is given on specific topics, e.g. vortex-induced vibrations and vortex-induced motions, determination hydrodynamic coefficients, higher order sum-frequency forces that may introduce springing and/or ringing response in vertical modes, wave slamming and its representation, estimation of hydrodynamic load on power cables subjected to accumulated marine growth, etc.

3.5 Load and material factors

IEC 61400-3-2 allows both the use of partial safety factors that is already applied in IEC 61400-1 as well as the working stress method (WSD) as used in ISO 19904-1. While IEC 61400-3-2 differs only between load favourability and type of design situation with respect to the partial safety factors, DNV-OS-J103 looks at different load factor sets, load categories, and safety classes.

Overall, IEC 61400-3-2 and DNV-OS-J103 both use 0.9 as the most optimistic value. While DNV-OS-J103's most pessimistic value is 1.55 and IEC 61400-3-2's only 1.5, there is a larger variety of less conservative values applied in DNV-OS-J103. A comparison between the two methods is thus not trivial but has been tried before (Using Partial Safety Factors in Wind Turbine Design and Testing (WD Musial - 1997))

Regarding fatigue failure in the IEC 61400-3-2 and DNV-OS-J103, partial safety factors are set to unity for both guidelines.

Material factors and resistances are not treated in IEC 61400-3-2. Instead reference is made to ISO structural and other recognized offshore design standards.

3.6 Materials

IEC 61400-3-2 refers only to the ISO 19901-7 and ISO 19904-1 and doesn’t give any further information. Generally in DNV-OS-J103 the material selection shall be undertaken in accordance with

the principles given in DNV-OS-J101. In addition some further guidelines for the use of different materials in FOWT (concrete, steel, etc.) and links to other standards are given.

3.7 Structural design

For the design methodology, see chapter 4.5.

The IEC 61400-3-2 provides a lot of requirements regarding loads and load calculations under the topic “structural design” which is already processed in chapter 4.4 loads.

For the **Ultimate limit state analysis** in IEC 61400-3-2 there is sensitivity against fatigue failure and the method of counting unclosed cycles respectively. So it is recommended to use concatenated simulation data sets to minimize this sensitivity. Furthermore in IEC 61400-3-2 a serviceability analysis has to be performed in the course of the ULS analysis, in which the designer shall propose appropriate limiting values to ensure the integrity and serviceability of the FOWT and related infrastructure.

3.8 Floating stability

In general IEC 61400-3-2 refers to the IMO intact stability code, Resolution MSC.267(85). In DNV-OS-J103 a lot of stability requirements are explicitly given for different types of FOWT. However in IEC 61400-3-2 alternative intact stability criteria based on dynamic-response can be used, which is not mentioned in DNV-OS-J103. Both standards don’t see damaged stability as a requirement for unmanned units, but IEC 61400-3-2 states explicitly, that it has to be proven that no other neighbouring facilities are damaged.

3.9 Station keeping system

Basically IEC 61400-3-2 references to the ISO 19901-7 standard. In the case of non-redundant station keeping systems, an increase in safety factors are to be considered according to IEC 61400-3-2 and DNV-OS-J103 as well.

3.10 Anchor system

The IEC 61400-3-2 is referencing the ISO 19901-4, ISO 19901-7 and DNV-OS-J103 standards and gives no further requirements.

3.11 Control system

Both standards refer to IEC 61400-1 and IEC 61400-3 for the control and protection system of the wind turbine itself. In both standards the resonance and dynamic amplification of motions due to control system actions shall be avoided. In addition to the IEC 61400-1 standard the IEC 61400-3-2 demands the activation of the protection system in the following events:

- failure of the control function of the floating support structure
- motions and accelerations of the floating sub-structure exceed operational limits
- tower inclination angle exceeds operational limits

3.12 Electrical and mechanical system

For the electrical system IEC 61400-3-2 refers to the relevant IEC or RCS rules without exactly specifying them. DNV-OS-J103 considers only the lightning and earthing system with referencing to the related standards.

Regarding the mechanical system both standards state that the larger motion of a FOWT and its influence on the design, wear, and lubrication of the mechanical systems shall be taken into account.

3.13 Corrosion protection system

IEC 61400-3-2 refers to ISO 19904-1 and ISO 20340 for guidance regarding corrosion protection systems and how these are accounted for in the design.

Generally the DNV-OS-J103 standard refers to DNV-OS-J101, but additionally floater specific requirements are provided.

3.14 Power cable design

While a big chapter in DNV-OS-J103 is dedicated to the power cable design, where criteria, requirements and guidance for structural design and analysis of power cable systems are given, the IEC 61400-3-2 and 61400-3 as well don’t mention this topic.

3.15 Assembly / transport / installation

The IEC 61400-3-2 references here ISO 19901-6 and IEC 61400-3-1. DNV-OS-J103 refers to DNV-OS-J101. In addition both standards basically mention that the stability and structural integrity of the FOWT during assembly, transportation and installation operations should be verified.

3.16 Commissioning / maintenance / monitoring

For operation and maintenance of FOWT the IEC 61400-3-2 points to the ISO 19901-6; in DNV-OS-J103 the DNV-OS-J101 is referenced. While commissioning is considered in IEC 61400-3-2 and some requirements are given, the DNV-OS-J103 doesn’t mention this topic. In addition to DNV-OS-J103 the IEC 61400-3-2 provides information about an emergency procedures plan.

3.17 Other

Marine Support Systems: In the IEC 61400-3-2 a small chapter is dedicated to the marine support systems, which includes the bilge- and ballast system; both systems are considered in the mechanical systems chapter in DNV-OS-J103 with a reference to the DNV-OS-D101 standard.

4 Code Comparison, DNV-OS-J103 :2013 vs. GL 2012-IV-2

4.1 Scope

While DNV-OS-J103 is an extension of DNV-OS-J101 which addresses the design of support structures (incl. tower) and station-keeping systems of FOWT, GL 2012 is a stand-alone guideline addressing both technical and non-technical aspects for the design of the whole offshore wind turbine (fixed and floating) incl. the main components, i.e. foundation, tower, rotor, nacelle etc.

4.2 Design principles

Both DNV-OS-J103 and GL 2012 consider FOWT to fulfil the requirements of the normal safety class. DNV-OS-J103 gives a nominal annual probability of failure of 10^{-4}. This also applies for station-keeping systems with redundancy. Station-keeping systems without redundancy shall be designed for a higher safety class, i.e. for a nominal annual probability of failure of 10^{-5}.

Both DNV-OS-J103 and GL 2012 provide design by partial safety factor method and design assisted by testing, as well as risk-based design.

It is worth to be mentioned here that GL 2012 does not allow down flooding of a FOWT, whereas DNV-OS-J103 allows sinking by considering damaged stability as an optional requirement.

4.3 External conditions

Both standards require that wind and wave conditions are to be adapted to FOWT. GL 2012 requires the general consideration of low-frequency components in wind and wave conditions, whereas DNV-OS-J103 requires explicitly the adaption of the EOG duration to critical FOWT natural frequencies. Regarding the other wind and wave models DNV-OS-J101 is referenced. GL 2012 requires the extension of the frequency range for wind and wave conditions to higher levels in order to cover ringing/springing effects (especially for TLP platforms).

4.4 Loads

Both DNV-OS-J103 and GL 2012 require longer simulation times than 10 minutes (as required for fixed OWT), GL 2012 being a bit more specific by requiring at least 20 minutes per load time series. Both standards require at least 3 hours of total simulation time per wind/wave bin.

DNV-OS-J103 contains a chapter describing the response characteristics of various floater types including tension leg platforms, deep-draught floaters, semisubmersibles and mono hull structures.

DNV-OS-J103 provides a detailed description about internal tank pressure loads due to 3 different tank filling scenarios.

Concerning design load cases, DNV-OS-J103 refers to DNV-OS-J101 and adds the following requirements:

- gust duration needs to be adapted for FOWT;
- adaption of the control system in order to minimize excitation of the floater;
- FOWT-specific transportation load cases;

- Interaction between internal and external pressure scenarios;
- unintended change in ballast distribution (e.g. failure of active ballast system);
- loss of mooring line or tendon.

It is noted that the load case definition of DNV-OS-J101 is very similar to IEC 61400-3.

GL 2012 contains a design load case definition which differs from DNV-OS-J101/IEC 61400-3. In addition to the DLC definition for fixed OWT, a FOWT-specific load case set shall be considered, including the consideration of:

- transient condition between intact and redundancy check condition;
- one single line break, redundancy check;
- leakage (damage stability).

GL 2012 requires that during the design of the FOWT the interaction of the turbine control system with low-frequency motions of the floater shall be considered.

4.5 Structural design

Regarding structural design, both standards use the LRFD method and require design of FOWT against limit states. Concerning the definition of limit states, however, there are some differences: GL 2012 requires design against ULS, FLS and SLS. In addition to that DNV-OS-J103 requires design against ALS.

There are some differences between the two standards concerning the application of load and material factors as follows:

For design against ULS, DNV-OS- J103 provides load factors depending on the load case considered, which correspond to IEC 61400-3. The ULS load factors provided by GL 2012 differ from IEC.

For the design against FLS, DNV-OS-J103 doesn’t provide any load factors. Instead, domain fatigue factors (DFF) are provided which depend on the safety class and structural element considered. In GL 2012, the load factor for FLS is $\gamma f=1.0$, but material factors γm are provided, depending on the type of material.

Load factor for SLS is $\gamma f=1.0$ in both DNV-OS-J103 and GL 2012, while the latter provides a material factor for SLS of $\gamma m = 1.0$. For ALS, DNV-OS-J103 requires a load factor of $\gamma f=1.0$.

4.6 Floating stability

Regarding floating stability, DNV-OS-J103 and GL 2012 both require intact stability. GL 2012 also requires damaged stability. This represents a deviation from DNV-OS-J103, which – with a view to the balance between large costs and limited gains – does not require damaged stability, but includes damaged stability as an option which may be adhered to on a voluntary basis only.

4.7 Station keeping system

For the design of station-keeping systems, including anchor foundations, DNV-OS-J103 provides much more detailed information than GL 2012. Besides some general information, the latter refers to “GL Rules of Offshore Technology” and “GL Rules for Material and Welding”.

DNV-OS-J103 makes a distinction between systems based on tendons (TLP’s) and systems based on mooring lines. The design is mostly based on rules for station keeping systems, (e.g. DNV-OS-E301) whose load factor requirements have been adjusted to reflect that 50-year loads are used as characteristic loads instead of 100-year loads.

For the anchor foundations, DNV-OS-J103 addresses the design of the various anchor types and provides material factors for the anchor considered.

4.8 Control system

It is a major difference between DNV-OS-J103 and GL 2012 that the former has a requirement for a floater motion control system to minimize excitation of floater motions. The control system can be based on the turbine control system or can be arranged otherwise. GL 2012 does not have such a requirement for a floater motion controller. However, GL 2012 requires that during the design of the FOWT the interaction of the turbine control system with low-frequency motions of the floater shall be considered. GL 2012 requires that motions, accelerations and heeling angles are monitored and the FOWT is being shut down in case of exceeded limits.

Additionally, GL 2012 requires monitoring of the mooring system and shut-down in case of mooring line loss as well as monitoring of tightness of floater compartments in order to trigger an alarm and/or shut-down of the FOWT in case of leakage.

4.9 Electrical and mechanical systems

Regarding the electrical system, DNV-OS-J103 has no FOWT-specific requirements but refers to DNV-OS-J101.

Regarding the mechanical system, DNV-OS-J103 requires to consider possible impact of floater motions on the design of the wind turbine’s mechanical systems (e.g. gearbox, lubrication and hydraulic systems). Regarding bilge and ballast systems DNV-OS-J103 refers to DNV-OS-D101. Regarding mooring equipment it is referred to DNV-OS-E301.

GL 2012 has no FOWT-specific requirements neither for electrical nor mechanical systems. Instead, the requirements for fixed offshore OWT shall be considered.

4.10 Power cable design

There is a major difference between DNV-OS-J103 and GL 2012 concerning the design of power cables. While GL 2012 includes only very general information about cable design and installation, DNV-OS-J103 provides very detailed requirements for the design of power cable systems exposed to dynamic loading.

4.11 Corrosion protection system

The requirements for the corrosion system are basically the same in both standards. Both standards include the requirement that floater motions shall be considered in the calculation of the splash zone in addition to the requirements for the fixed OWT.

4.12 Marine operations

DNV-OS-J103 is referring to DNV-OS-J101 and DNV-RP-H103 for marine operations in general. Following references are provided for more specific marine operations:

- DNV-OS-H101, Marine Operations, General;
- DNV-OS-H102, Marine Operations, Design & Fabrication;
- DNV-OS-H201, Load Transfer Operations;
- DNV-OS-H202, Sea Transports;
- DNV-OS-H203, Transit and Positioning of Mobile Offshore Units;
- DNV-OS-H204, Offshore Installation Operations;
- DNV-OS-H205, Lifting Operations;
- DNV-OS-H206, Sub Sea Operations.

GL 2012 provides more detailed requirements for the above mentioned marine operations, such as wind speeds, towing speeds, wave heights etc. No information about subsea operations is provided by GL 2012.

4.13 Inspection

GL 2012 doesn’t contain any FOWT-specific requirements for inspection; the requirements for fixed OWT apply. DNV-OS-J103, however, defines an inspection interval which depends on the DFF (see section 4.5). For fibre ropes, tethers and tendons made from synthetic fibre yarns, DNV-OS-E303 is referenced.

5 Code Comparaison, DNV-OS-J103 :2013 vs. ABS #195 :2013

The following sections are based on internal DNV GL work performed by Knut O. Ronold.

5.1 Scope

As the title of the ABS document indicates, ABS #195 is not a document with technical requirements only. It is also a document with requirements related to a classification service, for example requirements for surveys and documentation. Approximately 20% of the document relates to ABS' classification service while DNV-OS-J103 covers technical requirements only.

The contents of ABS #195 dealing with ABS' classification service are not addressed in this review, only the technical requirements.

5.2 General

Like DNV-OS-J103, ABS #195 addresses important issues such as target safety, environmental conditions, loads, materials, structural design, station-keeping, floating stability and corrosion protection. For some of these issues, ABS #195 addresses them only by referring to other ABS rules and in some cases to external rules such as API rules. DNV-OS-J103 follows a similar approach in many cases by referring to DNV-OS-J101 in order to avoid unnecessary duplication of material.

5.3 Safety level

Regarding target safety, ABS #195 states that the floating support structure can be designed to a safety level equivalent to medium (L2) exposure level as defined in ISO 19904-1. This corresponds to a target failure probability of $5 \cdot 10^{-4}$. DNV-OS-J103 is a little stricter by requiring normal safety class with a nominal target failure probability of 10−4. This formal difference is of minor importance as long as the safety factor requirements are similar in the two documents. ABS #195 further states that a higher safety level (L1, 3·10−5) may be warranted under certain circumstances such as little experience and low level of redundancy. Again DNV-OS-J103 is a little stricter by requiring high safety class (10−5), at least for the station-keeping system, under such circumstances. The major difference between ABS #195 and DNV-OS-J103 when target safety is concerned is perhaps the wording: ABS #195 says "can be designed to", where DNV-OS-J103 "requires" a specific target safety level.

5.4 Environmental modelling

Regarding environmental modelling, ABS #195 reproduces the wind models of IEC61400-1 and -3, including the Extreme Operating Gust (EOG) of 10.5 sec duration. DNV-OS-J103 leaves it to the designer to define appropriate gust models with longer durations than 10.5 sec and specifically states that the EOG of 10.5 sec duration is inadequate for design of most floating structures. Regarding wind profile models in storm conditions, ABS #195 specifies the Frøya profile[1]. DNV-OS-J103 also specifies this profile (not only for storm conditions) by referring to DNV-OS-J101.

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[1] For description of the Frøya spectrum, see DNV-RP-C205, section 2.3.4.12.

5.5 Loads

Regarding loads, ABS #195 applies the same categorisation of loads as DNV-OS-J103 does, except for the category of accidental loads. However, it appears that some types of accidental loads are still considered in ABS #195, for example in the case of a damaged station-keeping system with one mooring line lost, and a couple of survival load cases for the station-keeping system are also defined. ABS #195, like DNV-OS-J103, capitalizes on the table of IEC 61400-3 design load cases. Likewise, ABS #195 and DNV-OS-J103 require relevant additional load cases to be considered.

5.6 Structural design

Regarding structural design, ABS #195 offers two alternatives, WSD and LRFD, and provides safety factor requirements for both. In the case of LRFD, the same load factors are used for ULS design as those specified in IEC61400-3 and DNV-OS-J103 for the case that environmental loads are dominating. ABS #195 appears not to give any load factor requirements for the case that permanent load or functional load are dominating, which is the case in design against lifting forces and hydrostatic pressures, and which may be governing for deep draught floaters. For design against FLS, ABS #195 and DNV-OS-J103 use the same design rule format based on Design Fatigue Factors (DFF). ABS #195 requires DFF=5 for non-inspect able structures; DNV-OS-J103 requires DFF=6. For inspect able structures, both standards require DFF=3. DNV-OS-J103 requires DFF=2 for the tower; and ABS #195 does the same under certain conditions. Overall, the fatigue requirements of the two standards can be concluded to be fairly similar.

5.7 Station keeping systems

For the design of station-keeping systems, including anchor foundations, DNV-OS-J103 makes a distinction between systems based on tendons (TLP's) and systems based on mooring lines. Tendons are designed like any other structural component in the floater, i.e. with the same safety factors in the ULS and the same safety factors in the FLS. Mooring lines are designed according to the design rules for station keeping system (e.g DNV-OS-E301) whose load factor requirements have been adjusted to reflect that 50-year loads are used as characteristic loads instead of 100-year loads.

For the design of station keeping systems, including anchor foundations, ABS #195 appears to be based on API design rules; viz. API RP 2T for tendons and API RP 2SK for mooring lines. The safety factor requirements of API have been adopted unchanged in ABS #195, whereas ABS #195 applies 50-year loads as characteristic loads instead of API's 100-year loads. No adjustment of the safety factors to reflect the change in return period for characteristic loads has thus been made. This may be all right for an unmanned FOWT if design according to API is intended to be design to high safety class, but may imply a non-conservatism if design according to API is intended to be design to normal safety class only. There is a need here to investigate further which safety class is intended in API RP 2T and API RP 2SK.

Regarding station keeping, it should also be mentioned that in the case of no redundancy, ABS #195 requires a 20% increase in safety factors, which compares fairly well with DNV-OS-J103's requirement for going up one safety class in design.

5.8 Floating stability

Regarding floating stability, both ABS #195 and DNV-OS-J103 require intact stability. ABS #195 also requires damaged stability. This represents a deviation from DNV-OS-J103, which – with a view to the balance between large costs and limited gains – does not require damaged stability, but includes damaged stability as an option which may be adhered to on a voluntary basis only.

5.9 Corrosion protection

ABS #195 addresses corrosion protection, but this is limited to giving a reference to “industry standards”. DNV-OS-J103 refers to detailed requirements given in DNV-OS-J101. ABS #195’s definition of the splash zone is less accurate than the definition in DNV-OS-J103.

5.10 Control system

It is a major, or even fundamental, difference between ABS #195 and DNV-OS-J103 that DNV-OS-J103 has a requirement for a floater motion control system to minimize excitation of floater motions. The control system can be based on the turbine control system or can be arranged otherwise. ABS #195 does not have such a requirement for a floater motion controller. The experience from HyWind [1] shows how important this is.

5.11 Miscellaneous

DNV-OS-J103 has a minor section with requirements for marine operations in the context of transport and installation. ABS #195 seems not to include such requirements. DNV-OS-J103 has a separate section for power cable design. ABS #195 does not cover this topic. DNV-OS-J103 has a fairly comprehensive appendix on analysis guidance. ABS #195 has one page about analysis methodology. Regarding requirements for inspection, DNV-OS-J103 refers to detailed requirements in DNV-OS-J101, whereas no such requirements seem to be given in ABS #195. In particular, no maximum inspection interval associated with the DFF for inspect able structures is specified in ABS #195. In DNV-OS-J103 this is specified to be 5 years.

5.12 Conclusion

There are many similarities between ABS #195 and DNV-OS-J103 and relatively good agreement when DFF requirements for fatigue design are considered. However, there is a major deviation with respect to requirements for a floater motion controller, which DNV has and ABS does not have. And there is a major deviation with respect to requirements for damaged stability which ABS has and DNV does not have.

There is a potential non-conservatism in the design requirements for the station-keeping system given by ABS and based on API. This needs further investigation before a final conclusion can be reached.

6 Code Comparison, DNV-OS-J103:2013 vs. Class NK:2012

6.1 General

The Class NK “Guidelines for Offshore Floating Wind Turbine Structures” was issued in July 2012. Offshore floating wind turbine structure developers and operators will have to comply with the general requirements set by METI (Ministry of Economy, Trade and Industry) in order to operate in Japan. However, when it comes to the safety of floating units and the associated station-keeping and anchoring systems, METI has no specific competence within the field and refers to safety requirements as established by MLIT (Ministry of Land, Infrastructure, Transport & Tourism). Currently, integration processes of both the ministries standards are ongoing. In order for DNV GL to become an authorized certification body and the DNV-OS-J103 standard to be applicable for the certification of Offshore Floating Wind Turbine Structures, it is essential that the standard is equivalent or more stringent than the safety requirements as set by MLIT.

It has been informed that the MLIT standard to a large extent is based on input from academics of the universities of Tokyo and Kyoto and that the ambition has been to be in line with IEC 61400-3.

It seems that the Class NK standard is very much in line with the safety requirements as set by MLIT and it has therefore been authorized for certification purposes.

6.2 Scope

The Class NK standard covers mainly technical requirements, but is not free from service related comments and specifications, while DNV-OS-J103 covers technical requirements only.

Like DNV-OS-J103, Class NK addresses important issues such as environmental conditions, loads, materials, structural design, station-keeping, floating stability and corrosion protection. It is however noted that some very important topics are not dealt with in the guideline. This is further described in the following sections. Class NK addresses some issues by referring to other rules such as IEC and ship classification rules. DNV-OS-J103 follows a similar approach in many cases by referring to DNV-OS-J101 in order to avoid unnecessary duplication of material.

6.3 Design principles

Both DNV-OS-J103 and Class NK consider FOWT to fulfil the requirements of the normal safety class, giving a nominal annual probability of failure of 10^{-4}. For DNV-OS-J103 this also applies for station-keeping systems with redundancy. Station-keeping systems without redundancy DNV-OS-J103 require design for a higher safety class, i.e. for a nominal annual probability of failure of 10^{-5}.

DNV-OS-J103 provides design by partial safety factor method and design assisted by testing, as well as risk-based design, while Class NK provides design by partial safety factor method only.

6.4 Environmental modelling

Regarding environmental modelling, Class NK reproduces the majority of the wind models as described in IEC 61400-1 and -3 (but leaves out certain load cases), including the Extreme Operating Gust (EOG) of 10.5 sec duration. DNV-OS-J103 leaves it to the designer to the designer to define appropriate gust models with longer durations than 10.5 sec and specifically states that the EOG of 10.5 sec is inadequate for design of most floating structures.

6.5 Loads

Regarding loads, Class NK is using the design load case table of IEC 61400-3 with some changes. This is similar to DNV-OS-J103, which in addition requires additional load cases to be considered.

Class NK follows the IEC 61400-3 in the distinction between types of analysis required, stating ‘F’ for fatigue analyses and ‘U’ referring to ultimate loads. The design load cases indicated with ‘U’ are classified as normal (N), abnormal (A), or transport and erection (T). IEC states that abnormal design situations are less likely to occur and they usually correspond to design situations with severe faults that result in activation of system protection functions. The type of design situation, N, A or T, determines the partial safety factor to be applied to the ultimate loads.

The implication of the load factor table is an assumption of normal safety class.

In the Class NK guideline there are no statements on what to do if the station-keeping system is non-redundant. This is considered in DNV-OS-J103 by requiring a higher safety class than for the floater/turbine structure.

6.6 Structural design

In the Normal safety class, both Class NK and DNV-OS-J103 operate with the same partial load factor of 1.35. DNV-OS-J103 operate with the safety classes as discussed under target safety level, which is reflected in terms of different requirements for load factors for the respective safety classes. Class NK operates with the partial safety factors from IEC 61400-3.

It should be noted that in the case of station-keeping with no redundancy, DNV-OS-J103 requires the design to be increased with one safety class. Class NK has not considered this situation.

For design against fatigue, no requirements at all are provided in Class NK. This is considered by DNV GL to be very serious as fatigue often is a governing limit state for floating structures. This makes the Class NK guideline incomplete. The section on fatigue in the Class NK guideline is copied from IEC-61400-3 which does not provide any design rules related to DFF’s, but only refer to other standards. Without any firm requirement related to fatigue, specified for the floating wind turbine structures considered, there is an inherent risk for insufficient design.

In DNV-OS-J103, the prediction of fatigue life is based on calculations of cumulative fatigue damage under the assumption of linearly cumulative damage. The characteristic stress range history to be used for this purpose can be based on rain-flow counting of stress cycles.

6.7 Station keeping system

For design of station keeping systems, also including anchor foundations (anchor foundations are discussed below) DNV-OS-J103 makes a distinction between systems based on tendons (TLP’s) and systems based on mooring lines. Tendons are designed like any other structural component in the floater, i.e. with the same safety factors in the ULS and the same safety factors in the FLS. Mooring lines are designed according to the design rules of station keeping systems (e.g DNV-OS-E301) whose load factor requirements have been adjusted to reflect that 50-year loads are used as characteristic loads instead of 100-year loads.

For design of station keeping systems, the Class NK guideline appears to be based on API design rules (API RP 2SK) for mooring lines. The safety factors appear to be unchanged in the Class NK guideline, whereas Class NK applies 50-year loads as characteristic loads instead of API's 100-year loads. No adjustment of the safety factors to reflect the change in return period has thus been made. This may be all right for unmanned FOWT if designed according to API is intended to be design to high safety class, but may imply non-conservatism if design according to API is intended to be designed to normal safety class only. There is need here to investigate further which safety class that is intended in API RP 2SK.

It is not fully clear whether the safety factors presented by Class NK represent 100 year loads or have been adjusted to reflect a 50-year load situation, as is understood to be the basis for the guideline in their general introduction to the document.

6.8 Floating stability

Tension leg platform types remain to be assessed by the Class NK society with respect to stability and draft line. Column-stabilized, barge-type and spar-type concepts are dealt with in the guideline.

Regarding floating stability, Class NK and DNV-OS-J103 both require intact stability. Both standards state the same requirements for the intact stability when it comes to righting moments vs. wind heeling moments for the intact stability condition of the various structure types. However, Class NK does not cover the TLP solution in their guideline.

When considering intact stability, an average wind speed per minute is to be used and Class NK states that a wind speed of 25.8 m/s (10 m above sea level) may be assumed in the intact stability evaluations considering wind heeling moments. This is different from DNV-OS-J103 which operates with a constant wind speed.

DNV-OS-J103 is different and states that a wind speed of 51.5 m/s shall be assumed for the intact stability calculation. Should metocean data from the relevant site reveal that this wind speed will never occur at hub-height, a lower wind speed may be applied, based on the available data. However, to obtain sufficient stability also in the fault situation, that the turbine does not yaw out of the wind during severe storm conditions, it will be necessary to assume that the rotor plane is perpendicular to the direction of the wind when calculating the wind heeling moments and a wind speed of 36 m/s can be assumed for this situation.

Class NK requires that floating structures are to have proper freeboard and be subdivided by means of watertight decks and bulkheads to also provide sufficient buoyancy and stability to withstand the flooding of any single compartment, specified as below.

- compartment in abutment with external plates covering 5.0m upward and 3.0m downward from the draft line;
- compartment with penetrations under the draft line, such as submarine cable insertion points;
- compartments with a part receiving reaction force from the mooring line, and other areas with risk of immersion.

The floating structure shall have a positive stability in flooding of any of these compartments in order to withstand heeling moment induced to a wind based on horizontal wind velocity superimposed from any direction and floating structure motions due to waves.

The above requirements for compartmentalisation in Class NK do not have a counterpart in DNV-OS-J103 since the latter does not require damaged stability.

It is further stated in Class NK that the final waterline after flooding shall be below the lower edge of any down-flooding opening. Abilities to compensate for a damaged compartment that is flooded, for example by ballasting, pumping out from the damaged compartment, mooring force or similar, should not be considered in the damage stability calculations.

DNV-OS-J103 demands floating stability as an absolute requirement for permanently manned floating wind turbine units and this applies to all operational and temporary phases and both to an intact and damaged condition. DNV-OS-C301 can be applied for the evaluation of both intact and damaged stability according to DNV-OS-J103. For unmanned units, DNV-OS-J103 does not demand damaged stability, but consider this as option which may be adhered on a voluntary basis. The standard suggests that the choice between multiple compartments and only one compartment in the floater hull can be based on cost-benefit analyses.

For assessments of stability in damaged condition, if desired, the floating structure should have sufficient reserve stability to withstand a wind heeling moment based on wind speed (constant) of 25.8 m/s superimposed from any direction.

It is understood that MLIT believes that offshore floating wind turbine structures shall not sink even in a one compartment damaged scenario. Based on this, a double hull requirement is introduced. This is not stated explicitly in the Class NK guideline however, but it should be investigated if a rumoured double hull requirement stems from MLIT.

6.9 Design of anchor system

DNV-OS-J103 has a section dealing with the geotechnical design of the anchoring systems that transfer loads between the mooring lines or the tendons of the station-keeping system and the seabed soils. This section also deals with the design of grouted rock anchors for transfer of loads from the station-keeping system to a seabed consisting of rock rather than soil.

No similar section could be found in the Class NK guidelines.

6.10 Corrosion protection

DNV-OS-J103 refers to detailed requirements given in DNV-OS-J101 for corrosion protection and also recommends minimum corrosion allowance for chains, depending on which part of the mooring line that is considered.

Corrosion protection is dealt with in the Class NK guidelines, providing data for one-sided corrosion margins for structural members and also for chains. It is however not as detailed as what is provided in DNV-OS-J101 and DNV-OS-J103, respectively. Definition of the splash zone is lacking. No guidance on cathodic protection is provided in the Class NK guideline.

7 Other Standards to be used

In the following a brief description of the standards and guidelines, which are referenced in the sections above, is provided.

7.1 DNV GL Standards

7.1.1 General

DNV GL issues three types of documents:

- Service Specification (SE): describing the scope of work in accordance with requirements by the applicable certification system, e.g. IEC 61400-22
- Standards (ST, formerly OS): Describing the requirements to be fulfilled
- Recommended Practices (RP): describes ways and methods to document that the requirements in the standards are fulfilled

All DNV offshore standards covering marine operation, i.e. DNV-OS-H101, DNV-OS-H102 and DNV-OS-H201 through DNV-OS-H206, are called the “VMO Standard”. The overall objective of the VMO Standard is to ensure that marine operations are performed within defined and recognised safety levels.

A list of the most relevant standards to be used in connection with the DNV-OS-J103 is given below.

Service Specification

DNVGL-SE-0073:2014, *Project certification of wind farms according to IEC 61400-22*

Loads and environmental conditions

DNV-OS-J101:2014, *Design of Offshore Wind Turbine Structures*

DNV-RP-C205:2014, *Environmental Conditions and Environmental Loads*

DNV-RP-F205:2010, *Global performance analysis of deep water floating structures*

Structural design

DNC-OS-C101:2014, *Design of Offshore Steel Structures, General (LRFD Method)*

DNV-OS-C106:2014, *Structural Design of Deep Draught Floating Units (LRFD Method)*

DNV-OS-C105:2015, *Structural design of TLPs - LRFD method*

DNV-OS-C501:2012, *Composite components*

DNV-OS-C502:2012, *Offshore concrete structure*

Station keeping system

DNV-OS-E301:2014, *Position Mooring*

DNV-OS-E303:2013, *Offshore fibre ropes*

DNV-OS-E304:2013, *Details regarding steel wire ropes for mooring lines*

Marine and Machinery systems

DNV-OS-D101:2014, *Marine and Machinery Systems and Equipment*

New technology

DNV-RP-A203:2013, *Technology qualification*

Marine operations

DNV-OS-H101:2011, *Marine Operations, General*

DNV-OS-H102:2012, *Marine Operations, Design & Fabrication*

DNV-RP-H103:2014, *Modelling and Analysis of Marine Operations*

DNV-OS-H201:2014, *Lifting appliances used in subsea operations*

DNV-OS-H203:2012, *Transit and Positioning of Mobile Offshore Units*

DNV-OS-H204:2013, *Offshore Installation Operations*

DNV-OS-H205:2014, *Lifting Operations*

DNV-OS-H206:2014, *Sub Sea Operations*

7.1.2 DNV-OS-J101, Design of Offshore Wind Turbine Structures

DNV-OS-J101 provides principles, technical requirements and guidance for design, construction and in-service inspection of offshore wind turbine support structures and foundations. DNV-OS-J101 shall be used for design of bottom-fixed support structures and foundations for offshore wind turbines. The standard can also be used for design of support structures and foundations for other structures in an offshore wind farm, such as meteorological masts.

7.1.3 DNV-RP-C205, Environmental Conditions and Environmental Loads

This Recommended Practice (RP) gives guidance for modelling, analysis and prediction of environmental conditions as well guidance for calculating environmental loads acting on structures. The loads are limited to those due to wind, wave and current. The RP is based on state of the art within modelling and analysis of environmental conditions and loads and technical developments in recent research and development projects, as well as design experience from recent and ongoing projects.

The RP covers:

- **Environmental conditions** in Sec.2, Sec.3 and Sec.4
- Calculation of **environmental loads** in Sec.5, Sec.6, Sec.7, Sec.8 and Sec.9.
- Hydrodynamic **model testing** in Sec.10.

7.1.4 Offshore Standard DNV-OS-C105 “Structural Design of TLPs”

This standard provides an internationally acceptable standard of safety by defining minimum requirements for structural design of TLPs

The requirements and guidance are generally applicable to all configurations of tension leg platforms. The DNV-OS-C105 is based on the load and resistance factor design method (LRFD). LRFD is defined in DNV-OS-C101.

A TLP can alternatively be designed according to working stress design principles, which is defined in DNV-OS-C201.

A TLP can also alternatively be designed to API RP 2T as it has been accepted that it meets the safety levels required by DNV-OS-C105.

7.1.5 DNV-OS-C106 Structural Design of Deep Draught Floating Units (LRFD Method)

This standard provides requirements for the structural design of Deep Draught Floater (DDF) units, fabricated in steel, in accordance with the provisions of DNV-OS-C101 utilizing the LRFD design Method. For WSD methodology, DNV-OS-C106 refers to DNV-OS-C201.

A DDF platform is categorised as having a relatively large draught when compared to ship shaped, semisubmersible or TLP type units. This large draught is mainly introduced to obtain sufficiently high “Eigen period” in heave and reduced wave excitation in heave such that resonant responses in heave can be omitted or minimised.

A DDF can include a Spar, deep draught semi (DDS) or other deep draught floating units.

The unit is usually kept in position by a passive mooring system.

7.1.6 DNV-RP-F205, Global performance analysis of deep water floating structures

The Recommended Practice covers the following aspects

- response characteristics of different floating systems
- definitions of ‘coupling effects’, ‘decoupled analysis’ and ‘coupled analysis’
- load models for floater and slender structures
- coupling effects from slender structures to floaters
- necessary input parameters in coupled analysis
- how to efficiently perform coupled analyses.

7.1.7 DNV-OS-D101, Marine and Machinery Systems and Equipment

This offshore standard provides principles, technical requirements and guidance for design, manufacturing and installation of marine and machinery systems and equipment for mobile offshore units and floating offshore installations. The requirements of this standard are in compliance with relevant parts of SOLAS chapter II-1 and the IMO MODU Code.

The standard has been written for general world-wide application. Governmental regulations may include requirements in excess of the provisions by this standard depending on the size, type, location and intended service of the offshore unit or installation.

The objectives of this standard are to:

- provide an internationally acceptable standard of safety by defining minimum requirements for offshore marine and machinery systems;
- serve as a contractual reference document between suppliers and purchasers;
- serve as a guideline for designers, suppliers, purchasers and regulators;
- specify procedures and requirements for units or installations subject to DNV certification and classification.

7.1.8 DNV-OS-E301, Position Mooring

The objective of DNV-OS-E301 is to give a uniform level of safety for mooring systems, consisting of chain, steel wire ropes and fibre ropes. The standard contains criteria, technical requirements and guidelines on design and construction of position mooring systems. The DNV-OS-E301 is applicable for and limited to column-stabilised units, ship-shaped units single point moorings, loading buoys and deep draught floaters (DDF) or other floating bodies relying on catenary mooring, semi-taut and taut leg mooring system. DNV-OS-E301 is also applicable for soft yoke systems.

7.1.9 DNV-OS-E303, Offshore Mooring Fibre Ropes

The objective of this standard is to ensure that the design and manufactured quality of fibre-rope assemblies meet the requirements of designated locations, handling and service scenario for offshore applications, thereby providing the basis for ensuring reliable fibre-rope moorings.

7.1.10 DNV-RP-A203 Technology qualification

Technology qualification is the process of providing the evidence that a technology will function within specified operational limits with an acceptable level of confidence.

This Recommended Practice shows how these risks can be managed by the provision of evidence to reduce uncertainties.

The objective of this Recommended Practice is to provide a systematic approach to technology qualification in a manner that ensures traceability throughout the process, from the determination of functions, targets and expectations to relevant failure modes, qualification activities and evidence. Its aim is to ensure that the failure modes and the qualification activities are relevant and complete. This, in turn, should improve confidence in novel technology, and improve the likelihood of its commercialisation.

7.1.11 DNV-RP-H103, Modelling and Analysis of Marine Operations

DNV-RP-H103 gives guidance for modelling and analysis of marine operations, in particular for lifting operations including lifting through wave zone and lowering of objects in deep water to landing on seabed. The objective of this recommended practice is to provide simplified formulations for establishing design loads to be used for planning and execution of marine operations.

7.1.12 DNV-OS-H101, Marine Operations, General

DNV-OS-H101 gives general requirements and recommendations for planning, preparations and performance of marine operations. Recommendations and requirements in this Standard shall be considered in relation to the structural and operational complexity and sensitivity as well as type of marine operation to be performed.

7.1.13 DNV-OS-H102, Marine Operations, Design & Fabrication

This standard gives general requirements and recommendations for selection of loads, design (verification) and fabrication of structures involved in marine operations. The requirements in this standard are intended to be applied for design of temporary structures, verification of objects for temporary phases, verification of vessels and design of reinforcements in objects and vessels.

7.1.14 DNV-OS-H201, Load Transfer Operations

DNV-OS-H201 gives specific requirements and recommendations for marine operations involving load transfer without use of cranes, i.e. by use of (de-)ballasting. Typical load transfer operations are load-out, float-out, lift-off and mating. DNV-OS-H201 also applies for construction a float phases.

7.1.15 DNV-OS-H203, Transit and Positioning of Mobile Offshore Units

This standard provides specific requirements and recommendations for positioning any type of offshore unit such as semi-submersible units, self-elevating units, drilling ships, floating productions and/or storage units, loading buoys, offshore installation vessels and well intervention units. DNV-OS-H203 also provides specific requirements and recommendations for transit of mobile offshore units.

7.1.16 DNV-OS-H204, Offshore Installation Operations

DNV-OS-H204 provides specific requirements and recommendations mainly applicable for jacket installation operations. The principles and requirements given in this standard may be adopted for the installation operations of other types of objects, whenever applicable and for any relevant installation phases. The standard gives requirements to four main installations phases: launching, upending, positioning and setting down, as well as connection to foundation, i.e. by suction, piling and/or grouting. Connection of TLP to tendons is also briefly addressed.

7.1.17 DNV-OS-H205, Lifting Operations

DNV-OS-H205 provides specific guidance and recommendations for engineered onshore, inshore and offshore lifting operations, conducted both in air and sub-sea.

7.1.18 DNV-OS-H206, Sub Sea Operations

DNV-OS-H206 provides requirements, recommendations and guidance for load-out, transport and installation of subsea objects. The standard applies to subsea objects being lowered to their final position on the seabed by cranes or other means, or pulled down or ballasted from the sea surface. Typical objects covered are subsea structures, pipelines, umbilicals, bundles, cables and risers.

7.1.19 GL Rules of Offshore Technology

The Rules for Classification and Surveys apply to the Classification of mobile offshore units as well as fixed offshore installations. The Rules published by GL give the requirements for the assignment and the maintenance of class for the classification of mobile offshore units as well as for fixed offshore installations.

7.1.20 GL Rules for Material and Welding

The Rules for Materials apply to materials and products which are intended for the construction, repair and equipping of ships, offshore installations and other structures.

The Rules for Welding apply to all welding work performed in the course of new construction, conversion or repairs carried out on ships and their machinery installations, including steam boilers, pressure vessels and pipelines.

7.2 IEC Standards

IEC 60721-2-1:1982,	*Classification of environmental conditions – Part 2-1: Environmental conditions appearing in nature. Temperature and humidity Amendment 1:1987*
IEC 61400-1:2005,	*Wind turbines – Part 1: Design requirements*
IEC 61400-3-1:2015,	*Wind turbines - Part 3-1: Design requirements for fixed offshore wind turbines*
IEC 62305-3:2006,	*Protection against lightning – Part 3: Physical damage to structures and life hazard*
IEC 62305-4:2006,	*Protection against lightning – Part 4: Electrical and electronic systems within structures*

7.2.1 General

The International Electrotechnical Commission (IEC) is the world’s leading organization that prepares and publishes International Standards for all electrical, electronic and related technologies. The IEC 61400 is a set of design requirements made to ensure that wind turbines are appropriately engineered against damage from hazards within the planned lifetime. The standard concerns most aspects of the turbine life from site conditions before construction, to turbine components being tested, assembled and operated.

7.2.2 IEC 61400-1

This part of IEC 61400 specifies essential design requirements to ensure the engineering integrity of wind turbines. Its purpose is to provide an appropriate level of protection against damage from all hazards during the planned lifetime.

This standard is concerned with all subsystems of wind turbines such as control and protection mechanisms, internal electrical systems, mechanical systems and support structures.

7.2.3 IEC 61400-3

This part of IEC 61400 specifies additional requirements for assessment of the external conditions at an offshore wind turbine site and specifies essential design requirements to ensure the engineering integrity of offshore wind turbines. Its purpose is to provide an appropriate level of protection against damage from all hazards during the planned lifetime.

This standard focuses on the engineering integrity of the structural components of an offshore wind turbine but is also concerned with subsystems such as control and protection mechanisms, internal electrical systems and mechanical systems.

The design requirements specified in this standard are not necessarily sufficient to ensure the engineering integrity of floating offshore wind turbines.

This standard should be used together with the requirements of IEC 61400-1. The safety level of the offshore wind turbine designed according to this standard shall be at or exceed the level inherent in IEC 61400-1.

7.3 ISO Standards

ISO 13628-5:	*material selection for electrical cables*
ISO 2394:1998,	*General principles on reliability for structures*
ISO 2533:1975,	*Standard Atmosphere*
ISO 19900:2002,	*Petroleum and natural gas industries – General requirements for offshore structures; soil properties during earthquakes*
ISO 19901-1:2005,	*Petroleum and natural gas industries – Specific requirements for offshore structures – Part 1: Metocean design and operating conditions; for swell spectra (IEC -3-2 page 12)*
ISO 19901-4:2003,	*Petroleum and natural gas industries – Specific requirements for offshore structures – Part 4: Geotechnical and foundation design considerations; soil properties during earthquakes*
ISO 19901-6:2009,	*Petroleum and natural gas industries - Specific requirements for offshore structures - Part 6: Marine operations; Assembly, Transportation and Installation*
ISO 19901-7:2013,	*Petroleum and natural gas industries - Specific requirements for offshore; design of catenary, semi-taut or taut station keeping systems structures - Part 7: Station keeping systems for floating offshore structures and mobile offshore units*
ISO 19902:2007,	*Petroleum and natural gas industries – Fixed steel offshore structures*
ISO 19903: 2006,	*Petroleum and natural gas industries – Fixed concrete offshore structures*
ISO 19904-1:2006,	*Petroleum and natural gas industries — Floating offshore structures — Part*

	1: Monohulls, semisubmersibles and spars; hydrodynamic modelling (vortex effects), material requirements plus corrosion protection systems; assessment of impact loads, soil properties during earthquakes, WSD
ISO 19906:2010,	*Petroleum and natural gas industries – Arctic offshore structures; sea ice*
ISO 19901-2:	*soil properties during earthquakes*

7.3.1 General

The series of International Standards applicable to types of offshore structure, ISO 19900 to ISO 19906, constitutes a common basis covering those aspects that address design requirements and assessments of all offshore structures used by the petroleum, petrochemical and natural gas industries worldwide. Through their application the intention is to achieve reliability levels appropriate for manned and unmanned offshore structures, whatever the type of structure and the nature or combination of materials used.

7.3.2 ISO 19904-1, Petroleum and Natural Gas Industries – Floating Offshore Structures – Part 1: Monohulls, Semi-Submersibles and Spars

This part of ISO 19904 provides requirements and guidance for the structural design and/or assessment of floating offshore platforms used by the petroleum and natural gas industries to support the following functions: production, storage and/or offloading, drilling and production, production, storage and offloading, as well as drilling, production, storage and offloading.

7.4 API Standards and others

IMO Resolution MSC.267(85),	*International Code on Intact Stability, 2008 (2008 IS CODE)*
API RP 2FPS: 2011,	*Recommended Practice for Planning, Designing, and Constructing Floating Production Systems; wave crest consideration for air gap analysis*
API RP 2T: 2010,	*Recommended Practice for Planning, Designing, and Constructing Tension Leg Platforms*

7.4.1 General

The American Petroleum Institute (API) is the national trade association that represents all aspects of America’s oil and natural gas industry.

7.4.2 API RP 2SK, Design and Analysis of Station-keeping Systems for Floating Structures

The purpose of this Recommended Practice is to present a rational method for analysing, designing or evaluating station-keeping systems used for floating units. This method provides a uniform analysis tool which, when combined with an understanding of the environment at a particular location, the characteristics of the unit being moored, and other factors, can be used to determine the adequacy and safety of the mooring system. API RP 2SK addresses station-keeping system (mooring, dynamic positioning, or thruster-assisted mooring) design, analysis, and operation. Different design requirements for mobile and permanent moorings are provided.

7.4.3 API RP 2T, Recommended Practice for Planning, Designing, and Constructing Tension Leg Platforms

This Recommended Practice is a guide to the designer in organising an efficient approach to the design of a tension leg platform. Emphasis is placed on participation of all engineering disciplines during each stage of planning, development, design, construction, and installation.

7.5 National requirements

7.5.1 General

When national requirements are available, they shall be considered.

The national requirements overrule the employer requirements and the standards issued by the certification bodies.

7.5.2 Germany

For all German projects the BSH Standards need to be considered. They contain requirements for standard hierarchy to be considered and cyclic loading of foundations (for fixed OWT).

8 Other Relevant References

Various research projects on floating wind turbines from the last decade have been dedicated to the development design guidelines, best practices and their validation through small and full-scale measurements. In the following the results from reports and specific research projects are collected and commented.

These results from scientific projects are seen as an indispensable supplement to the standards with more in-depth guidance on practical issues or scientific background and proof for the requirements by the different standards.

IEC 61400-3-2[p41]: Annex Tsunami: reference documents:

- Goto, C. and Sato, K.: Development of Tsunami Numerical Simulation System for Sanriku, Report of PARI, vol. 32, NO. 2, pp. 3-44, June 1993.
- http://www.bousai.go.jp/jishin/tsunami/hinan/1/pdf/sub.pdf (in Japanese)
- Imamura, F., Yalciner, A.C. and Ozyurt, G.: Tsunami modeling manual 2006.
- IUGG/IOC Time Project, IOC Manuals and Guides, No. 35, UNESCO, 1997
- Kokubun, Kentaroh, Taniguchi, Tomoki and Inoue, Shunji: Effects of Earthquake and Tsunami on Floating offshore wind turbine, Proceedings of the International Symposium on Marine and Offshore Renewable Energy 2013.

8.1 Results from research projects

In the following scientific publications and technical reports related to offshore wind standards are presented. First, load case simulations with extreme and fatigue responses for different floating and fixed-bottom concepts for wind turbines are shown before publications on environmental conditions and general information on the interpretation of standards is presented.

A prevalent question is the requirements on the simulation length in order to capture effects from wind, waves and currents for the calculation of the fatigue of floating wind turbines. It has been studied if assumptions from the oil and gas industry also hold for offshore wind technology:

Haid et al. [2] have performed an extensive simulation study on the required simulation length of design load simulations of the OC3-Hywind model, [3], according to the IEC standard [4]. Due to the transient loads on nonlinear dynamic simulation models the occurrence of extreme and fatigue loads might depend on the number of seeds per wind/wave case and the length of the simulation. However, the study showed that the simulation length does not significantly impact the loads and rather the method for estimating the fatigue damage (rainflow counting) is of importance.

Another extensive simulation study on the OC3-Hywind spar model has been performed by Barj et al. [5]. They simulated a large range of wind speeds, wave heights, wave periods and wind/wave misalignments using FAST [6]. It showed that especially the case of perpendicularly misaligned wind and waves might be important to consider as design load case. Eventually, it turned out, however, that aligned wind and waves yield the maximum extreme and fatigue loads. The authors expect these results to be also valid for other floating platform types.

The response of a spar-type floating wind turbine under extreme environmental conditions has been studied by Utsunomiya et al. [7]. They state that state-of-the-art simulation models can capture most of the extreme responses when compared to experimental data except if strong currents are present, which can yield also vortex-induced motion. The methods for obtaining the dynamic response of spar-type platforms with varying mooring lines is provided by Karimirad, [8].

In the case of TLPs, Bachynski et al. [9] have studied the effect of misaligned wind and waves on the fatigue response to second-order wave forces for two different TLPs. The study showed that for generally misaligned wind and waves the fatigue loads at tower base, tower top and fairleads decreased even though the aerodynamic damping is reduced for side-side excitation. However, the effect of second-order loads still increased for misaligned wind and waves.

Looking at semi-submersible platforms, a publication by Aguirre et al. [10] gives practical insight to the design process of the Nautilus semi-submersible platform looking at the requirements of different standards.

Also specific studies have been addressed to the response and the loads on mooring lines. An extreme-load model for mooring lines to be used for certification has been presented by del Jesus et al. [11]. It has the aim of reducing the uncertainty of predicted loads using existing measurements and a mixed extreme model which combines measurements and theoretical data. It turns out that the model assumed wave heights might in reality alter up to more than 10%.

Masciola et al. has evaluated the dynamic-response based intact stability criterion for floating wind turbines for ABS, see [12]. Governing load cases have been defined for simulating the input for this alternative intact stability criterion. Compared to the commonly applied area-ratio-based criterion the latter one might be more favourable for floating wind turbines due to the large transient effects of the coupled dynamic system. Another study on the impact of the mooring system on the overall dynamics has been performed by Huijs [13]. He shows the sensitivity of the design parameters like the vertical location of the fairleads on the static and dynamic properties.

A common coupled simulation model for jacket-type offshore wind turbines has been validated with full-scale data from the German Alpha Ventus research wind farm by Kaufer et al., [14]. High-resolution measurement signals were compared to simulations for the strains at the blade roots, the tower and the jacket substructure. For floating wind turbines, first measurement data of an 1:8 scale model off the coast of Maine/USA has been presented by Viselli et al. [15].

Besides the intact stability evaluation various studies have been performed for damage stability assessment. A recent example of an analysis of the risk associated with drifting vessels for a wind farm was presented by Hirokawa et al. [16].

After these projects on the simulation techniques of platforms and mooring lines some research on environmental conditions is here summarized.

A review work has been performed in the Marinet project on the simulation of wind and wave environments; see Bredmose et al. [17]. The report nicely summarizes available distributions for wind, waves and wind/wave misalignments together with example site conditions. The second part comments on scaling methods for model tests of floating wind turbines.

An extensive met-ocean dataset of the US coast has been published by Stewart et al. [18]. According to the authors the assumed met-ocean conditions are crucial for the design loads but often the real measurement data of a specific site is not available. Therefore, the project compiled the data for different freely available site measurements, created conditional probability density functions and came up with “generic” sites of US coasts available for research.

A comparable dataset for two different shallow-water sites is given by Fischer et al. for the European FP6-UPWIND project, see [19]. The two sites are in the North Sea with 21m and 25m water depth and an extrapolation for a deep-water site. A complete dataset for the design of offshore wind turbines is available therein.

An example of wind resource assessment in the German Bight including the estimation of extreme events can be found in [20].

Finally, a comparison of different available standards for offshore wind turbines has been performed by Saigal et al. [21]. The considered standards are the ones by API, DNV, GL, and the IEC. The effect of uncertainty with respect to various variables used in the standards has been assessed.

The risk-based approach for the general development of standards for different marine renewable energy platforms performed by Macadré et al. for Bureau Veritas might also be of interest, see [22]. This is especially useful for combined platforms but the ideas presented might be applicable to floating wind turbines.

9 Conclusion

Several standards from different certification bodies are available for the design of floating wind turbines and they have been described in this document. The focus has been put in comparing the main standards, e.g. DNV-OS-J103, IEC 61400-3-2, ABS #195, GL2012, and ClassNK 2012. However the complete design of a floating wind turbine system requires the use of several codes, which can be selected from different "certification systems", e.g. DNV, IEC, ISO, API, etc.

When a standard (and a certification system) has been chosen for the design, compatible standards shall be used for the other aspects of the design, in order to avoid possible inconsistencies and gaps.

Floating wind turbines are considered a developing technology, which is not fully developed yet. Therefore it is expected that the status of the standards will also improve in the coming years, making use of the experience from industrial demonstration projects and from the on-going research.

In particular, it is expected that an agreement will be reached on the method and ways to fulfil the requirements described in the existing standards, e.g. how to validate the numerical models with model tests.

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