Guidelines for Composite Materials in Marine Structures

TERMS OF REFERENCE

1. Historical Background and Definition of the Problem

Owners of waterborne transport infrastructure currently face a monumental challenge with thousands of aging infrastructures deteriorating in the corrosive water environments and requiring billions of Euros in repair or replacement. For example, the USA has over 13,000 marine steel structures and is facing a navigation infrastructure maintenance work backlog of about $34 billion (similar figures are available on OECD or ITF…]. Owners need solutions that are cost effective and low maintenance. This is where marine composite structures can help. Composite materials offer several advantages including corrosion resistance, ease of construction, high strength-to-weight ratio, and low life-cycle maintenance costs.

Former PIANC InCom WG191 "Composites for Hydraulic Structures" was approved in 2015 and published in 2020. This report provided excellent background on composite materials, usage of composites in marine applications, design methods, inspection, and maintenance. However, in the few short years since WG 191, there have been significant advances in the adoption of composites, implementation of larger marine structures, and design standards.

Despite these advances, the widespread adoption of composite materials in major marine structures is limited due to:

- **Lack of Unified Technical Guidance:** There are no internationally accepted, unified design standards or codes specifically tailored to composite materials under hydraulic conditions (e.g., high hydrostatic pressures, wave actions, vessel impacts, constant moisture, and UV exposure).
- **Material Complexity:** Composites are anisotropic and heterogeneous, making their design, connection detailing, and behavior under fatigue and long-term creep more complex than isotropic metals.
- **Skepticism & Lack of Familiarity**: Asset owners, waterway authorities, and design engineers are often unfamiliar with long-term performance, durability, non-destructive testing (NDT), and repair methodologies for composite structures.

This PIANC WG aims expected to compile global best practices and structural design methodologies in a comprehensive guidance report so as to help port and waterway authorities confidently implement composite materials.

2. Objectives

The main objective of this Working Group (WG) is to produce a comprehensive, international guidelines document for the design, material selection, manufacturing, installation, inspection, and maintenance of composite materials in marine structures.

Specifically, the report will:

- Provide a clear framework for applying Limit State Design (LSD) and Partial Safety Factor Design (PSFD) concepts to composite materials in marine environments (for new structures but also for the upgraded existing marine structures). The WG will focus on limit states, on material parameters and on resistances in a marine environment; but, the assessment of representative values of actions (such as water levels, hydraulic pressures, waves and currents' pressures, impacts by ships or debris, ice, temperature…) is outside of the scope of the WG.
- Compile best practices for connection detailing (adhesives, hybrid joints, mechanical fastening) in water-retaining structures.
- Summarize the state-of-the-art in inspection and maintenance techniques
- Offer practical guidance on life-cycle cost analysis (LCCA) to demonstrate the long-term economic benefits of composite structures over traditional materials.
- Build trust among port and waterway operators by compiling documented, long-term case studies of existing composite marine installations.

3. Earlier Reports to be Reviewed

- PIANC InCom WG 191: Composites for Hydraulic Structures (2020)
- CEN/TS 19101: Design of Fibre-Polymer Composite Structures (2022)
- ASCE 74-23: LRFD Design for Pultruded FRP Structures (2023)
- CROW-CUR Recommendation 96: Fibre-Reinforced Polymers in Civil Engineering Structures (2019)

4. Scope of Work

To achieve the objectives, the work begins with a comprehensive, global state-of-the-art review to compile existing case studies, lessons learned, and operational performance of marine composite structures like Fiber Reinforced Polymer (FRP) gates, sheet piling, and floating structures. Following this initial assessment, the group will define rigorous material characterization and selection criteria for aquatic environments, specifically addressing critical durability concerns such as hydrothermal degradation, UV exposure, freeze-thaw cycles, and marine bio-fouling.

These material baselines will inform the development of structural design and engineering guidelines based on Limit State Design (LSD) and Partial Safety Factor Design (PSFD) principles taking into account a range of possible target reliability levels. Among other calibration method, the Design Value Method (DVM) may be used by the WG. Particular emphasis will be placed on evaluating structural behavior under critical hydraulic load cases, including hydrostatic and hydrodynamic pressures, cyclic wave fatigue, and high-energy vessel or debris impacts—while providing dedicated guidance on mitigating connection failures at composite-to-composite and hybrid metal interfaces.

In addition to design, the scope covers the full physical lifecycle of composite structures, starting with an evaluation of fabrication techniques such as pultrusion, vacuum-assisted resin transfer molding, and filament winding, alongside factory and on-site quality assurance criteria. The group will establish practical guidelines for the transport, handling, and underwater installation of these lightweight systems. Finally, the scope addresses long-term asset management by drafting standardized inspection protocols and evaluating advanced non-destructive testing (NDT) technologies, such as infrared thermography and ultrasonic testing, to detect sub-surface damage, delamination, or water ingress. To support ongoing operations, standard guidelines will be developed for field repairs, wet layup rehabilitation, and structural retrofitting of existing conventional concrete or steel infrastructure with composite reinforcements.

5. Intended Product

The final product of the WG will be a comprehensive PIANC technical report entitled "Guidelines for Composite Materials in Marine Structures."

The report will include:

- Engineering Guidelines: Structured chapters detailing design criteria, material parameters (characteristic values and design values, according to the target reliability levels that are be assessed later on by National Regulatory Bodies) and manufacturing processes.
- Standard Detail Catalog: Illustrative diagrams of successful joints, seals, and connection configurations.
- Case Study Database: An organized appendix of historical projects, including cost-benefit analyses and operational feedback.
- Checklists for Owners: Step-by-step guidance for owners during procurement, specification writing, and final acceptance testing.

6. Working Group Membership

The Working Group seeks an interdisciplinary panel of experts, including:

- Public Waterway Authorities & Port Operators: To provide user requirements, operational expectations, and maintenance perspectives.
- Design Engineers & Consultants: To provide expertise in structural modeling, finite element analysis (FEA), and practical engineering challenges.
- Composite Material Scientists & Manufacturers: To contribute specialized knowledge on polymer formulations, fiber architectures, and fabrication methods.
- Academic Researchers & Testing Institutions: To provide insights into experimental testing, long-term durability models, calibration of material or resistance partial factors and innovative NDT methodologies.

7. Target Audience

The report will serve:

- Civil engineers and structural designers draft specifications for waterways and ports.
- Procurement officers and asset managers in national, regional, and municipal maritime administrations.
- Quality control inspectors and marine structure contractors.
- Composite fabricators seeking to understand the unique constraints of marine projects.

8. Relevance

8.1. Relevance to Countries in Transition

Composite materials are highly relevant for countries in transition. While initial material costs may be higher, the extremely low maintenance requirements and ease of installation (without the need for heavy, high-capacity cranes) make composites a highly economical and resilient choice for regions with limited specialized maintenance budgets and infrastructure.

8.2. Climate Change and Adaptation

Rising global temperatures, sea-level rise, and increased storm severity subject coastal and inland structures to higher salinity, more frequent wetting-drying cycles, and greater hydrodynamic loads. Composite structures do not corrode, making them structurally resilient under aggressive, climate-altered marine environments.

8.3. Working with Nature

Composites support the Working with Nature philosophy by eliminating the need for toxic anti-corrosion coatings, heavy metal paints, or chemical preservatives (such as creosote used in timber) that leach into aquatic ecosystems. The environmental impacts must therefore be raised.

8.4. UN Sustainable Development Goals

This WG directly supports several UN SDGs:

- SDG 9 (Industry, Innovation, and Infrastructure): Fosters the deployment of innovative, durable materials to build resilient infrastructure.
- SDG 12 (Responsible Consumption and Production): Minimizes material consumption and reduces waste by avoiding premature structural replacements and minimizing chemical maintenance footprints.
- SDG 14 (Life Below Water): Eliminates harmful environmental run-off from paints and corrosion by-products.