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Development, engineering, production and life cycle management of improved FIBRE-based material solutions for the structure and functional components of large offshore wind enerGY and tidal power platforms

D4.6 (WP4): Critical review of applicable standards and gaps

Responsible Partner: TSI

Contributor(s): BV, TSI, TIDETEC, ENEROCEAN, COMPASSIS

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EXECUTIVE SUMMARY

In an effort to respond properly to the rising challenges facing the marine structure industry, composite materials technology is expected to play a greater role in the development of promising energy renewable structures. In comparison with traditional materials like steel or concrete, composite materials offer a significant weight reduction, corrosion resistance, greater structural shape adaptation to complicated geometries, longer fatigue life, and higher vibration damping which can be explained by the heterogenous structure of the composite laminates facilitates the phenomena of dissipation of energy due to their multiple number of layers and anisotropic structure. One of the greatest advantages of FRP materials is that they are not prone to corrosion, which can result in a dramatic reduction of the offshore maintenance costs in the renewable energy offshore platforms (REOPs). Thus, FRP structures are ideal for the immediate and future challenges of the offshore industry to take advantage of the significant potential benefits that are just beginning to be exploited. In order to realise this potential, it is necessary to understand the current technology and future development of composite materials, the specific requirements and economic constraints, as well as certification and regulatory developments for reaching standardization as soon as possible.

Despite the convenient immunity to corrosion along with the high strength and young modulus to weight ratio of Fibre Reinforced Polymers (FRP), the majority of the Floating Offshore Wind Turbine (FOWT) concepts developed up to date that has reached a high TRL are based on conventional materials like steel and concrete. Similarly, the major part of the components of the tidal power generators are also made out of traditional materials. Without a doubt, one of the main issues is the lack of regulations and standards to enable the application of lightweight FRP materials in the design and construction of REOPs and the different technology gaps that need to be addressed to demonstrate the viability of using FRP materials in the offshore industry. The primary objectives of this report are to review the current state of international regulations, guidelines and standards relevant to the use of conventional and FRP materials in offshore platforms and marine turbines as well as to identify gaps that avoid the uptake of FRP materials in the design and construction of REOPs. This work is devoted to provide guidance for the development of regulations and standards, in the field of offshore structures operating with turbines designed in composite materials.

As a first step, TSI has enlisted the applicable standards for designing of offshore structures in composites using a large list of classification societies' standards (BV, DNV, LR, RINA, ABS, RS, ClassNK, CCS) and other standards from international regulatory bodies (ISO, API, IEC) have been reviewed by the authors with the purpose to get a deeper understanding of the regulations related to the use of conventional and unconventional materials on marine structures, focusing the efforts on FRP applications. Regarding the second step, TSI has identified the potential existing gaps of these standards and has discussed about the use of composite materials in the design and construction of the W2Power structure and the housing of the Tidal Turbine. From our perspective, the main Issues to be addressed by the future standards include FRP manufacturing; assembly & construction; maintenance & repairs; material mechanical performance, material damage resistance, material durability and environmental degradation and material flammability & fire resistance; and, structural design, structural optimization, testing and structural reliability,

Disclaimer: *With no doubt, the authors might miss existing standards or regulatory frameworks that might be included in this deliverable. If any of the readers of this document possesses information in this regard useful for the improvement of this work, do not hesitate to contact TSI.*

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1. INTRODUCTION – WHY FRP TECHNOLOGY IN OFFSHORE AND WIND TURBINE PLATFORMS?

A current trend in the transport industry is the process of making vehicles, ships and aircrafts lighter in an effort to reduce the energy consumed and the greenhouse gas emissions emitted. Nowadays, the greatest advances in terms of weight reduction are currently made in the aeronautic industry, representing the main driver of innovation. With respect to the shipping industry, the FIBRESHIP project (1) promoted the use of FRP materials in the construction of large-length ships (over 500 GT), developing three specific targeted vessels such as a containership, a ROPAX, and a Fishing Research Vessel, to harness the main benefits of composites and generate operation impacts such as the reduction of fuel consumption and greenhouse gas emissions emitted, supporting the international effort of waterborne transport zero-emission industry. Similarly, the technical and economic feasibility of using fibre reinforced polymer materials (FRP) in the design and construction of current commercial ships has recently been researched in the RAMSESS project (2).

This process of optimising resources and reducing pollution is also reaching other emerging sectors such as marine renewable energy, in particular the design of tidal turbines with rotating turrets in composite materials or in the design of floating and fixed platforms also in composite materials. These sorts of projects are becoming more and more common year by year, which means that this innovative approach is moving in a good direction. The main purpose of maximising the use of FRP materials is to improve the efficiency of the REOPs both technically and economically. Looking at fixed and floating foundation applications, the drastic weight reduction exerted by the FRP materials is expected to reduce the cost for the transportation, mooring and commissioning of the turbine's foundation.

In general, it can be said that composite materials are of interest because of the excellent relationship between their mechanical properties and their weight. A composite material, understood as the union of a plastic resin and a polymer fabric (metal and concrete unions are not considered), enables the manufacture of more complex structures with more complex geometries due to the adaptability capability of the material and an optimized design of the foundation structure in terms of stress and fatigue.

The FIBREGY Project aims to address two Renewable Energy Offshore Platforms (REOPs) concepts which has been selected by the consortium as the most promising solutions from the market uptake point of view. The W2Power concept is a twin-wind turbine semi-submersible platform developed by ENEROCEAN, and the TIDETEC'S tidal power turbine is a cost-effective technology to harness tidal phenomena to generate green energy. The overall objective of the FIBREGY project is to enable the extensive use of FRP materials in the design and construction of certain elements of the W2Power and TIDETEC's tidal turbine, with the purpose to demonstrate to the marine and renewable community the multiple advantages of FRP lightweight materials in the design and construction of marine renewable energy platforms.

The re-engineering and design optimization of the two targeted platforms (W2 Power and TIDETEC's turbine) as well as the application of innovative production and building techniques, are expected to reduce the uncertainty of the application of FRP materials in marine structures and contribute in the searching of levelized cost of energy (LCoE) reduction of the offshore renewable energy generation compared to current technology baseline.

At present, the applications of fibre reinforced polymers (FRP) in the marine industry are increasing day by day. This rising demand of FRP technology generates the need of increasing expertise in this area. The main benefits of a composites design can be summarised as a reduction in CAPEX and OPEX, improved service life, reduced environmental impact, among other benefits that will be analysed in the FIBREGY project. Below, the above-mentioned FRP impacts are detailed and substantiated below:

- CAPEX: The application of FRP materials in this new generation of REOP will lead to an important CAPEX reduction. In the short term, the significant reduction of weight of REOPs due to the extensive use of FRP materials will have a relevant impact in the transport and installation costs of the offshore platforms as well as a reduction of the mooring costs. In the long term, the implementation of serial and automated production techniques will lead to a reduction of the production lead times and to the possibility of using pre-manufactured structural elements, resulting in a reduction of manufacturing costs of the structures supporting the generation systems of REOPs. In summary, the main points that will help to bring about a reduction in CAPEX are:
    - Reduction on the weight of the structure and components.
    - Optimized design and manufacturing processes (modular building strategy).
    - Readiness of the concepts for serial and automated production.

- OPEX: The use of FRP materials will play an important role in operational expenditures. Special emphasis should be paid to the immunity to corrosion of FRP materials as an interesting approach to reduce the maintenance costs of the REOP. Apart from that, it should be highlighted that FRP materials show a superior fatigue performance due to their high fatigue limit and greater flexibility that allows the design of structures with more complex geometries. The main points that help to bring about a reduction in OPEX are:
    - Increase of structural fatigue life.
    - Immunity to corrosion due to the composite materials characteristics.
    - Advantage predictive maintenance by monitoring the structure with embedded sensors.

  Design and operating life: Another interesting aspect is the design and operation life of the REOPasset. The offshore structures are subjected to harsh environmental conditions which result in corrosion, and wave fatigue cycling. As mentioned above, the implementation of FRP materials offer superior fatigue performance and corrosion resistance, which is an important factor to enhance the design and operating life of the REOPs.

- Low environmental impact: The Structural Materials and Global climate report (3) states that a drastic reduction of greenhouse gas emissions can be achieved by the application of advanced FRP materials in the construction of FRP structures. In other words, the drastic reduction of weight thanks to the application of FRP materials lead to a reduction in the transportation costs of the FRP assets, as well as the amount of greenhouse gas emissions emitted during the transportation. In the near future, it is expected that the application of closed mould resin infusion processes instead of open mould processes will reduce the level of exposure of the shipyard workers to volatile organic compounds (VOCs).

In spite of the fact that there has been a remarkable increase of the acceptance of FRP materials for the development of marine structures by the regulatory and classification societies, nowadays, the application of FRP materials is practically non-existent in the REOP sector, boosting the need of projects such as FIBREGY to address this lack of knowledge and increase the awareness of this potential solution.

If we look at the shipping sector, Fibre-Reinforced Polymers (FRP) materials are widely used for building the hull and secondary structures of small-length vessels (smaller than 50 meters in length). As a result, most of the leisure and sailing yachts, small fishery ships, small naval ships, patrol boats and rescue vessels below 25 m length have been currently constructed with FRP materials.

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However, the application of FRP materials in the construction of large-length ships (greater than 50 meters in length) is limited to secondary structures as per example the superstructure, due to the constriction of regulations such as SOLAS (IMO). The FIBRESHIP project (1) worked towards the development of new design guidelines to enable future regulations of design and construction of a new generation of large-length vessels with lightweight FRP materials.

With respect to the offshore wind energy sector, floating offshore wind platforms are commonly constructed with conventional materials as steel or concrete, while tidal power generators only in steel materials. However, the application of FRP materials is only limited to the design and construction of blades and auxiliary components of the offshore platforms (e.g., pipes). The limited application of FRP materials in offshore wind and tidal turbine platforms (REOPs) can be explained by the potential lack of knowledge of the offshore industry in the design and construction of REOP concepts with FRP materials or the lack of standards to ensure the financial investment in the application of FRP materials in this sort of structures.

Currently, there are no existing regulations focused directly on the design of marine renewable energy platforms in FRP materials, which leads to an interesting dilemma. At a first level, REOPs are not designed with FRP materials because of the lack of design guidelines and regulations to support platform designers. At a second level, the regulations for the design of REOPs-based on FRP does not exist because designers do not commonly apply FRP materials in the design of energy offshore platforms. The FIBREGY project intends to solve this problem and break this vicious circle through a compilation of standard regulations that can be adapted to the design of offshore platforms and tidal turbines with FRP materials, enabling their design and construction, and even more important, ensuring the certainty of investment in this sort of renewable energy platforms.

2. OBJECTIVE

The current document aims to make a state of the art of the existing regulations for the design and construction of offshore wind platforms and marine turbines that consider conventional materials as steel or concrete and unconventional ones as FRP materials. The two major objectives of this document can be drawn as follows:

Firstly, review of the state of the art of the current regulations, guidelines and recommendations related to the use of conventional and unconventional materials in energy renewable platforms. To address this task, it has been reviewed a large list of mandatory and voluntary rules and regulations issued by the most important classification societies (e.g., BV, DNV, LR, RINA, ABS, Class NK, among others) and international regulations (e.g., ISO, IEC, etc.). In this critical review, it has been considered the existing rules and recommendations for certification of REOPs as well as the design guidelines and rules for the construction of large-length FRP ships (over 500 GT) (4). These second one rules related to ship regulation and standardization can be extrapolated to marine renewable sector if it is necessary.

Secondly, identification of the regulatory gaps in the current regulatory framework to enable the use of FRP materials in the design, construction, and operation of the new generation of hybrid FOWT. The identification of the gaps will consider the existing regulations related to the use of FRP materials as per example (5), (6), (7), (8), (9), (10), among others. After this analysis, the next step is to develop project design guidelines and recommendations to support designers in the design of floating platforms and marine turbines in FRP materials such as W2Power and Tidetec's Tidal Turbine. This critical issue will be addressed in the context of the D4.7 of the FIBREGY project, which aims to generate new design, performance criteria and production guidelines for the development of a new generation of REOP concepts based on FRP materials.

The outcome of both deliverables will be discussed and review in a Standardization Committee composed by three major classification and certification societies (BV, DNV, and LR), which is a good indicator of the high quality of the research work carried out in the FIBREGY project. The project design guidelines and recommendations for using FRP in large FOWTs will lay the foundations for the development of a new generation of FOWT and tidal turbines in the near future.

3. METHODOLOGY OF ANALYSIS

A series of standards and guidelines issued by the different national and international organizations for the design of oil & gas and energy offshore platforms have been considered in this study for the identification of the regulatory gaps for the design of floating platforms and marine turbines in lightweight FRP materials. This critical study is carried out to shed some light on the development of future standards for the certification of a new generation of lightweight FOWTs structures.

The methodology applied for this critical review is focused on the following steps:

1. Identification of current applications of FRP in offshore and land-based marine turbines. Regulations and standards:

This criterion covers all standards that contain significant data for design structural components in composite materials under stress conditions. Standards in which it is possible to find applicable data for the certification of a general offshore platform and the certification of land-based tidal turbines.

2. Identification of regulations and standards related to the use of conventional materials (steel and concrete) to be used in the design of FOWT structures. Overview of the materials in different classification societies.

The criteria include all the regulations or guidelines concerning the offshore platform design in steel and concrete materials. After this analysis, a design standard for FOWTs in composite materials (FRP) is draw up with the aim of identifying possible gaps and critical issues.

3. Structural applications of FRP materials in other engineering areas (maritime transport, defence, aerospace…)

Since composite materials are innovative materials in the marine structural design, it is possible that no data about the design and calculation of FRP platforms are available. That is why it is necessary to consider other naval architecture and marine standards that do not cover offshore platforms and marine turbines. Standards for vessel design in composite materials are currently developed and these provide a great quantity of structural behaviour data for these lightweight materials.

4. Gaps and possibilities of FRP in both areas, offshore and land-based turbines.

This task is focused on analysing the standards, guidelines, and rules collected along this research. Looking for any data that could be useful, and identifying areas that are not covered or that need to be analysed in more detail.

The main idea behind this task is to lay the foundations for the future rules and class regulations to be adopted by the marine community for the development and engineering of the new generation of renewable energy platforms.

3.1. Selection of classification societies and regulations governing floating platforms.

There is an increasing number of regulatory institutions operating at the marine and maritime level. To carry out a critical review, a large list of mandatory and voluntary classification society rules and regulations issued by the most important classification societies (BV, DNV, LR, RINA, ABS, Class NK, RS, CCS) and international and regional regulations (ISO, IEC, API) have been considered in this study. Below, it can be found the criteria for the selection of the classification societies and regulatory institutions analysed in the context of this study:

- **Volume of regulations:** The first criteria for the selection of the classification society regulation is the number of areas regulated by the classification society organisation, as well as their rigour and precision.
- **International reputation**: This is a parameter that reflects the worldwide influence of the regulatory entity in the marine sector.
- **World-wide registered fleet:** An approach in the maritime sector, which allows understanding the volume of work carried out by a regulatory organisation, even if it is very focused on one region. It also provides a sense of the international weight of the country of origin.
- **Experience with FRP materials:** This gives an idea about the connection of the organisation with composite materials. There are entities that are focused on the certification of composite structures, such as small leisure boats or yachts.
- **Offshore Renewable Energy and Oil & Gas impact**: Degree of Involvement of the regulatory agency with the offshore renewable energy and oil & gas industry.
- **Growth of the regulatory entity:** This factor indicates the potential impact that the regulation could have in the future.

3.2. Analysis of sort of materials regulated by Classification Societies

The analysis of the regulatory frameworks is mainly focused on the structural integrity of the wind and turbine offshore platforms. It is evident that there is a lack of information for the design of an offshore structure with unconventional materials and therefore, it is required to carry out a large number of inspections and periodic revisions in new generation of FRP-based REOPs. In line with this, the FIBREGY consortium will evaluate the mechanical and environmental performance of the FRP materials used for the design and construction of the large- and real-scale REOPs demonstrators in the project.

The material standards focused on the design of REOPs have been included in the gaps analysis, with a special interest on the following information:

- Certifications and qualifications of the individual materials used in the manufacturing of the FRP composite (e.g., fibres, reinforcements, sandwich core materials, etc.).
- Tests to obtain safety certifications, such as fire behaviour, water absorption and materials collapse, among others.
- Evaluation of the materials failure modes, chemical resistance, aging, as well as materials behaviour against extreme temperatures.

3.3. Main criteria that documents must have to be considered useful for the research

The development of new design guidelines and regulations for the building of REOPs in composite materials will make possible to follow the lessons learnt from the aeronautics and space industry in FRP technology. To create new guidelines and regulations for the design of a new generation of REOPs with FRP materials is essential to know the thematic areas covered by the existing regulations. In particular, this revision of the literature considers regulations and recommendations focused on the design of REOPs with FRP materials and other unconventional materials, avoiding the standards focused on the use of conventional materials as steel and concrete. The main standards and guidelines considered in this critical review are defined below:

- Standards, guidelines, and rules applied for the design of FRP-based ships.
- Standards, guidelines, and rules applied for the design of offshore platforms with FRP materials (if any).
- Standards, guidelines, and rules applied for the design of offshore platforms using non-metallic materials as concrete.
- Standards, guidelines, and rules dealing with materials, such as steel, aluminium, wood and including FRP as one of the materials covered.
- Standards, guidelines, and rules of FRP materials used in auxiliary naval industry
- Standards, guidelines, and rules of FRP materials used in auxiliary offshore industry
- Standards, guidelines, and rules for the inspection and maintenance of FRP structures.

Due to the lack of certification standards with relevant information in the field FRP-based REOPs, it was necessary to include standards, guidelines, and rules that belong to other engineering fields (e.g., shipping industry) in order to widen the action framework in the literature review.

As mentioned in section above, this deliverable is exclusively focused on the **structural performance** of REOPs designed with lightweight FRP materials. Other relevant impacts of the application of FRP materials in REOPs (e.g., stability, seakeeping, noise damping, etc.) are briefly mentioned. These other impacts might be expected to be considered in future projects or specific works on the matter.

3.4. Aspects to consider in the design of an offshore platform, problems and solutions

Given the shortage of regulations regarding offshore platforms in composite materials, it is necessary to know how the different institutions, in other areas, deal with these materials. Typically, the most important aspects to consider in the design of an offshore platform structure are related to its location, the environmental conditions and the loads that the structure will withstand.

As is well known, offshore platforms can be mainly classified into two categories:

- Fixed platforms (e.g., jackets, monopiles, tripiles, GBF, tripod, etc.) with foundations grounded to the seabed.
- Floating platforms moored to the seabed, which can be divided into other categories according to the mooring system and geometry, such as a TLP, semisub, SPAR or barge.

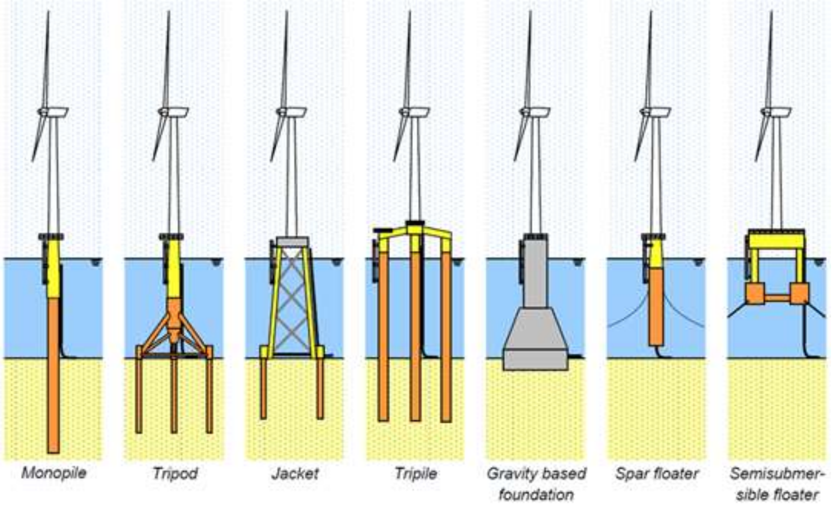


Figure 1 – Offshore wind foundation types (11)

Metocean conditions, such as wind, waves, tides and sea currents in the platform location as well as the depth, distance to shore, seismicity and ground conditions among many others are considered in the design of these offshore platforms.

Regarding *loads* to be withstood by the structure, these ones are dependant of metocean conditions and other characteristics of the site as well as the structure geometry, mass properties and mooring system. Equipment, fixed ballast and other onboard weights (such as ladders, cranes, etc.) contribute to the *permanent loads* on the structure, as well as all the possible non-permanent loads due to variable weights such as ballast tanks or technical personnel embarkation are considered as *variable functional loads*. With respect to *environmental loads*, metocean conditions effects are mandatory along with other ones such as earthquakes. *Accidental loads* are all those resulting from random events such as collision impacts, unforeseen weight changes, mooring failures, etc. In addition, temperature changes, construction deformations and creep loads are some of the loads considered as *deformation loads*. Last, but not least important, it is also important to mention the *pressure loads* caused by internal and external hydrostatic and hydrodynamic loads impacting on the structure.

These inputs are taken into account in both the study of the structure and selection of materials. The current regulations specify the different analyses to be carried out to prove the structural capacity of the structure. For example, Ultimate Limit State (ULS) evaluates the behaviour of the FOWT structure through its failure by collapse, which can arise due to buckling, plasticisation, joint collapse, etc. In parallel, Fatigue Limit State (FLS) assess failures due to fatigue, while Accidental Limit State (ALS) is about failures caused by accidents and Service Limit State (SLS) evaluates failures of the FOWT in normal operation during its service.

This brief introduction attempts to provide guidance on the assessment needs to be covered for the evaluation of composite materials as a primary building material. For reference purposes, the standards specify safety values for stresses and safety values for the construction material, according to the nature of the failure and the platform type in question.

In summary, the aim is to evaluate the standards that work with composite materials in order to obtain information about limit stress values and safety coefficients, among other criteria of interest. Through the comparison with the existing regulations, it will be possible to enable the potential implementation of some basic rules and criteria for the development REOPs design in composite materials.

4. REGULATORY FRAMEWORK FOR MARINE RENEWABLE ENERGY PLATFORMS

4.1. General overview

The main classification societies and international regulatory bodies that include standards in their portfolio related to the field of offshore platforms, marine turbines and composites are given in **Table 1**.

Classif. Society Acronym	Classif. Society full name	Website	Country
ABS	American Bureau of Shipping	https://ww2.eagle.org/en.html	USA
API	American Petroleum Institute	https://www.api.org/	USA
BV	Bureau Veritas	http://erules.veristar.com/dy/app/bootstrap.html	France
CCS	China Classification Society	https://www.ccs.org.cn/ccswzen/	China
ClassNK	Nippon Kaiji Kyokai	https://www.classnk.or.jp/hp/en/index.html	Japan
DNVGL	Det Norske Veritas Germanischer Lloyd	https://meet.dnvgl.com/sites/rulesandstandards/SitePages/Home.aspx	Norway
LR	Lloyd’s Register	https://www.lr.org/en-za/rules-regulations/	UK
RINA	Registro Italiano Navale	https://www.rina.org/en/rules	Italy
RS	Russian Maritime Register of Shipping	https://rs-class.org/en/	Russia

Table 1 – Principal classification societies with Offshore Platform Standards

The criteria for the selection of the classif. societies and regulatory institutions analysed in the context of this study was mentioned in **Section 3.1**. **Table 2** reveals the rating given to each of the quality indicators (e.g., volume regulations, international reputation, etc.) from the certification organizations, where a score of 1 represents the lowest impact and 5 stands for the highest impact.

Classification Society	Volume of regulations	International reputation	World-wide registered fleet	Experience with FRP materials	Offshore and Oil&Gas Impact	Growth of the regulatory entity
ABS	5	5	4	4	4	2
API	3	5	1	3	5	2
BV	5	5	5	5	4	2
CCS	2	2	2	1	2	5
ClassNK	4	4	3	3	3	3
DNV.GL	5	5	5	5	5	2
LR	5	5	5	4	4	2
RINA	4	4	4	5	3	3
RS	2	2	2	3	2	4

Table 2 – Evaluation of the impact from the different classification societies on offshore platform standardization

Apart from the classification societies, there are international organizations covering all aspects related to safety, including structural integrity. The main international bodies dealing with composite materials considered in the present study are shown in **Table 3**:

Entity	Name	Website	Country
IEC	International Electrotechnical Commission	https://www.iec.ch/homepage	International
IMO	International Maritime Organization	https://www.imo.org/en	International
	International Convention for the Safety of Life at Sea (SOLAS)	https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-(SOLAS),-1974.aspx	
ISO	International Organization for Standardization	https://www.iso.org/	International

Table 3 – International Regulatory Entities Dealing with Offshore Platform Standards

4.2. Overview of standards and regulations related to marine renewable energy structures.

Each classification society arranges the information in the most consistent way possible to cover all the necessary requirements for the certification of the material and structures to be designed with it. The following breakdown points are adopted for the regulatory review of offshore wind platforms in this task.

- Certification Procedure – methodology, certification requirements
- Materials - Manufacture, Inspection, Certification and Testing Procedures
- Stability, Weight Control, Watertightness and Weathertightness
- Structural Design Requirements - Structural principles, Scantling, Elements Structural Design, Joints and Connections
- Design Conditions and Load Cases - Loading conditions, Load cases, Limit States (ULS, FLS, ALS, SLS), Safety factors, Material factors.
- Equipment, Mooring, Risers and Tendon Legs System (TLS) – Loads, tensions, components, etc.
- Hull Scantlings - Basic allowable stress factor, Global Finite Element Model, Calculation Method (WSD - LRFD method)
- Safety
- Inspection, Life Cycle considerations

In the specific case of tidal turbines, the thematic areas of the classification society agencies are focused on the following thematic areas.

- Certification Procedure – methodology, certification requirements
- Materials - Manufacture, Inspection, Certification and Testing Procedures
- Support Structure and Turbine
- Structural Design Requirements - Structural principles, Scantling, Elements Structural Design, Joints and Connections
- Load Cases - Loading conditions, Load cases (ex. Loads induced by the fluid flow), Safety factors, Material factors.
- Turbine elements Scantling
- Inspection, Life Cycle considerations

- Electrical Installations (New procedure with, Certification Procedure, Design Conditions and Load Cases, Materials and Life Cycle Considerations)

Due to the large number of rules included in this critical review of applicable standards and identified gaps, it has been included a set of Tables in **Annex** of this deliverable, with the main rules, guidelines and notations emitted by the different classification societies and international regulatory bodies of the marine sector.

4.3. Overview of standards and regulations related to the use of materials in marine structures

The selection of the optimum conventional (e.g., steel, concrete) and unconventional materials (e.g., FRP) plays a key role on the existing manufacturing standards that specifies their characteristics, properties and compliance requirements. Therefore, the specifications include a set of protocols and design procedures to manufacture specimens at a coupon level with the purpose to obtain the mechanicals and environmental performance of the materials selected. Besides that, it is also included a large number of manufacturing recommendations and guidelines for the alloys commonly used by the shipbuilding industry. It is important to make sure that the properties and integrity of the materials are maintained throughout the manufacturing process, construction, and life cycle of the REOPs. Below, it can be found the most relevant materials standards issued by the most important regulatory organizations of the maritime and shipbuilding sectors.

Classification Society	Code	Name of the rule	Year
ABS	-	Materials and Welding	2021
BV	NR216	Rules on materials and welding for the classification of marine units	2021
CCS	-	Rules for Materials and Welding	2018
ClassNK	RU Part K	Materials	2020
DNVGL	RU-SHIP	Rules for Classification Ships_Pt2_Materials and welding	
LR	-	Rules for the Manufacture Testing and Certification of Materials	2020
RINA	NCC	Certification of Marine Materials	-
RINA	NCC24	Rules for the Type Approval of Components of Composite Materials Intended for Hull Construction	2020
RINA	RES6	Rules for Pleasure Yachts_Part D-Materials and Welding	2021
RS	-	Rules for the Classification and Construction of Sea-Going Ships_Part XIII - Materials	2021

Table 4 – Rules for Materials and Welding of marine structures

The most common materials used for the marine industry in the construction of regular ships and offshore structures are steel and their respective alloys. In parallel, the aluminium is the material most frequently applied for the construction of lightweight vessel structures, such as small yachts or vessel superstructures. Historically, the wood has been used widely in shipbuilding of ships and it is currently used for some recreational and small boats. Last, but not least important, FRP materials are also commonly used for the construction of small length ships, superstructures, and non-structural secondary applications.

Below, it is carried out a critical comparison of the mechanical and electrical behaviour of FRP, steel and aluminium materials commonly used in shipbuilding, with a special emphasis on the corrosion resistance, strength, weight, among other factors (see **Table 5**).

Characteristics	FRP	Steel	Aluminium	Concrete
Corrosion resistance	One of the main advantages of FRP materials is that are not prone to corrosion. However, it should be paid attention to the connections CFRP and metal that are susceptible to galvanic corrosion. Furthermore, it shows a good resistance to a broad range of chemicals, moisture and water immersion.	Steel is affected by oxidation and corrosion. Requires painting or galvanizing for many applications.	Galvanic corrosion can be produced.	Reinforced concrete is water resistant and will not corrode, if properly maintained. If not, the steel reinforcement might corrode compromising the strength of the structure.
Strength	It has greater flexural strength than timber and working longitudinally can be stronger than steel and aluminium.	Homogeneous material. Yield strength	Homogeneous material. Flexural strength	Good Impact Resistance, Excellent Fatigue Life and Cryogenic Behaviour. Resistance to Fatigue, Crack Propagation, and Buckling.
Weight	The consortium of the FIBRESHIP project demonstrated that FRP-based ships are up to 75% and 30 % lighter than identical vessels built in traditional materials as Steel and Aluminium. The specific weight of FRP materials vary in the range of 1.25 - 2.5 g/cm^3 depending on the material type and configuration (12).	One of its most characteristic disadvantages against aluminium and FRP is their weight. The specific weight of steel is in the range of 7.8 - 7.9 g/cm3. It requires special lifting equipment to move and place elements during construction.	Lightweight metal material, reaching a third of the weight of steel. The specific weight of Aluminium is in the range of 2.7 - 2.75 g/cm3	The specific weight of Concrete is in the range of 2.2 – 2.4 g/cm3
Stiffness	The Modulus of elasticity of FRP materials vary from 62 GP to 175 GPa depending on the material type and plies orientation (12). It will not be permanently deformed under working load.	Generally, the modulus of elasticity of steel is 200 GPa..	The modulus of elasticity of Aluminium is about 69-72 GPa depending on the alloy type.	The modulus of elasticity of concrete is in the range of 17-30 GPa.
Electrical conductivity	Non-conductive. High dielectric capability.	Conducts electricity. Grounding potential.	Conducts electricity. Grounding potential.	Dry concrete offers high resistance and therefore, it can be classified as an insulator. Dry concrete has resistivity in the range of 1012 ohm-mm.
Impact resistance	It will not be permanently deformed after impacts, but internal delamination might occur. Glass mat in pultruded parts distributes impact load to prevent surface damage, even in sub-zero temperatures.	It can be permanently deformed after impacts.	It is easily deformed after impacts.	Concrete structures are sensitive to dynamic or impact loads. These structures are sensitive to brittle, shear or punching shear failure.
Manufacturing	As compared to metallic materials, it does not require hot work and can be easily transported and installed due to the lighter weight.	It requires welding and cutting equipment. Heavier material requires special equipment to lift and install structural elements.	Good mechanical processability (welding, brazing, soldering or mechanical joining).	Good separation of Processing/Storage
Cost	FRP is more expensive than traditional materials. However, it requires less maintenance and have longer cycle life.	Lower initial cost.	Aluminium is cheaper than FRP and steel.	Concrete is a cost-efficient alternative to structural steel, with reduced Maintenance costs. The labour and materials costs are important.

Table 5 – Rules for Materials and Welding

To be more specific,

Characteristics comparison of the most used metals and Composite materials							
Material	**Density** *[g/cm3]*	**Tensile Yield Point** *(MPa)*	**Specific yield point** *(MPa/kg)*	**Tensile Young's Modulus** *(GPa)*	**Melting Point** *(°C)*	**Thermal Cond.** *(W/m.K)*	**Linear expansion Coef.** *(x10-6/°C)*
Steel	7.85	200/1300	25/165	210	1425	26/46	10/18
Aluminium	2.70	100/400	37/148	70	500/660	170/237	27
FRP	1.6/2.1	100/1400	62/666	12/40	N/A	0.5	5/10
Concrete	2.2/2.4	2/5 (traction)	1/2 (traction)	14/50	1500	2.25	13/14

Table 6 lists the mechanical properties of the three most common materials used in the construction of ships and FOWT. In comparison conventional materials (e.g., steel, and aluminium), the FRP materials show superior high strength and stiffness to weight ratio and absence of corrosion.

Characteristics comparison of the most used metals and Composite materials							
Material	**Density** *[g/cm3]*	**Tensile Yield Point** *(MPa)*	**Specific yield point** *(MPa/kg)*	**Tensile Young's Modulus** *(GPa)*	**Melting Point** *(°C)*	**Thermal Cond.** *(W/m.K)*	**Linear expansion Coef.** *(x10-6/°C)*
Steel	7.85	200/1300	25/165	210	1425	26/46	10/18
Aluminium	2.70	100/400	37/148	70	500/660	170/237	27
FRP	1.6/2.1	100/1400	62/666	12/40	N/A	0.5	5/10
Concrete	2.2/2.4	2/5 (traction)	1/2 (traction)	14/50	1500	2.25	13/14

Table 6 – Characteristics comparison of the most used metals and Composite materials

The classification societies apply different certification schemes to assess the materials used for the construction of FRP structures, including:

- Laboratory tests to be carried out to obtain the material properties.
- The materials applied for the structural design.
- The characteristics required for the structural design.
- The methods used for the manufacturing of the materials.
- The inspection and maintenance procedures of the structures in operation.

4.3.1. Safety Factors

In addition to standards focused on the testing, design and inspection of materials, there are also structural design standards, in this case for offshore platforms and marine turbines, which contain specific analyses regarding the behaviour of materials under specific load and stress conditions. One of the most important areas to be covered by the above-mentioned standards is the safety factors.

Safety factors are used to increase the loads to be taken by the structures, to cover potential design defects, material degradation and to consider any punctual condition that may exceed the initial estimated loads. Furthermore, the uncertainties in the strength and stiffness of a material that could work in a plastic regime are covered by the inclusion of a material factor. In the *Load and Resistance Factor Design* (LRFD) study methodology, it takes into account the collapse of the structure, where the plasticisation of the materials leads to the consequent loss of stiffness of the structure. The safety factor is applied to avoid that the material enters the plastic deformation regime (non-linear analysis). A safety factor is applied to the Elastic Limit, material factor, which makes it possible to consider that once this elastic reserve is exceeded the material will collapse. Below, two examples of material factor and one of load factor are presented in **Figure 2** and **Figure 3**.

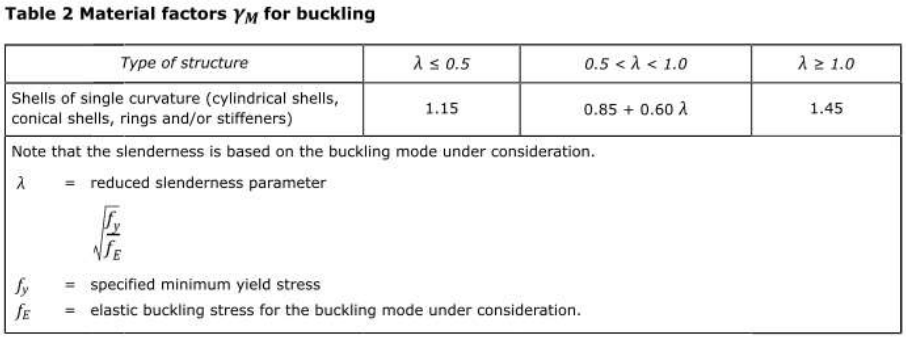


Table 2 Material factors γ_M for buckling

Type of structure	$\lambda \leq 0.5$	$0.5 < \lambda < 1.0$	$\lambda \geq 1.0$
Shells of single curvature (cylindrical shells, conical shells, rings and/or stiffeners)	1.15	$0.85 + 0.60\,\lambda$	1.45

Note that the slenderness is based on the buckling mode under consideration.

λ = reduced slenderness parameter

$$\sqrt{\frac{f_y}{f_E}}$$

f_y = specified minimum yield stress

f_E = elastic buckling stress for the buckling mode under consideration.

Figure 2 – Table with material factors for buckling from DNVGL_OS-C101_Design of offshore steel structures, general - LRFD method.

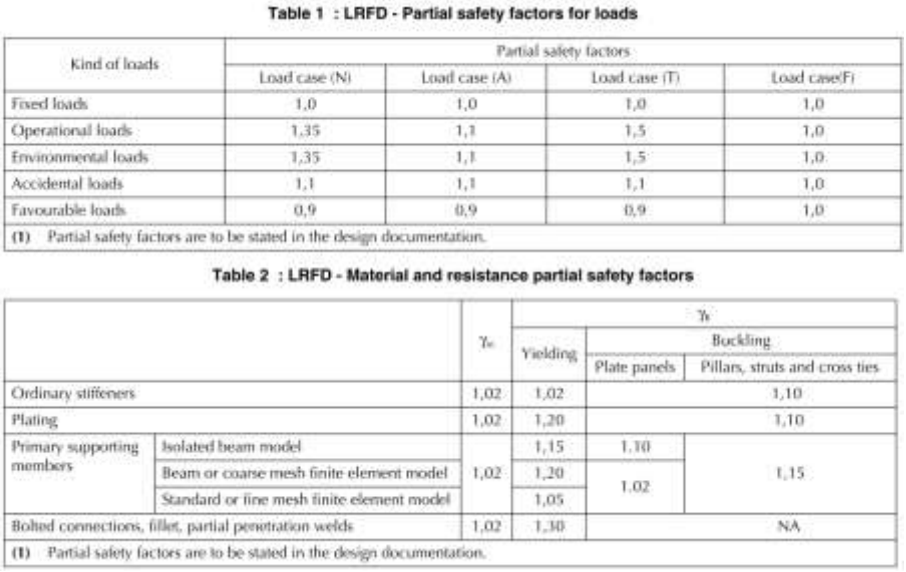


Table 1 : LRFD - Partial safety factors for loads

Kind of loads	Partial safety factors			
	Load case (N)	Load case (A)	Load case (T)	Load case(F)
Fixed loads	1,0	1,0	1,0	1,0
Operational loads	1,35	1,1	1,5	1,0
Environmental loads	1,35	1,1	1,5	1,0
Accidental loads	1,1	1,1	1,1	1,0
Favourable loads	0,9	0,9	0,9	1,0
(1) Partial safety factors are to be stated in the design documentation.				

Table 2 : LRFD - Material and resistance partial safety factors

		γ_m	γ_R		
			Yielding	Buckling	
				Plate panels	Pillars, struts and cross ties
Ordinary stiffeners		1,02	1,02	1,10	
Plating		1,02	1,20	1,10	
Primary supporting members	Isolated beam model	1,02	1,15	1,10	1,15
	Beam or coarse mesh finite element model		1,20	1,02	
	Standard or fine mesh finite element model		1,05		
Bolted connections, fillet, partial penetration welds		1,02	1,30	NA	
(1) Partial safety factors are to be stated in the design documentation.					

Figure 3 – Table 1 with LRFD-partial safety factors from loads and LRFD-Material and Table 2 resistance partial safety factors from “BV_NI572 - Classification and Certification of Floating Offshore Wind Turbines”.

5. BUILDING STRATEGIES & TECHNIQUES FOR MARINE TURBINES AND OFFSHORE PLATFORMS WITH FRP MATERIALS

Composite materials based on FRP are a great alternative to traditional materials, which have been recurrent in other industries and have multiple particular uses. This is why many technological innovations are being developed in this area. Fibre Reinforced Polymers (FRP) has been used for the last 30 years in civil, aeronautic and marine applications, in the latter case, mostly in small leisure vessels and oil & gas sector.

FRP materials can be manufactured by means of lamination with multiple configurations. The most popular configurations are based on (i) *monolithic laminates*, where the plies of the composite are overlapped at different angles; and (ii) *sandwich laminates*, where a light core element is inserted in the intermediate regions between two composite laminates, playing a dual role increasing the inertia momentum and the stiffness of the material element.

The matrix of the composite laminate is composed by a resin with the function to transmit the stresses among the distinct layers of the laminate. The main characteristics of a resin are toughness, strength and ductility. The mission of the fibres is to withstand the forces and stresses applied to the composite material. The main characteristics of the fibres are hardness, stiffness, and lightness. Currently, the incorporation of dopant elements (e.g., nanofibres) is increasing attention among the composite's community as a practical approach to develop composites with enhanced mechanical performance (13).

From the design point of view, the most important characteristic of a FRP laminar material is the orientation of the fibres, which has the most remarkable properties in the longitudinal direction. The typology of fibres more commonly used in the marine sector are defined below:

- Unidirectional fibres: unidirectional elements that can be used directionally or superimposed at different angles;
- MAT: fibres without any specific direction;
- Roving: a woven that presents a perpendicular intercrossing of fibres.

Unlike monolithic laminates, sandwich structures are very sensitive to impact loads, which can cause damages in the sandwich core and local subsidence, affecting the mechanical performance of the structures. On the other hand, it is known that the lightweight sandwich materials have a large number of benefits as higher bending stiffness, higher local strength and lower risk to buckling.

5.1. FRP material assessment

The materials to be used in the development of FOWT and tidal turbines needs to be tested and certified to perform their functions in the aggressive sea environment. To acquire the certification of the classification society, it is required to carry out tests at lab scale with coupon level samples, as well as tests in the shipyards with large- and full-scale demonstrators. The approval of the materials is carried out by following the guidelines and recommendations of the classification societies (e.g., BV, DNV, LR, etc.) as well as from the standards generated by the international regulatory bodies (e.g., ISO, IEC, among others).

For the particular case of FRP materials, the individual components of this laminar material (e.g., fibre and resin) need to get the approval from the classification society. Looking at the existing fibres (e.g., glass fibre, carbon fibre, aramid fibre, boron fibre, etc.), it is required to evaluate the mechanical parameters from the different failure modes in the FRP laminar configurations applied to a specific geometry of the structure. In fact, the properties of the fibres need to be evaluated in both dry and wet conditions following the guidelines stated in the standard procedures. In general, the parameters of interest are known as the linear density, average diameter, tensile strength, Young Modulus, and many others. Similarly, the resin component (also known as matrix) of the composite material needs to be analysed in two different conditions: liquid and cured state. In the first case scenario “liquid state”, the parameters commonly evaluated are the viscosity, density, and gel time of the resin, among other factors. In the second case scenario “cured state”, the most relevant tests to assess the properties of the resin in the cured state are the volumetric variation as a function of the temperature, water absorption, ultimate bending strength, etc.

Last, the FRP laminar materials in their final state (as a combination of two or more constituent materials “fibres” and “matrix”) also needs the corresponding approval from the classification society. For this particular case, experimental testing campaigns carried out by classification societies technicians are usually focus on the percentage of fibre/resin, density, water absorption, shear resistance, heat behaviour, weight per unit of surface area, as well as traction and compression tests in multiple composite directions, among a wide variety of tests.

Last, but not least important, it is essential to point out that the certification level to be obtained depends on the structural function and material typology. In this regard, designers and structure manufacturers have a wide range of sandwich and monolithic panels configurations of composite laminar materials based on FRP to overcome the classification societies’ requirements and ensure the structural safety of the marine renewable energy platform.

5.2. Regulatory Framework for Structural applications of FRP in the marine sector

The existing Classification Societies' regulations dedicated to the design and construction of FRP ships have the potential to be used as a starting point for the development of a new series of regulations focused on the design of marine renewable energy structures based on FRP. At least, this is the main idea of the authors.

5.2.1. Regulations for vessels designed in FRP

The current regulatory framework applied to the marine sector have been developed as a compendium of prescriptive rules, codes and standards and conservative principles, which are often based on conventional materials such as steel or aluminium. The primary objective of the classification society standards is to verify the strength, structural integrity and reliability of the ships, as well as the critical points of naval platforms.

Classification Societies	Code	Rule	Year
ABS	HSC	High Speed Naval Craft	2020
ABS	NVR	Combatant high-speed craft called Naval Vessel Rules	1994
BV	NR396	Rules for the Classification of High-Speed Craft	2002

Classification Societies	Code	Rule	Year
BV	NR500	Rules for the classification and the certification of yachts	2016
BV	NR600	Hull structure and arrangement for the classification of cargo ships less than 65m and non-cargo ships less than 90m	2018
ClassNK	RU_HSC	Rules for High Speed Craft (2020) - Part 3_Ch 5_Moulding of FRP for Hull Structure - Part 6_Ch 2_Hull Construction for FRP Craft	2020
ClassNK	-	Rules for the Survey and Construction of Ships of Fibreglass Reinforced Plastics	2019
ClassNK	-	Rules for the Survey and Construction of Governmental and Naval Ships	2020
DNVGL	OS-C501	Composite Components	2013
DNVGL	RU-HSLC	Pt3 Ch4_Hull structural design, fibre composite and sandwich constructions	2020
DNVGL	RU-YACHT	Yachts - Pt3-Hull_Ch5-Composite scantlings	2018
DNVGL	ST-0490	TP52 Racing yachts	-
LR	-	Guidance note for the Classification of Special Service Craft. Calculation Procedures for Composite Construction	2013
LR	-	Guidance Notes for the Classification of Special Service Craft. Version 1.0 Design Details	2013
LR	-	Rule and Regulations for the Classification of Special Service Craft. Part 8 Hull Construction in Composites	-
LR	-	Rules and regulation for the classification of ships	-
RINA	-	Rules for the Classification of Charter Yachts	2007
RINA	RES22	Rules for the Classification of Ships with Reinforced Plastic, Aluminum Alloy or Wooden Hulls	2008
RINA	RES6	Rules for Pleasure Yachts	2021
RINA	RU-FPV	RU Fast Patrol Vessels_Part B_Ch 4_Sec 1 - 4 Composite Structure	2007
RS	-	Rules for the Classification and Construction of Sea-Going Ships_Part XVI_Hull Structure and Strength of Glass-Reinforced Plastic Ships and Boats	2021
IMO	HSC code	Code of Safety for High Speed Craft	2008
USCG IMO	USCG	PFM 1-98 Policy File Memorandum on the Fire Performance Requirements for Plastic Pipe per IMO Resolution A.753(18)	
USCG IMO	USCG	PFM 2-98 Policy File Memorandum on the Use of Fiber Reinforced Plastic (FRP) Gratings and Cable Trays	

Table 7 –Standards used for the design and construction of FRP vessel structures

In the framework of these standards, the design and construction of ships with lightweight FRP materials is considered addressing the following points:

- Certification Procedure – methodology, certification requirements
- Materials - Manufacture, Inspection, Certification and Testing Procedures
- Stability, Weight Control, Watertightness and Weathertightness
- Structural Design Requirements - Structural principles, Scantling, Elements Structural Design, Joints and Connections
- Design Conditions and Load Cases - Loading conditions, Load cases, Safety factors, Material factors.

- Hull Scantlings - Basic allowable stress factor, Global Finite Element Model, Calculation Method
- Final testing and construction inspection
- Service Inspection, Life Cycle considerations

5.2.1.1. Structural Design

For a simplified structural FRP design (without combinations of global and local loads), the rules proposed by the classification societies are based on a simplification of the material behaviour. Subsequently, the laminar material is analysed with loads in the main working direction, and afterwards it is analysed the other directions, where the material is working in shear conditions.

For the above-mentioned purpose, an orthotropic material is considered as a first step. In other terms, the mechanical properties for the different orientations are the same as the laminate, but the existence of interlaminar failures are not included into the analysis. The main outcome of the first step is to obtain the preliminary dimensions of the scantlings of the FRP structure. Subsequently, with the other two approaches, the interlaminar failures due to the tensile and compressive stresses of each layer are taken into account for the different FRP orientations.

As commented in the safety factors section, it is important to make sure that the scantlings are able to withstand the loading stresses. For this purpose, safety factors are introduced with a theoretical value of failure, expressed as a function of the elastic limit (stress/strain). As a general rule, this value needs to be higher than the actual stress/strain values determined through the structural calculations.

In general, the safety factors recommended by the classification societies for FRP structures vary in the range from 3 to 3.6, as can be deducted from the current regulations applied to small-length FRP vessels.

It is important to mention that various sections of the design rules are referred to the strength and watertightness of the hull and tanks, as well as their watertightness limits, which are both of primary importance for the development of new standards for the design of FRP marine renewable energy platforms. For instance, FOWT structures are composed of watertight structural elements, providing strength as main structure and buoyancy as floaters of the platform.

5.2.1.2. Material testing, Manufacturing and inspection

After the design process, the following step is the construction stage of the FRP structure. In order to fulfil the design requirements, it is strictly necessary that the materials used for the construction of the FRP structures present the same characteristics specified in the design process. To achieve this goal, it is required to test the pristine samples of the materials required for the design and construction of the FOWT platform.

After the manufacture of the laminate elements by the shipyard, a series of FRP samples manufactured with the same typology and lamination techniques should be tested. The selected samples will be subjected to mechanical and physical-chemical tests in order to characterise and confirm that they have the same mechanical characteristics as the theoretical laminates.

According to ISO and equivalent standards, the main mechanical tests required by the Classification Society are the following ones:

- Tensile Tests

- Bending Tests
- Shear tests for sandwich materials
- Interlaminar shear tests
- Measurement of the density and fibre content

After the construction stage, the structure needs to be analysed again using non-destructive testing, such as visual inspections, ultrasounds and radiographs.

The construction of marine renewable energy structures needs to be carried out following a quality system approved and certified by the regulatory body in charge of the structure. The mission of the regulatory body is to inspect and confirm that everything is carried out following the instructions and requirements specified in the regulations.

With respect to the transportation, manufacturing, and regular inspections, the building of an offshore platform does not significantly differ from the construction of others engineering civil structures. As a result, the information included in the quality systems of ships built with FRP materials can be used for the design of offshore platforms with FRP materials. The innovations in the field of materials, processing, connections, among other should be included in the framework of the recommendations.

5.2.2. Standards with FRP data potentially applicable to marine renewable energy platforms

Another offshore field where the FRP materials are widely used is the Oil & Gas industry. In this continuously developing area, composites directional drilling systems and production risers are tested for offshore platforms. The applications for FRP materials in this industry that has been used for a long time are the oil gathering and transmission pipelines, as well as the standards that cover the use of low- and high-pressure fibreglass pipes and downhole pipelines as mentioned by the API regulatory body.

Another of the greatest advantages derived from the application of FRP materials in oil & gas assets is their high resistance to corrosion phenomenon. This is one of the main reasons to promote the extensive use of FRP materials for the design of marine renewable energy platforms. Currently, FRP materials are mainly used in secondary structures such as handrails, gratings, gangways, cable trays, water cooling and non-hazardous sewage lines, which are structurally non-critical systems.

Below, it can be appreciated the different areas in which composites have been incorporated as a primary construction material in marine structures:

1. Composite Grids and Hand rails.
2. Piping System, Low-pressure composite valves, Fire water pump casing and sea water lift pump casing.
3. High pressure accumulator bottles.
4. Blast and Fire Protection, Modular panelling for partition walls and Water and fuel storage tanks.
5. Boxes, housings and shelters.
6. Spoolable type thermosetting tubes, Sump Caissons and pull tubes.
7. Cable support systems.
8. Non-structural platforms on deck manufactured with pultruded structural profiles.

9. Flexible and Floating Risers, Drill pipe.
10. Tendons and Offshore bride connecting between platforms.
11. Sub-sea structural components.

Besides oil & gas industry, composite materials based on fibre are also used in other industries as structural reinforcement for cemented structures such as concrete. This can be explained because these structures are susceptible to shear-stresses problems under compression loads. A coating manufactured using composite materials, with its fibres arranged horizontally to work in traction, would assume the expansion in the horizontal plane of these structures. **Table 8** introduces the regulatory framework applicable to offshore platform elements susceptible to be designed in FRP. Further information and details regarding the areas of each standard that contain data about composite materials can be found in the appendix section.

Classification Society	Code	Rule	Year
ABS	ORC	Offshore-Racing Council	1994
	Facilities	Facilities on Offshore Installations_Appendix 3 Fiber Reinforced Plastic (FRP) Gratings	2014
BV	NI432	Certification of Fibre Ropes for Deepwater Offshore Services	-
	NI603	Rules for current and tidal turbines (with notions on fatigue of composites)	2015
	NI613	Adhesive Joints and Patch Repair	2015
CCS	-	-	-
ClassNK	RU_Part C	Hull Construction and Equipment_Annex C1.1.7-5	2020
	-	Guidance for the Approval and Type Approval of Materials and Equipment for Marine Use	-
DNVGL	IV-Part 6	Rules for Classification and Construction Industrial Services	
	OS-C201	Structural design of offshore units - WSD method	
	OS-C501	Composite Components	2013
	RP-F202	Composite Risers	2003
	OS-C502	Offshore Concrete Structures_Appendix E - E.2 FRP reinforced structures	2018
	ST-0376	Rotor blades for wind structure	-
	DS-J102	Design & Manufacture Wind turbine blades	-
	CP-0086	Adhesive systems	-
	RP-C301	Design, fabrication, operation and qualification of bonded repair of steel structures	2015
	CG-0154	Steel sandwich panel construction	2016
LR	-	Rules and Regulations for the Classification of Offshore Units_API RP 15CLT_BS 5400 1984	2020
	-	Rules for the Application of Sandwich Panel Construction to Ship Structure (Steel Sandwich Panel)	2020
RINA	RU-WB	Rules for the Classification of Workboats	2020
	RU-FPV	RU Fast Patrol Vessels	2007

Classification Society	Code	Rule	Year
	-	Rules for the Classification of Ships with Reinforced Plastic, Aluminium Alloy or Wooden Hulls	2008
	RU-CS	Rules for the Classification of Ships	2012
	RINAMIL	RINAMIL- Part D	2017
RS	-	Rules for the Classification and Construction of Subsea Pipelines	2021
	MODU-FOP	Rules for the Classification, Construction and Equipment of Mobile Offshore Drilling Units and Fixed Offshore Platforms	2021

Table 8 – Standards of Offshore Platform Elements Susceptible to Be Designed in Composite Materials

The information included in the standards given in the above table is relevant from the engineering point of view. In particular, some of these standards are focused on the different types of failure of the FRP laminates, which are different from metal failure modes. On one side, some standards are devoted to the analysis of catastrophic failures and progressive failures in FRP laminar materials. On the other side, other standards are more focused on the analysis of ductile and brittle failures, which presents different amounts of plastic deformation leading up to the final failure. As a general conclusion, it should be highlighted that the safety factor selected for the FOWT design is dependent on the failure modes of the materials. The safety factors recommended for the 'ductile' failures can be found on the DNV standard "RP-F202 Composite Risers", while the safety factors for the other failure modes should be referred in the report "OS-F201 Dynamic Riser". If we look at the design of risers with FRP materials, the standard "RP-F202 Composite Risers" recommends to refer to follow the guidelines indicated in the standard "OS-C501 Composite Components" elaborated by the classification society DNV.

As an example, **Figure 4** shows a flowchart of the steps recommended by ABS for the design of FRP pipes that should be followed by the designers to develop a product with high quality standards for the target application.

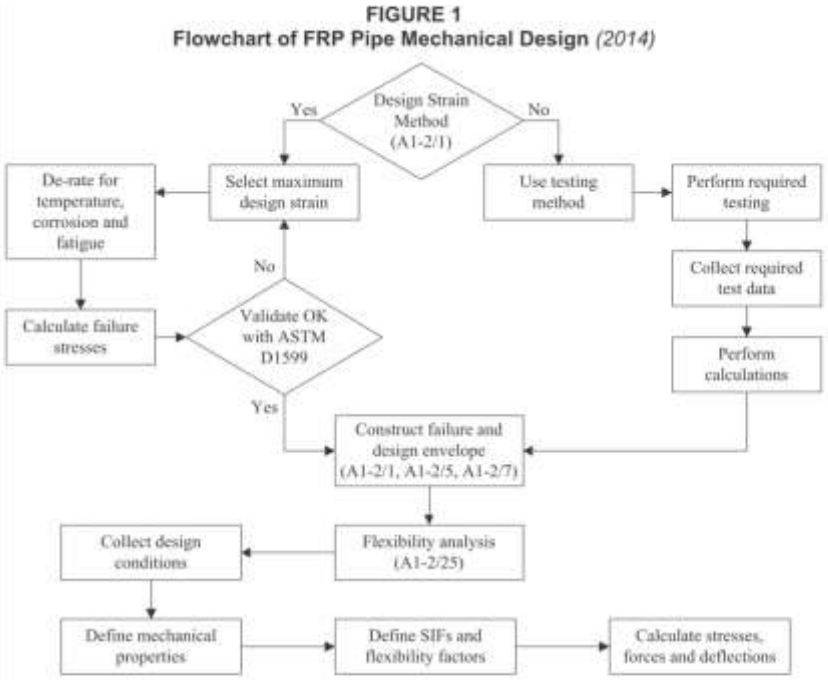


Figure 4 – Flowchart of FRP Pipe Mechanical Design from ABS - Facilities on Offshore Installations

As mentioned in the document of action of FIBREGY, the marine community needs to develop a process for the design of offshore wind and marine turbine platforms with FRP materials. To address this task, from the point of view of the authors, the concepts defined in the section 4.2 should be included in the context of the new standard, as defined below:

- Certification Procedure – methodology, certification requirements
- Materials - Manufacture, Inspection, Certification and Testing Procedures
- Stability, Weight Control, Watertightness and Weathertightness
- Structural Design Requirements - Structural principles, Scantling, Elements Structural Design, Joints and Connections
- Design Conditions and Load Cases - Loading conditions, Load cases, Limit States (ULS, FLS, ALS, SLS), Safety factors, Material factors.
- Equipment, Mooring, Risers and Tendon Legs System (TLS) – Loads, tensions, components, etc.
- Hull Scantlings - Basic allowable stress factor, Global Finite Element Model, Calculation Method (WSD - LRFD method)
- Safety
- Inspection, Life Cycle considerations

Apart from that, the standards should add relevant information about the material mode failures, safety factors, manufacturing process, inspection and maintenance, among other topics.

Even though it is not addressed in this deliverable, the effect of FRP materials on the stability of floating platforms needs to be properly addressed by the regulatory entities to ensure the integrity of the FOWT. This is attributed to the drastic weight reduction in FOWTs built with FRP materials that along with the weight of equipment/tanks has a great influence on stability in a floating offshore renewable platform.

5.2.3. Standards for tidal turbines designed in FRP

Table 9 reveals a series of standards to support the design of tidal turbines with lightweight FRP materials issued by the classification societies BV and DNV. The blades of a tidal turbine are designed to withstand the harsh metocean conditions of a marine environment, such as high hydrodynamic forces, corrosion due to salt water and the impact of suspended particles and marine fauna. Although marine turbine rotor tip speeds are relatively low, cavitation erosion has been often observed, being another consideration to keep in mind for tidal turbines.

Classification Society	Code	Rule	Year
BV	NI603	Rules for tidal turbines (with notions on fatigue of composites)	2015
DNVGL	SE-0163	Certification of tidal turbines and arrays	2015
DNVGL	ST-0164	Tidal turbines	2015

Table 9 – Standards of Tidal Turbines

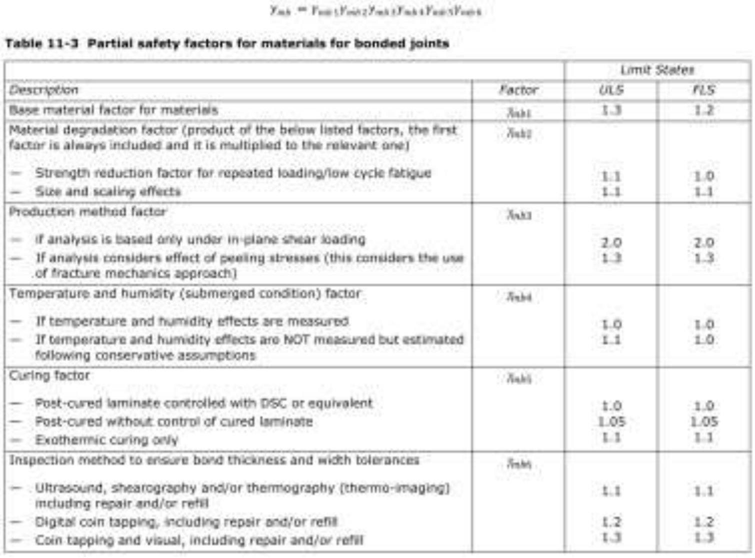
The FRP materials can be easily damaged during the manufacturing process (e.g., drop tool impact, injection moulding processing faults, incompatible materials blended together, etc.) or during the operation service of the component (e.g., bird strikes, hailstone impacts, matrix and shear cracks, etc.), which results in a reduction in structural integrity. One of the problems with composite materials is that the damage is not always visible from the outside, and therefore it is required sophisticated equipment for the detection of damage defects (e.g., delamination failures). In addition, constant underwater exposure could result in a rise in the internal humidity content of the composite, which also decreases its mechanical properties. Resin-dominated properties, such as interlaminar shear strength, can be reduced by up to 60% (14). Safety factors and design procedures for tidal turbine standards take into account the environmental harshness and material deficiencies of an operating environment similar to the one in a land-based tidal turbine.

In parallel to these standards, it is possible to consider other standards listed in the **Table 10**, concerning composite vessel propeller design. The materials and manufacturing methodologies used in these designs are highly resistant to cavitation, erosion and impact. The adaptation of these cavitation-resistant composite materials can significantly improve the performance and economic viability of land-based tidal turbine.

Classification Society	Code	Rule	Year
BV	NI663	Propeller in Composite Materials	2020
ClassNK	-	Guidelines for Composite Propellers (2016)	2016

Table 10 – Standards and Guidelines of Propellers in Composite Materials

The main topics addressed in the above-mentioned standards are the considered materials, the foundation as the main support structure, the marine turbine and the associated electrical systems. In the case of FRP elements designed with FRP materials (e.g., blades), the material properties (e.g., tensile strength, compressive strength, young modulus, ultimate limit state, shear modulus, among others) need to be determined by experimental lab testing.



$$\gamma_{Mb} = \gamma_{Mb1}\gamma_{Mb2}\gamma_{Mb3}\gamma_{Mb4}\gamma_{Mb5}\gamma_{Mb6}$$

Table 11-3 Partial safety factors for materials for bonded joints

		Limit States	
Description	*Factor*	*ULS*	*FLS*
Base material factor for materials	γ_{Mb1}	1.3	1.2
Material degradation factor (product of the below listed factors, the first factor is always included and it is multiplied to the relevant one)	γ_{Mb2}		
— Strength reduction factor for repeated loading/low cycle fatigue		1.1	1.0
— Size and scaling effects		1.1	1.1
Production method factor	γ_{Mb3}		
— If analysis is based only under in-plane shear loading		2.0	2.0
— If analysis considers effect of peeling stresses (this considers the use of fracture mechanics approach)		1.3	1.3
Temperature and humidity (submerged condition) factor	γ_{Mb4}		
— If temperature and humidity effects are measured		1.0	1.0
— If temperature and humidity effects are NOT measured but estimated following conservative assumptions		1.1	1.0
Curing factor	γ_{Mb5}		
— Post-cured laminate controlled with DSC or equivalent		1.0	1.0
— Post-cured without control of cured laminate		1.05	1.05
— Exothermic curing only		1.1	1.1
Inspection method to ensure bond thickness and width tolerances	γ_{Mb6}		
— Ultrasound, shearography and/or thermography (thermo-imaging) including repair and/or refill		1.1	1.1
— Digital coin tapping, including repair and/or refill		1.2	1.2
— Coin tapping and visual, including repair and/or refill		1.3	1.3

Figure 5 – Table 11-3 Partial safety factors for materials for bonded joints from DNVGL - ST-0164_Tidal turbines

It can be noticed that the considered material and load safety factors have been highlighted of critical importance throughout the document. In the case of FRP materials, the latter factor is considered as the most critical factor due to the multiple conditions affecting the material type. Standards provided in abovementioned **Table 9** give values for materials and their joints. **Figure 5** shows an example of the safety factors associated to ULS considered by DNV for tidal turbines. This figure provides safety values for the blade bonded joints of a tidal turbine, which could be directly applied in the joints design of shore-based tidal turbine casing.

5.2.4. Structural Repairs Standards with FRP

There are several options to repair structures built with metallic materials. Traditionally, the hot welding method has been used in this sort of repairs. At present, one of the increasingly popular techniques for repairing metal structures is through the application of composite/steel patches bonded to the damaged steel structure.

In addition, for the hypothetical case in which a structure needs to be reinforced (e.g., due to a design modification or increment of the tensional state), it is possible to increase the structural strength through the use of composite patches. The application of FRP patches as structural repair for marine structures presents the advantages of being a simple and rapid solutions with minimum downtimes. The only drawback to using this engineering solution based on FRP patches is the increment of the weight and thickness of the marine structure. Below, it is described the reasons why FRP patches can be used as a structural repair for marine structures:

1. Minimum requirement for support from platform services.
2. Minimum impact on platform operations.
3. Minimum impact on existing structure.
4. Minimum offshore operation.
5. Minimum through life maintenance requirement.

The qualification steps for the implementation of bond repairs in marine structures addressed several aspects: application of the bonded repair, extension of the asset life, loads, environment conditions, conductivity, and other considerations regarding the failure and reparation modes. The bond repair standards recommend to assess the criticality of the reparation and the level of safety required for the target application (e.g., high, medium, low and no safety requirement). For this reason, the safety factors are selected as a function of the downtimes and criticality of the structure repaired. A general recommendation issued by the classification societies is to address a structural analysis in linear and non-linear regime, as well as an evaluation of the strength of the bonded repair.

Currently, it has been published regulatory standards, such as the one presented in **Table 11**, which deal with the repair of steel structures with FRP materials. This type of standards required numerical calculations in a non-linear regime in order to verify that the reparation carried out in the steel structure has been performed satisfactorily. Therefore, it is necessary to select the safety factors and design guidelines that can be extrapolated for the design of Floating Offshore Wind Turbine (FOWTs).

Classification Society	Code	Name	Year	Notes
ABS	CRSSP	Composite Repairs of Steel Structures and Piping	2021	
BV	N613		2021	In Progress
BV	NI613	Adhesive Joints and Patch Repair	2015	
DNVGL	RP-C301	Design, fabrication, operation and qualification of bonded repair of steel structures	2015	
DNVGL	CG-0154	Steel sandwich panel construction	2016	Steel Sandwich Panel
LR	-	Rules for the Application of Sandwich Panel Construction to Ship Structure	2020	Steel Sandwich Panel

Table 11 –Standards focused on Repairs of Steel Structures with Composites

FRP patches act as a replacement of the damaged materials, and therefore they need to fulfil with the structural criteria required for the target application. The value of the above-mentioned standards is the feasibility study carried out to demonstrate that FRP materials can be applied as substitutes of metallic patches in a metallic structure. It is required to provide the scantling dimensions, safety factors, applicability, reliability, among other interesting factors that should be addressed in the standards of FOWTs platforms.

The standard “Composite Repairs of Steel Structures and Piping” issued by the classification society ABS defines the design steps to approve a composites repair through material addition in both steel structures and piping. The most relevant part of this standard is that provides interesting information about the loading conditions and material requirements needed in offshore wind and tidal turbine platforms. The ABS regulation evaluates the levels of criticality of the composites repair, the most critical level is the class C that recommends reparations for critical structural elements affected by fatigue, loss of adhesion on the structural joints, among others.

The standard mentioned above recommends a series of materials factors for composite repairs. To assess the capacity of the static adhesion in Class C composite repairs, a material factor of 1.35 and 1.00 for the assessment of the bond repair in the short and long term is required. The fracture and fatigue safety factors recommended by ABS are 1.5 and 15, respectively.

5.3. Shortcomings and opportunities of FRP.

Nowadays, the production capacity in numbers of FRP-based ships and FOWTs does not achieve its full potential due to the high production costs of large structures, the lack of knowledge from the industrial stakeholders for the adoption of composite materials in their designs and production chains, and the lack of investment guarantees by investors that will distrust on one technology not yet standardized and not close from its real readiness to market in a short-term.

In fact, in comparison to steel structures, the costs for the installation and manufacturing of FRP structures are higher. Additionally, the shipyards and majority of professionals of the construction sector are more experienced in the construction of marine structures with conventional materials. These factors, together with the limited budgets for construction projects, influence negatively in the bet of designing FOWT structures with FRP materials despite their well-known potential benefits. In recent years, thanks to the increasingly interest from offshore stakeholders in innovative measures to reduce LCoE, regulations and guidelines issued by the certification bodies and regulatory bodies have been significantly improved, clarifying the specifications related to the design, construction and inspection of offshore structures with FRP materials.

As discussed above, FRP materials does not suffer from corrosion phenomena, and are more resistant material to acid and alkaline chemical attacks. This reduces the need of cathodic protection systems and protective coatings required for the protection of metallic materials, which extends the useful life of the structure due to their protection against the environmental aggressions and anti-corrosion properties. Nowadays, there a large number of European companies working on the continuous improvement of the manufacturing technologies of FRP components such as, Schöck Bauteile GmbH (Germany), Sireg Geotech S.r.l. (Italy), iXblue (France), TUCO (Denmark), among others. The main idea behind this is that the automation of the assembly systems and the implementation of new manufacturing procedures led to a significant reduction of the production lead times and manufacturing costs of the fibre-based assets. Below, a set of innovative manufacturing processes are listed in order to have in mind as long as their industrial development and roll-out in the market is consolidated:

- Curved pultruded profiles
- Automated tape laying (ATL) and automated fibre placement (AFP)
- Hot Stamping
- Modular assembling
- Curved modular panels
- Additive manufacturing (3D printing)

As long as the business plan is sustainable in the marine renewable energy sector, the FRP structures have found their way into diverse industrial applications such as:

- Small-vessels industry (e.g., FRP ships)
- Aerospace industry
- Automotive industry
- Military applications
- Civil engineering
- Oil and Gas sector
- Railway industry
- Onshore green energy sector

6. GAP ANALYSIS AND APPROACH TO BE CONSIDERED

As it was pointed out in the abovementioned methodology to carry out the critical review of applicable standards, the last step considers a gap analysis in order to lay the foundations and set the path for the development of future guidelines and specific standards for marine renewable energy platforms made in fibre-based composites. Despite this deliverable is focused on Floating Offshore Wind and Tidal Turbine platforms, this study can be extrapolated to other blue energy production methods that need a marine foundation such as offshore fixed platforms, floating solar platforms or WECs (wave energy converters), among others. Furthermore, the authors would like to highlight that this analysis is only focused on the study of unmanned REOPs, and therefore the gap analysis does not address the fire impact of these marine renewable energy structures. All gaps analysed in this document are referred to materials, structure, manufacturing, inspection and loading of the platforms.

6.1. Identification of regulation gaps to be implemented in future FOWT standards

Standards used for the design of floating offshore wind platforms are mainly oriented to concrete and steel. Although it is possible to use the design methodology that they present for composite materials, there are no available acceptance criteria for fibre-based platforms. Composite materials are difficult to characterize, and that is why two geometrically identical platforms may have a very different structural behaviour from each other depending on factors like laminate stacking sequence or fibre orientation.

The lack of FRP-based floating structures results in a lack of information about the structural behaviour that FOWTs would have with this material in their primary structure. Consequently, the future standards and rules to be developed shall be a living document under continuous updating. From a structural perspective, the aspects with major impact in the definition of a floating platform are described below.

Average lifetime of offshore assets is estimated in 25-30 years, depending on different factors. In the case of a wind farms, the most critical element that defines the service life is the wind turbine. It is expected however that the use of composite materials for the manufacture of the whole structure, as well as the standards that are being developed in this field will allow to considerably lengthen the lifetime of offshore assets in general, and the wind farms in particular. Likewise, if repowering actions to extend the lifetime of wind farms are considered for the owner, foundations must be prepared to endure and overcome the effect of time accordingly.

Due to the lack of information about the behaviour of composite materials under the loads of an offshore platform, the *initial design* is considered by the authors of major importance. From the structural point of view, the FRP materials present worse mechanical performance than steel. From a geometrical point of view, it is possible to increase the stiffness of a fibre-based composite structure by increasing its inertia through geometric design improvement. Load cases calculation has to be based on both local and global loads, as well as on a combination of both. Additionally, the fact that FRP materials tend to turn fragile and hard after the exposition to atmospheric conditions must be taken into account. Especially when it comes to critical elements such as joints, which can be affected by many factors such as water absorption, chemical exposure, manufacturing process, load type or tension direction among others.

Current standards on *structural design* of offshore platforms demand the performance of a collapse analysis to study the ultimate limit state (ULS). This analysis is currently focused on the elastic limits of the FRP materials as well as the buckling failures of slender elements and flat panels. In the case of composite materials, it is necessary to determinate the ultimate collapse load through an analysis consisting on incrementing the loads applied until the structure collapses. For that, it is necessary to know which are the most critical load conditions, such as the wave causing the greatest torsion, the wind-induced moments or any other combination of metocean loads and internal weights effects. In order to evaluate the results of these analysis it is necessary to design criteria for the different failure modes. Composite materials based on FRP are orthotropic materials which can lose its integrity due to delamination and specific directional stresses. These factors must have their own consideration within the different analysis: ULS, FLS, ALS, SLS.

The *final performance* of FRP materials is strongly influenced by the manufacturing process and the expertise of composite lay-up technicians. The conformity and quality of the final product with respect to the theoretical design is essential to guarantee the expected performance of the design during the life-cycle. The safety factors recommended by the regulatory body depends on the manufacturing procedure, as well as the percentage of fibre/resin of the composite material that affects to the mechanical performance and failure modes of the FRP material.

The *scantling* of a steel-based marine platform is of vital importance due to the corrosion phenomena and loss of material over its lifetime (criterion of minimum scantlings). The exposure of the materials to the aggressive sea environmental conditions and biofouling will also affect to the FRP structures in terms of wear and abrasion, which must be taken into account in the robustness criteria. With the intention that the design of the marine renewable energy platform fulfils with the requirements of lower maintenance and longer useful life, it is necessary to get insight about the degradation of the materials, breakages, points of embrittlement in the material, among other factors.

Furthermore, the key structural considerations are enlisted below:

- The whole structure is designed to withstand global and local loads.
- It should be paid carefully attention to the scantling of slender elements and floater elements.
- Analysis of the “slender elements” under critical fatigue situations. Designers must stiffen the structure in order to avoid the motions of the structure that can initiate phenomena of fatigue on the joints between structural elements.
- The stress concentration points of the new generation of lightweight FOWTs will be determined using prior knowledge of the typical “hot spots” (structural critical zones) in steel-based offshore platforms. With the aim to study the stress evolution, designers perform dynamic analyses by means of wave spectra or real wave measurements. In these numerical simulations, the dynamic behaviour of the FRP structure is studied at different metocean conditions as per example the most critical environmental sea state conditions or even combining wind, wave and current, to consider the multiple effect of these loads on the dynamic response of floating offshore wind turbines.

A finite element structural analysis should be required to identify the stress concentration points of the FOWT and how these critical hot spots behave under extreme and service loading conditions. FEA needs to consider a study of the local and global behaviour of the structure in static and dynamic conditions.

- Identification of the structural geometries more appropriated to increase the stiffness of the FOWT based on FRP. A potentially useful geometry would be a double structure with inner and outer layers with a good load distribution. In comparison to steel, considering that FRP materials have a Young Modulus lower than steel and therefore, it exhibits greater deformations, this geometrical approach can be a solution.
- In general, the joints of a single element, like the floater and the turbine housing, possess worse properties than the materials used for the construction of the FRP section or panel. This well-known weakness results in a loss of stiffness in the joint connections, which can be solved by selecting unions with appropriated geometries (e.g., higher contact area) as well as of more resistant materials.

- Platform mooring system represents a critical element from the design point of view. This is due to the fact that the joints of the fairleads to the structure are critical stress concentration points, which should be defined properly in terms of safety factors, materials and manufacturing systems.
- It is well known that a drastic weight reduction can be achieved by the implementation of lightweight FRP materials in the construction of FOWTs. This will have a major impact on the stability, seakeeping and mooring system definition of the floating platform, as well as on the inertias of a turbine. It might be beneficial or harmful for the dynamic behaviour of the structure from the point of view of motions, and each case must be analysed independently.

After the assessment and review of literature, it can be stated that the main aspects to be considered as gaps that should be addressed in the development of new rules and standards are the following:

- Analysis of the failure modes in structures made of FRP materials.
- Study of the critical design loads of the platform (e.g., collapse study, determination of Ultimate limit States (ULS) by a collapse analysis with incremental loads, etc.)
- Fatigue ageing under dynamic loading (FLS). Safety and material performance factors.
- Accidental Limit State (ALS). Safety and material performance factors.
- Analysis of the effects of the construction of FOWTs with FRP materials such as stability, inertia matrix, ballast, mooring, seakeeping, etc., on the design phase.
- Analysis of the FRP materials behaviour in extreme conditions of temperature and humidity.
- Analysis of the global structural failures due to metocean loads, specifically due to design waves, most critical wind loads and combination of both effects.
- Fairlead assessment and mooring system loads (e.g., tendon connections, mooring line fairleads, etc.).
- Analysis of global structural failures in fire situations.
- Implementation of hybrid materials (composites/metal) construction systems in FOWTs.
- Maintenance and monitoring of the condition of the structural health in operation (SHM).
- Construction and in service survey

Other requirements for composite offshore platforms, which are structurally relevant, are polar accreditation and ice class compliance, especially since many platforms are installed in the cold locations such as North Sea or Baltic Sea. In addition, other areas of special relevance are the study of the points of towage for towing the platforms to their operational location, the support points for fixing and installation and the fitting of decks for the equipment mounting.

Last but not least, standards regarding installation of electrical systems (e.g., control systems, alarm and security systems) for the inspection and maintenance of FOWT platform should be developed as well as the installation of advanced stabilization ballast systems also need to be addressed in standards, due to the weight changes that these devices produce in floating offshore platforms.

6.2. Identification of regulation gaps to be implemented in future tidal turbine standards

Despite the structural design of a tidal turbine in FRP materials involves lesser complexity than a FOWT, there are points that can jeopardize the design and the manufacturing process if they are not considered since the beginning. The key points considered by the authors in this regard are the following:

- Fatigue of structural components and joints.
- Frictional degradation (e.g., bearings and rotating components of the turbine).
- Stresses at support points and hot spots, Steel-FRP hybrid joints, bearings, etc.
- Impacts from loose parts (e.g., screws, etc.).

The existing regulations in the field of tidal turbines contain sufficient information to enable the design and certification of materials, structure, and production process of a tidal turbine. However, it would be interesting to develop rules and guidelines to define the specific design of land-based tidal turbines. Referencing each point to standards that provide the required information.

As suggested by the FIBREGY consortium, it is needed to create new design and manufacturing standards focused on the application of FRP materials in land-based tidal turbines structures.

The key structural aspects to be considered in the opinion of the authors are enlisted below:

- The structure requirements need to be designed considering the different failure modes: Fatigue, Cracking, Delamination, Permeability, Creep and Stress relaxation (in water and particularly seawater), Impact, Wear, Chemical, water degradation, and so on.
- The stress concentration points, "hot spots", of the new generation of lightweight tidal turbines will be evaluated on the basis of prior knowledge in the critical areas of a turbine housing. The evolution of stresses as a function of the turbine rotational movement should be studied.
- A finite element structural analysis including local loads (e.g., supports), global loads (e.g., water flow), static loads (e.g., structural weight), and dynamic loads (e.g., turbine rotations and other vibrations) should be required.
- It is known that the joints of an element are weak points in the structure, even more in hybrid structures (steel and FRP). Therefore, the proper selection of joinings with enhanced geometries and higher resistant materials is of critical importance to avoid mechanical problems in the connections of land-based tidal turbines.
- An exhaustive analysis of the bolting points and interfaces FRP-steel should be carried out to avoid excessive stress concentrations in the land-based tidal turbines.
- The support points of the turbine on the housing are considered critical from the structural point of view. Therefore, the interaction between the metallic and FRP components of the turbine should be evaluated via finite element analysis. A fatigue analysis should also be carried out.
- Bearings are critical elements in a turbine. For instance, the incorrect mounting of the bearings and its wear can affect to the dynamic integrity of the housing. This should be evaluated using FEM modal analyses allowing the criticality assessment of this potential structural problem.
- The bearing and material dimensional changes due to the effect of temperature shifts may affect the performance of the specific asset, creating undesirable stresses and displacements that can lead to critical failures. This circumstance should also be considered for extending the life-cycle of the tidal turbine.

This section attempts to collect and bring together all useful key considerations as a starting point for the development of future design and manufacturing of land-based tidal turbines and ensuring the best structural performance of the design and building of this marine renewable energy asset.

7. OTHER ASPECTS CONSIDERED IN THIS RESEARCH

7.1. Considerations on Fire Aspects

It is well known that fibre reinforced polymer (FRP) materials do not behave in the same manner as conventional steel materials in fire situations. For instance, the use of FRP materials without a good insulation in shipbuilding might compromise the safety of the ship due to a wide number of reasons such as:

- The mechanical properties of composite materials decrease at high temperatures (around 100 ºC),
- FRP materials are flammable materials,
- the matrix of the composite burns and produces a toxic combustion product harmful to human health, and
- the loss of load-bearing capabilities in fire situations compromise the level of safety in the ship.

Consequently, the International Maritime Organization (IMO) through SOLAS (International Convention for the Safety of Life at Sea) obliges using steel or equivalent material, which is commonly interpreted by marine stakeholders as a prohibition of the use of FRP materials as primary structural elements in ships over 500 GT (approx. greater than 50 m in length).

The oil & gas platforms present an important number of fire accidents due to the nature of the activities involved in this sector as per example exploration, storage and processing of hydrocarbons. Similarly, the number of fire accidents is also large in offshore wind turbines, and it represents around the 10 and 30% of the overall number of the loss-of-power generation incidents in wind power plants (15). In order to avoid these catastrophic accidents and the cost of the downtimes and repairs that they produce, the most recent regulatory frameworks forced the installation of advance active and passive fire systems in the offshore energy renewable energy platforms.

The majority of the fire safety regulations have been issued by the regional regulatory authorities and IMO after the lessons learnt from shipping and oil & gas accidents. For instance, the 1914 SOLAS convention was issued after the sinking of the Titanic in 1912, the 1948 SOLAS Convention was originated by the devastating fire on board of the passenger ship Morro Castle, etc.

Another interesting fire accident occurred in the oil platform "Deepwater Horizon", which was a semi semi-submersible ultra-deepwater fast-positioning oil platform that could operate in water depths of up to 2,400m. **Figure 6** shows a photography of the oil platform which was burning for more than one day during the catastrophic accident.

Figure 6: Deepwater Horizon semi-submersible mobile offshore drilling unit explosion (16)

If we look at the wind turbines, it is known that there is an average of one fire per 2,000 turbines per year. The fires are usually originated in the nacelle, where the main ignition points are the transformer, the braking system and the converter/condenser cabinets. The economic costs incurred due to this type of fire accidents are significant for the wind operators. This is attributed to several reasons as per example, the elevated cost of an 3-10 MW offshore wind turbine which is around 3 to 10 million dollars, the costs of non-productivity in the wind farm due to the production downtimes, among others.

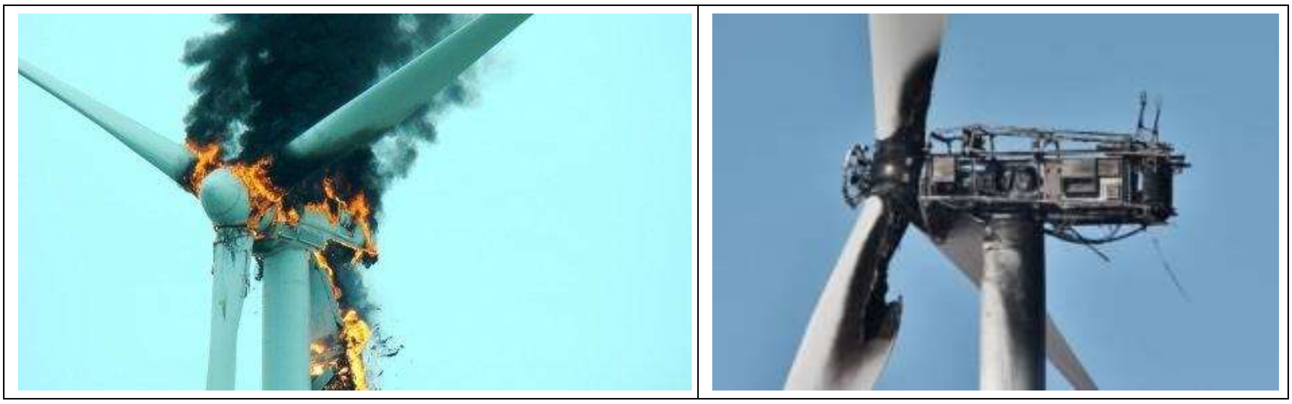


Figure 7: Fire accident in onshore wind turbine (17)

Below, the most important regulatory frameworks from the maritime transport industry such as SOLAS, FTP Code and HSC Code are briefly described.

7.1.1. International Convention for the Safety of Life at Sea (SOLAS)

The main barrier for the massive implementation of FRP materials in the design and construction of large-length ships (over 500 GT) is fire safety. One of the most notable SOLAS principles concerned to fire safety remarked that "*the materials used in the construction of the hull, superstructures, structural bulkheads, decks and deckhouses shall be steel or other equivalent material*". According to SOLAS regulations, an equivalent material can be defined as "*any material which, by itself or due to insulation provided, has integrity properties equivalent to steel at the end of the applicable exposure to the standard fire test*" as per example aluminium with an appropriated fire insulation. The above regulation limits the extensive application of FRP materials in development of lightweight ships, which are commonly used for building hulls structures of small length vessels up to 25 m as mentioned in previous sections.

Alternatively, SOLAS regulatory framework states that "*alternative design and arrangements*" are allowed for the shipbuilding of large-length vessels over 500 GT (greater than 50 m in length) on the basis of equivalent safety, representing an opportunity for the development of a new generation of large-length lightweight vessels until new standards and rules in this regard are issued by classification societies and other regulatory bodies.

It is well known that the thermal behaviour of FRP and steel-based materials are completely different. If we look at the positive side, FRP materials show a very good insulation performance as compared to metallic materials in fire situations. However, a critical issue of FRP materials is that the load bearing capabilities of FRP materials decrease significantly when the material reaches the glass transition temperature (typically ca. 100 ºC). In order to avoid to reach a temperature rise leading to the loss of mechanical properties of the material, the insulation is applied for both unexposed and exposed face of the FRP structure. One of the most important outcomes achieved in the FIBRESHIP project (Grant Agreement 723360) was the development of a new notation to qualify the fire rating of decks and bulkheads built in FRP materials. Based on this new fire notation, new requirements for the fire test procedures and insulation for FRP structures were defined along with new classification of spaces on-board for the FRP lightweight vessels, among others. Further information about the discoveries and innovations of the FIBRESHIP project can be found on the deliverables 4.7 "Project guidance notes" (18) and D7.1 "Measurements report" (19).Fire Test Procedures (FTP) Code

The FTP code is required to certificate the good fire behaviour of composite components implemented in the design of lightweight ships, as a guarantee of the proper fire performance of them. The fire tests of the FTP code evaluate the fire resistance, flammability, spread of flame, smoke and toxicity of the materials used in shipbuilding. According to the SOLAS regulations, the approval of these fire tests is mandatory to approve the materials to be used in the building of ships.

7.2. Considerations on disposal and recycling of hybrid REOPs

It is well known that a large number of fibre reinforced polymer (FRP) offshore structures delivered in the decades of 1960s and 1970s are currently at the end of their lifetime. Consequently, the disposal and recycling of offshore wind platforms and tidal turbine (REOPs) structures at the end of their life-cycle is a relevant issue for the international marine community. In this paragraph, the recycling of offshore wind platforms and tidal turbines is addressed from two different perspectives: (i) considerations on disposal and recycling of REOPs built with conventional materials as per example steel; and (ii) considerations on disposal and recycling of REOPs constructed with FRP lightweight materials.

(i) Considerations on disposal and recycling of REOPs built with conventional materials

An interesting aspect of metallic materials is that they can be melted and converted into other useful physical forms either by rolling, moulding, forming, among others. Therefore, it exists the possibility that the metallic components of the REOPs can be applied for the construction of new marine components or be left as scrap.

(ii) Considerations on disposal and recycling of REOPs constructed with FRP lightweight materials

The application of thermoplastic-based composites in the construction of REOPs structures is attracting great interest among the offshore renewable energy industry due to environmental sustainability awareness and their high potential for reforming and/or recycling at the end of life. This is attributed to the fact that obsolete FRP structures based on thermoset resins can be melted down and reused for the development of FRP marine components as rotor blades and FRP hulls from small boats. Unfortunately, the majority of the existing FRP structures were not designed to be recycled at the end of their lifetime. In other terms, the major part of the FRP structures based on thermosetting polymers that irreversibly becomes rigid when heated, limiting drastically the recycling possibilities of the existing boats at the end of their lifetime. Nowadays, the most common options for recycling the existing FRP structures based on thermosetting polymers are the Incineration with energy recovery, the mechanical recycling, and the landfill in controlled areas. More effort should be carried out by the industry, performing designs and manufacturing keeping in mind recycling for the sake of circular economy and environmental sustainability.

In the last decade, the disposing of FRP ships at the end of the life is becoming a high priority for the administration and marine community that encounter difficulties for the management of the large number of ships abandoned in the sea. Nowadays, the majority of the wasted generated in the disposing of FRP vessels go to landfill, or in particular where space is limited, they are burned or sunk. From the perspective of the developed countries, the recyclability rate of FRP materials has a good margin for improvement due to the limited capacity of recycling and destruction facilities. From the developed countries point of view, the lack of recycling or destruction facilities is a critical issue for the management of ship waste. Indeed, an important number of times the ships are abandoned at the sea with the potential environmental risks for the marine environment and marine fauna. With the purpose to avoid the problems mentioned hereabove. The member states of the IMO are working in a cooperative way for the development of sustainable options for the management of fibreglass vessels at the end-of-life (20).

7.3. Other FRP platform projects

In this context, it is clear that composite materials should be included as one of the first-choice materials for the design of marine renewable energy platforms. This assertion is refuted by the vast number of international projects that are studying the feasibility of FRP application in structures of any kind, such as offshore renewable energy ones both floating and fixed.

One interesting example is the feasibility project carried out by Entrion Wind and Acteon (through InterMoor, see below **Figure 8**, which aimed to design a monopile FRP platform fully restrained at depths between 35 and 85 metres in order to minimise the levelized cost of energy (LCOE) and reduce the risk of the solution for large-scale deployment.

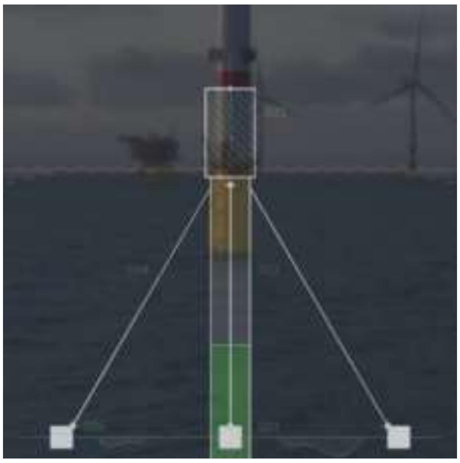


Figure 8 – FRP Monopile Design for 10-15 MW Turbines - Ref. (21)

Likewise, another interesting example of projects such as FIBREGY or the abovementioned is the one focused on the use of wrapped composite joints for jacket foundations for offshore wind carried out by GROW with a set of partners such as TU Delft, Shell, Smulders, HSM Offshore, Enersea, Siemens Gamesa, Tree Composites, BuFA, AOC and Sazlgitterrelated (see **Figure 9**). This project consists of full-scale and multi-axial tests of the wrapped joints and execute a performance validation considering different scenarios to achieve the following objectives: reducing the amount of steel in jackets (40-60%), reducing lead time of jackets in production due to the possibility of prefabrication, reducing manufacturing costs with respect to conventional jackets and monopiles (25-50%); and reducing the carbon footprint of the turbine foundations (30%-70%).

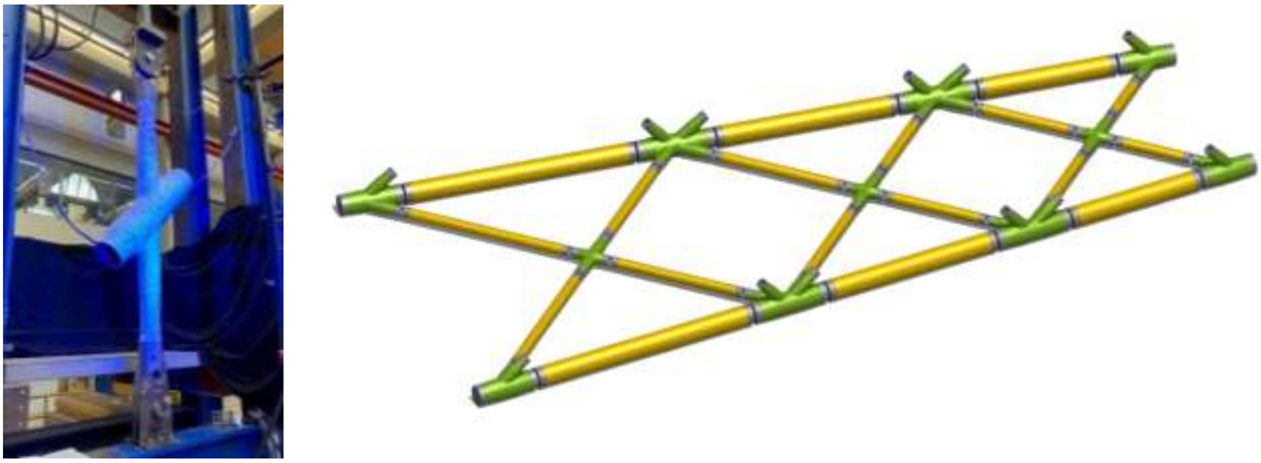


Figure 9 – Test composite joints (left) and Modular jacket assembly with wrapped composite joints (22).

8. CONCLUSIONS

Nowadays, as it has been pointed out along the document, the majority of offshore wind and tidal turbine platforms are designed and constructed using conventional materials. In contrast, Fibre-Reinforced Polymers (FRP) are not quite used in offshore renewable energy platforms, barely limiting their use in rotor blades and other secondary components. This is a clear indicator that the building of offshore renewable energy platforms with FRP materials has not achieved its full potential and therefore, the market cannot benefit from the multiple advantages of FRP materials. This limitation is due to the lack of design guidelines and hands on experience for the manufacturing of energy renewable energy platforms in these materials.

This document does not intend to be a compilation of mandatory provisions. Rather, it is a synthesis of the existing standards and regulations of FRP materials and manufacturing techniques in the marine field, which can be applied for the design and construction of offshore wind and tidal turbines platforms (REOPs). The final goal of task T4.3 is to lay the foundations of future standards at European and international level for REOPs in FRP materials.

It should be noted that the design of FRP-based REOPs have to be considered cost-effective from a life-cycle perspective, and fulfil with the design, production and maintenance requirements required by the marine renewable sector. For such purpose, it has been currently developed multiple manufacturing technologies that being properly applied can allow manufacturing costs reduction. Some of the identified technologies that can make the design of FRP-based structures more competitive are: Curved pultruded profiles, Automated tape laying (ATL), automated fibre placement (AFP), Hot Stamping, Modular assembling, Curved modular panels, or Additive manufacturing.

Due to the lack of design and construction standards for FRP-based REOPs, it has been selected and analysed a series of standards with sufficient information to support the fibre based design of this innovative Floating Offshore Wind Turbine (FOWTs) and Tidal Turbines. To carry out this critical analysis, it has been assessed two types of standards:

1. The standards applied for different work areas (e.g., ship construction and tidal turbines). The standards contain guidelines and recommendations for the design of the main and secondary structural elements.
2. The standards in the field of the FOWTs that have an indirect impact. For example, the design of non-structural elements in FRP such as grids, hand rails, piping system, etc.

In short, the new guidelines and recommendations for the design of offshore platforms should include different sections dealing with materials, design criteria, inspection and data collection, etc. Below, it can be appreciated the schematic proposed in the document.

- Certification Procedure – methodology, certification requirements
- Materials - Manufacture, Inspection, Certification and Testing Procedures
    - Certification and testing of raw materials
    - Factory fabrication and testing
    - Final testing and construction inspection
    - In-service inspection
- Stability, Seakeeping, Weight Control, Watertightness and Weathertightness - (platforms)
- Structural Design Requirements - Structural principles, Scantling, Elements Structural Design, Joints and Connections

- Design Conditions and Load Cases - Loading conditions, Load cases, Limit States (ULS, FLS, ALS, SLS), Safety factors, Material factors.
- Equipment, Mooring, Risers and Tendon Legs System (TLS) – Loads, tensions, fairleads resistance, components, etc. - (platforms)
  - Analysis should be based on global loads, local loads and a combination of global and local loads.
  - Materials are more flexible, with different behaviours than steel. The large deflections of the local panels must be quantified.
  - Appropriate failure mode criteria, since unidirectional stress evaluation does not provide enough prediction capability.
- Hull Scantlings - Basic allowable stress factor, Global Finite Element Model, Calculation Method (WSD - LRFD method)
- Safety
- Inspection, Life Cycle considerations
- Decommissioning

The upcoming regulations, standards and/or guidance notes for the design of FRP-based REOPs need to be functional and fast to obtain the approval of the designs by the regulatory bodies. Other impact areas for the certification of these structures are related to the non-destructive testing of materials such as radiography, ultrasound, modal analysis, etc., as well as certification of performance qualification of the specialized workers in this sector.

Moreover, it should be paid carefully attention to the inspection and monitoring of the structural behaviour of FRP materials throughout the life cycle of the marine renewable energy asset. For such purpose, a database with historical performance data of the asset should be required to determine the variation in the material properties after exposure to chemicals and UV rays, fire, and other critical factors that cause changes in the properties of the initial design.

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9. ANNEX

9.1. Standards and regulations related to the use of conventional materials for the design of FOWT structures (steel, concrete, etc.) of each classification society

9.1.1. ABS

Code	Name	Year
MOU	Mobile Offshore Units	-
Offshore Installations	Offshore Installations	-
SPM	Single Point Moorings	-
FPI	Floating Production Installations	-
Facilities	Facilities on Offshore Installations	2014
OUS	Conditions of Classification - Offshore Units and Structures	2021

Table 12 – ABS Rules for Offshore Building and Classing

Code	Name	Year
Pipeline Guide	Subsea Pipeline Systems	-
Riser Guide	Subsea Riser Systems	-
FLGT	Floating Offshore Liquefied Gas Terminals	-
GBLNGT	Gravity-Based Offshore LNG Terminals	-
BFOWTI	Guide for Building and Classing Bottom-Founded Offshore Wind Turbine Installations	-
FOWTI	Floating Offshore Wind Turbine Installations	-

Table 13 – ABS Guides for Offshore Building and Classing

9.1.2. BV

Code	Name	Year
NR216	Rules on materials and welding for the classification of marine units	2021
NR445	Rules for the classification of offshore units	2019

Table 14 – BV Offshore Main Rules

Code	Name	Year
NR426	Construction survey of steel structures of offshore units and installations	2006
NR493	Classification of mooring systems for permanent offshore units	2015

Code	Name	Year
NR494	Rules for the classification of offshore loading and offloading buoys	2006
NR534	Rules for the classification of self-elevating units - jack-ups and liftboats	2016
NR542	Classification of floating gas units	2019
NR551	Structural analysis of offshore surface units through full-length finite element models	2010
NR569	Classification for drilling ships	2016
NR578	Rules for the classification of tension leg platforms	2012

Table 15 – BV Other Offshore Rules and Rule Notes

Code	Name	Year
NI572	Classification and certification of floating offshore wind turbines	2019
NI594	Design and construction of offshore concrete structures	2017
NI604	Fatigue of top chain of mooring lines due to in-plane and out-of-plane bendings	2014
NI611	Guidelines for fatigue assessment of ships and offshore units	2020
NI624	Risk-based structural integrity management of offshore jacket structures	2017
NI631	General certification scheme for Marine and Renewable Energy technologies	2016
NI525	Risk based qualification of New Technology	2020
NI615	Buckling assessment of plated structures of steel ships and offshore units	2021
NI638	Long term calculations (general guidance on hydro structural calculations)	2018
NI613	(under rewriting) Adhesive joints	2015

Table 16 – BV Offshore Guidance Notes

9.1.3. DNVGL

Code	Name	Year
RU-OU-0101	Offshore drilling and support units	2020
RU-OU-0103	Floating LNG-LPG production, storage and loading units	2020
RU-OU-0104	Self-elevating units, including wind turbine installation units and liftboats	2020
RU-OU-0512	Floating Offshore wind turbine installation	2020
RP-0584	Design, development and operation of floating solar photovoltaic systems	2021
ST-0119	Floating wind turbine structures	2018

ST-0376	Rotor blades for Wind turbines	2015

Table 17 – DNVGL Offshore Rules for Building and Classing

Code	Name	Year
OS-C101	Design of offshore steel structures, general - LRFD method	2019
OS-J101	Design of Offshore Wind turbine Structures	2010
OS-C201	Structural design of offshore units - WSD method	2017
OS-C401	Fabrication and testing of offshore structures	2020
OS-C502	Offshore Concrete Structures	2018
OS-F101	Submarine Pipeline System	2013
ST-0378	Offshore and platform lifting appliances	2020
ST-0164	Tidal turbines	2015
ST-0126	Support structures for wind turbines	2020
SE-0422	Certification of floating wind turbines	2018

Table 18 – DNVGL Offshore Standards and Other Standards

Code	Name	Year
RP-C203	Fatigue design of offshore steel structures	
RP-F202	Composite Risers	2003

Table 19 – DNVGL Offshore Recommended Practice

Code	Name	Year
SI-0003	Verification for compliance with United States regulations on the outer continental shelf	2015
SI-0166	Verification for compliance with Norwegian shelf regulations	2018
SI-0167	Verification for compliance with United Kingdom shelf regulations	2020

Table 20 – DNVGL Verification for compliance

9.1.4. LR

Code	Name	Year
-	Rules and Regulations for the Classification of Offshore Units	2020
-	Rules and Regulations for the Construction and Classification of Floating Docks	2020

Table 21 – LR Offshore Rules for Building and Classing

Code	Name	Year
-	Guidance Notes for Offshore Wind Farm Project Certification	2020

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Table 22 – LR Offshore Guidance Notes

9.1.5. RINA

Code	Name	Year
RES17	Rules for Offshore Units	2021
RES11	Rules for the Classification of Steel Fixed Offshore Platforms	2015

Table 23 – RINA Offshore Rules for Building and Classing

Code	Name	Year
GUI32	Guide for the Certification of Offshore Wind Turbine Structures	2018

Table 24 – RINA Offshore Guide for Building and Classing

9.1.6. ClassNK

Code	Name	Year
RU Part K	Materials	2020
RU Part PS	Floating Offshore Facilities for Crude Oil Petroleum Gas Production, Storage and Offloading	2020
RU Part P	Mobile Offshore Drilling Units and Special Purpose Barges	2020
-	Rules for Floating Docks	2019

Table 25 – ClassNK Offshore Rules for Building and Classing

Code	Name	Year
-	Guidance for the Approval and Type Approval of Materials and Equipment for Marine Use	2020
GL_FLNG	Guidelines for Floating Offshore Facilities for LNGLPG Production, Storage, Offloading and Regasification	2016

Table 26 – ClassNK Offshore Guide for Building and Classing

9.1.7. RS

Code	Name	Year
FPU	Rules for the Classification, Construction and Equipment of Floating Offshore Oil-and-Gas Production Units	2021
MODU-FOP	Rules for the Classification, Construction and Equipment of Mobile Offshore Drilling Units and Fixed Offshore Platforms	2021
OGE	Rules for the Oil-and-Gas Equipment of Floating Offshore Oil-and-Gas Production Units, Mobile Offshore Drilling Units and Fixed Offshore Platforms	2021

Table 27 – RS Offshore Rules for Building and Classing

9.1.8. CCS

Code	Name	Year
-	Rules for Classification of Mobile Offshore Units	2016
-	Rules for Materials and Welding	2018
-	Rules for Lifting Appliances of Ships and Offshore Installations	2007

Table 28 – CCS Offshore Rules for Building and Classing

Code	Name	Year
-	Guidelines for Certification of Subsea Production System	2016

Table 29 – CCS Offshore Guide for Building and Classing

9.1.9. INTERNATIONAL & REGIONAL STANDARDIZATION ASSOCIATIONS

9.1.9.1. API

Code	Name	Year
-	Standards For Safe Offshore Operations	2020
RP 14F	Design, Installation, and Maintenance of Electrical Systems for Fixed and Floating Offshore Petroleum Facilities for Unclassified	2020
RP 2A WSD	Planning, Designing, and Constructing Fixed Offshore Platforms-Working Stress Design	-
RP 2A	Offshore Structure Standards	-
RP 2AL FRLD	Planning Designing and Constructing Fixed Offshore Platforms	-
RP 2SIM	Structural Integrity Management of Fixed Offshore Platforms	-

Table 30 – ClassNK Offshore Rules for Building and Classing

9.1.9.2. ISO

Code	Name	Year	Notes
19900:2019	Petroleum and natural gas industries — General requirements for offshore structures		
19906:2019	Petroleum and natural gas industries - Arctic offshore structures		

Table 31 – ISO_ Offshore Structures Standards

9.1.9.3. IEC

Code	Name	Year	Notes
61400	Standards for Wind Turbine		
62600	Standards for wave, tidal and other water current converters	2020	

Table 32 – IEC_ Offshore Structures Standards

9.1.9.4. IMO

Code	**Name**	**Year**	**Notes**
MODU	2009 Mobile Offshore Drilling Units	2020	by IMO - International Maritime Organization

Table 33 - IMO Offshore Structures Standards.

9.2. Identification of current FRP applications. Regulations and standards.

9.2.1. ABS

Code	Name	Year	Sections	Notes
NR426	Construction survey of steel structures of offshore units and installations	2006		
HSC	High Speed Naval Craft	2020	Part 3 _ Chapter 1-General_ Section 1 _ 31 Fiber-Reinforced Plastic (FRP)	
			Part 3 _ Chapter 1-General _ Section 2 _ 7 Effective Width of Plating	
			Part 3 _ Chapter 1-General _ Section 3 _ 11 Structural Acceptability	Acceptance criteria for calculations
			Part 3 _ Chapter 2-Hull Structures and Arrangements _ Section 1 _ 1 Primary Hull Strength	
			Part 3 _ Chapter 2-Hull Structures and Arrangements _ Section 3 _ 5 Fiber Reinforced Plastic	TABLE 4 Design Stresses for FRP TABLE 6 Coefficient v for FRP Sandwich Panels Shear Strength TABLE 8 Plating Subject to Military Mission Loads"
			Part 3 _ Chapter 2-Hull Structures and Arrangements _ Section 6 Arrangement, Structural Details and Connections	
			Part 3 _ Chapter 4-Fire Safety Measures _ Section 1-Structural Fire Protection	Apply IMO 1994 High-Speed Craft Code Application
Materials and Welding	Materials and Welding	2021	Part 2 - Materials and Welding_Chapter-6 Materials for Hull Construction-Fiber Reinforced Plastics (FRP)	
ORC	Offshore-Racing Council	1994		
NVR	Combatant high-speed craft called Naval Vessel Rules	1994		
Facilities	FACILITIES ON OFFSHORE INSTALLATIONS	2014	APPENDIX 1 Plastic Pipe Installations	
			APPENDIX 3 Fiber Reinforced Plastic (FRP) Gratings	

Table 34 – ABS_FRP Rules and Rule Notes

9.2.2. BV

Code	Name	Year	Sections	Notes
NR500	Rules for the classification and the certification of yachts	2016	Chapter 7-Structure Design and Scantling Requirements for Composite and Plywood	
			Chapter 8-Hull Outfittings	
NR600	Hull structure and arrangement for the classification of cargo ships	2018	Chapter 2_Section 3_Article 3-Composite material structure	

Code	Name	Year	Sections	Notes
	less than 65m and non-cargo ships less than 90m			
			Chapter 4-Hull Scantling	Applies to different points in the chapter, or a specific topic for this material.
			Chapter 5-Other Structure	Applies to different points in the chapter, or a specific topic for this material.
NR546	Hull in composite materials and plywood, material approval, design principles, construction and survey	2018	-	Applies to the entire document
NI663	Propeller in Composite Materials	2020		
NI432	Certification of Fibre Ropes for Deepwater Offshore Services			
NI603	Rules for tidal turbines (with notions on fatigue of composites)			

Table 35 –BV _FRP Rules and Rule Notes

9.2.3. DNVGL

Code	Name	Year	Sections	Notes
IV-Part 6	Rules for Classification and Construction Industrial Services			
RU-HSLC	Pt3 Ch4_Hull structural design, fibre composite and sandwich constructions	2020	Part 3 - Chapter 4	All document
RU-YACHT	Pt3Ch5_Composite scantlings	2018	All document	
RU-SHIP	Pt2Ch3_Materials and welding_Non-metallic materials		Section 3 Manufacture of products made of FRP	
RU-YACHT	Yachts - Pt3-Hull_Ch5-Composite scantlings	2018	Part 3 - Chapter 5	All document
OS-C201	Structural design of offshore units - WSD method		See DNV-OS-C501	
OS-C501	Composite Components	2013	All document	This guide teaches what a composite material is, how it should be designed and calculated.
RP-F202	Composite Risers	2003	All document	This Recommended Practice (RP) document gives criteria, requirements and guidance on structural design and analysis of riser systems made of composite materials exposed to static and dynamic loading for use in the offshore.
OS-C502	Offshore Concrete Structures	2018	Appendix E - E.2 FRP reinforced structures	For predict the crack width in structural elements which are

Code	Name	Year	Sections	Notes
				reinforced by FRP surface reinforcement
			Appendix F Requirements to content in certificates for FRP bars	For designing structural elements using FRP reinforcement bars
			Appendix G QA/QC system for manufacture of FRP bars	For designing structural elements using FRP reinforcement bars
ST-0490	TP52 Racing yachts			
ST-0376	Rotor blades for wind structure			
DS-J102	Design & Manufacture Wind turbine blades			
CP-0086	Adhesive systems			

Table 36 – DNVGL_FRP Rules and Rule Notes

9.2.4. LR

Code	Name	Year	Sections	Notes
-	Rules and Regulations for the Classification of Special Service Craft	2020	Pt 3_Ch 3_2.14 Composite Rudders	
-	Rules and Regulations for the Classification of Special Service Craft	2020	Pt 4 - Additional Requirements for Yachts	This Part of the Rules contains the particular requirements for the construction and classification of yachts with an overall length of 24 m or greater.
-	Rules and Regulations for the Classification of Special Service Craft	2020	Pt 8 - Hull Construction in Composite	
-	Rules and Regulations for the Classification of Special Service Craft	2020	Pt 15_Ch 2_14.4 Fittings for composite hulls	
-	Rules and Regulations for the Classification of Special Service Craft	2020	Pt 17 _Fire Protection, Detection and Extinction	Insulation notes for composite materials
-	Guidance Notes for the Classification of Special Service Craft Calculation Procedures for Composite Construction	2013	All Document	To clarify the procedures contained in the Rules and Regulations for the Classification of Special Service Craft
-	Rules for the Manufacture Testing and Certification of Materials	2020	Ch 14_St 5 - Control of Material Quality for Composite Construction	
-	Rules and Regulations for the Classification of Offshore Units	2020	"API RP 15CLT Composite Lined Steel Tubular Goods API RP 15CLT. Recommended practice for composite lined steel tubular goods.	International standard recommendations to be followed. Applies to Composite lined, bridges and rubber

Code	Name	Year	Sections	Notes
			BS 5400 1984: Steel, concrete and composite bridges – Part 9: Bridge bearing"	

Table 37 – LR_FRP Rules and Rule Notes

9.2.5. RINA

Code	Name	Year	Sections	Notes
NCC24	Rules for the Type Approval of Components of Composite Materials Intended for Hull Construction	2020	All document	These Rules do not concern the acceptance of materials for the purposes of structural fire protection. - laminating thermosetting resins and gel coats, thermoplastic polymers glass fibres and relevant products, aramid fibres and relevant products, carbon-graphite fibres and relevant products, core materials for sandwich laminates
RES6	Rules for Pleasure Yachts_Part A- Classification and Surveys	2021	APPENDIX 1-Additional Scope of Survey for Yachts With Reinforced Plastic Hulls	
			Chapter 4 - Reinforced Plastic Hulls	Applies to monohull yachts with a hull made of composite materials and a length L not exceeding 60 m
			Chapter 6 - Plastic Materials	
RU-WB	Rules for the Classification of Workboats	2020	Pt B_Ch 1_Sec 3 - 1.1.2 Rudder with stock and blade made of composite material	
			Pt B_Ch 2-Glass Reinforced Plastic Hull	
			Pt C_Ch 1_Sec 2-3 Protection against lightning for vessels with reinforced plastic or wooden hull	
RU-FPV	RU Fast Patrol Vessels_Part B - Hull and Stability	2007	Part B_Ch 4_Sec 1 - 4 Composite Structure	
	RU Fast Patrol Vessels_Part C-Machinery Systems and Fire Protection	2007		
	RU Fast Patrol Vessels_Part D-Materials and Welding	2007	Chapter 6 - Plastic Materials	
-	Rules for the Classification of Ships with Reinforced Plastic, Aluminium Alloy or Wooden Hulls	2008	Chapter 2_Surveys of Ships with Reinforced Plastic Hull	Design Principles and Stability - Material and Construction - Design Loads and Hull Scantling - Hull Outfitting - Rudders - Equipment - Testing
RU-CS	Rules for the Classification of Ships	2012	Part A-Classification and Surveys	
RINAMIL	RINAMIL- Part D	2017	Pt D_Ch 4_Sec 3 - 2 Structural fire protection for hull built in composite materials	

Code	Name	Year	Sections	Notes
-	Rules for the Classification of Charter Yachts	2007		Not currently included into the rules and regulations database.

Table 38 – RINA_FRP Rules and Rule Notes

9.2.6. ClassNK

Code	Name	Year	Sections	Notes
RU_HSC	Rules for High Speed Craft (2020)	2020	Part 3_Chapter 5_Moulding of FRP for Hull Structure	It is supported by the document "Standards for the survey and construction of fiberglass-reinforced plastic vessels"
		2020	Part 6_Chapter 2_Hull Construction for FRP Craft	It is supported by the document "Standards for the survey and construction of fiberglass-reinforced plastic vessels"
-	Rules for the Survey and Construction of Ships of Fibreglass Reinforced Plastics	2019	All document	Relies on other regulations, such as the general rule for steel vessels. e.g. Obtain loads
-	Guidelines for Composite Propellers (2016)	2016	All document	Requirements for the approval of manufacturing process for composite propellers and the testing/inspection of the product in the form of guidelines.
RU_Part C	Hull Construction and Equipment	2020	Annex C1.1.7-5_Guidance for the Use of Fiber Reinforced Plastic (FRP)	
-	Guidance for the Approval and Type Approval of Materials and Equipment for Marine Use		Part 2_Chapter 9_ APPROVAL OF USE OF FIBER REINFORCED PLASTIC (FRP)	
-	Rules for the Survey and Construction of Governmental and Naval Ships	2020	Part 3_Chapter 2_2.1 Hull Structural Materials_2.1.4 FRP	Material Description
-	Rules for the Survey and Construction of Governmental and Naval Ships	2020	All document	Throughout an entire document there are references regarding to safety criteria values, stress, damage, etc.

Table 39 – ClassNK__FRP Rules and Rule Notes

9.2.7. RS

Code	Name	Year	Sections	Notes
-	Rules for the Classification and Construction of Sea-Going Ships_Part XIII - Materials	2021	2 Procedures of Testing_2.3.6 Determination of relative glass content in glass-reinforced plastic by mass.	
-	Rules for the Classification and Construction of Sea-Going Ships_Part XIII - Materials	2021	6 Plastics and materials of organic origin_6.2 Materials for reinforced plastic structures	
-	Rules for the Classification and Construction of Sea-Going Ships_Part XIII - Materials	2021	6 Plastics and materials of organic origin_6.8 Plastic pipes and fittings	
-	Rules for the Classification and Construction of Sea-	2021	All Document	Displacement ships of glass-reinforced plastic from 12 to 30

Code	Name	Year	Sections	Notes
	Going Ships_Part XVI_Hull Structure and Strength of Glass-Reinforced Plastic Ships and Boats			m in length having the speed v^3,05y/L knots
-	Rules for the Classification and Construction of Subsea Pipelines	2021	3 Requirements for Determining Riser Dynamic Response to Environmental Conditions and Loads_3.4.2 Composite Riser Pipes.	
-	Rules for the Classification and Construction of Subsea Pipelines	2021	4. Materials_4.3 Riser Pipes of Composite Materials	
-	Rules for the Classification and Construction of Subsea Pipelines	2021	APPENDIX 7_Strength and Stability of Riser Pipes Made of Composite Materials	
MODU-FOP	Rules for the Classification, Construction and Equipment of Mobile Offshore Drilling Units and Fixed Offshore Platforms	2021	Part II. Hull_3 Strength Issues Specific to Platforms_3.4 Fop Reinforced and Steel Concrete Structures	
MODU-FOP	Rules for the Classification, Construction and Equipment of Mobile Offshore Drilling Units and Fixed Offshore Platforms	2021	Part VIII. Systems and Piping_2 General Requirements for Systems and Piping_2.2. Plastic Piping	

Table 40 – RS_FRP Rules and Rule Notes

9.2.8. CCS

Code	Name	Year	Sections	Notes
N/A	N/A	N/A	N/A	N/A

Table 41 – CCS_FRP Rules and Rule Notes

9.2.9. API

Code	Name	Year	Sections	Notes
15S	Spoolable Reinforced Plastic Line Pipe	-	-	-

Table 42 – API_FRP Rules and Rule Notes

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