

Hull in Composite Materials and Plywood, Material Approval, Design Principles, Construction and Survey

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NR 546 DT R02



Rule Note



Documents

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RULES & GUIDANCE NOTES

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GENERAL CONDITIONS

1. INDEPENDENCE OF THE SOCIETY AND APPLICABLE TERMS

- 1.1 The Society shall remain at all times an independent contractor and neither the Society nor any of its officers, employees, servants, agents or subcontractors shall be or act as an employee, servant or agent of any other party hereto in the performance of the Services.
- 1.2 The operations of the Society in providing its Services are exclusively conducted by way of random inspections and do not, in any circumstances, involve monitoring or exhaustive verification.
- 1.3 The Society acts as a services provider. This cannot be construed as an obligation bearing on the Society to obtain a result or as a warranty. The Society is not and may not be considered as an underwriter, broker in Unit's sale or chartering, expert in Unit's valuation, consulting engineer, controller, naval architect, designer, manufacturer, shipbuilder, repair or conversion yard, charterer or shipowner; none of them above listed being relieved of any of their expressed or implied obligations as a result of the interventions of the Society.
- 1.4 The Society only is qualified to apply and interpret its Rules.
- 1.5 The Client acknowledges the latest versions of the Conditions and of the applicable Rules applying to the Services' performance.
- 1.6 Unless an express written agreement is made between the Parties on the applicable Rules, the applicable Rules shall be the Rules applicable at the time of entering into the relevant contract for the performance of the Services.
- 1.7 The Services' performance is solely based on the Conditions. No other terms shall apply whether express or implied.

2. DEFINITIONS

- 2.1 "Certificate(s)" means classification or statutory certificates, attestations and reports following the Society's intervention.
- 2.2 "Certification" means the activity of certification in application of national and international regulations or standards, in particular by delegation from different governments that can result in the issuance of a Certificate.
- 2.3 "Classification" means the classification of a Unit that can result or not in the issuance of a classification Certificate with reference to the Rules. Classification is an appraisalment given by the Society to the Client, at a certain date, following surveys by its surveyors on the level of compliance of the Unit to the Society's Rules or to the documents of reference for the Services provided. They cannot be construed as an implied or express warranty of safety, fitness for the purpose, seaworthiness of the Unit or of its value for sale, insurance or chartering.
- 2.4 "Client" means the Party and/or its representative requesting the Services.
- 2.5 "Conditions" means the terms and conditions set out in the present document.
- 2.6 "Industry Practice" means international maritime and/or offshore industry practices.
- 2.7 "Intellectual Property" means all patents, rights to inventions, utility models, copyright and related rights, trade marks, logos, service marks, trade dress, business and domain names, rights in trade dress or get-up, rights in goodwill or to sue for passing off, unfair competition rights, rights in designs, rights in computer software, database rights, topography rights, moral rights, rights in confidential information (including know-how and trade secrets), methods and protocols for Services, and any other intellectual property rights, in each case whether capable of registration, registered or unregistered and including all applications for and renewals, reversions or extensions of such rights, and all similar or equivalent rights or forms of protection in any part of the world.
- 2.8 "Parties" means the Society and Client together.
- 2.9 "Party" means the Society or the Client.
- 2.10 "Register" means the public electronic register of ships updated regularly by the Society.
- 2.11 "Rules" means the Society's classification rules and other documents. The Society's Rules take into account at the date of their preparation the state of currently available and proven technical minimum requirements but are not a standard or a code of construction neither a guide for maintenance, a safety handbook or a guide of professional practices, all of which are assumed to be known in detail and carefully followed at all times by the Client.
- 2.12 "Services" means the services set out in clauses 2.2 and 2.3 but also other services related to Classification and Certification such as, but not limited to: ship and company safety management certification, ship and port security certification, maritime labour certification, training activities, all activities and duties incidental thereto such as documentation on any supporting means, software, instrumentation, measurements, tests and trials on board. The Services are carried out by the Society according to the applicable referential and to the Bureau Veritas' Code of Ethics. The Society shall perform the Services according to the applicable national and international standards and Industry Practice and always on the assumption that the Client is aware of such standards and Industry Practice.
- 2.13 "Society" means the classification society 'Bureau Veritas Marine & Offshore SAS', a company organized and existing under the laws of France, registered in Nanterre under number 821 131 844, or any other legal entity of Bureau Veritas Group as may be specified in the relevant contract, and whose main activities are Classification and Certification of ships or offshore units.
- 2.14 "Unit" means any ship or vessel or offshore unit or structure of any type or part of it or system whether linked to shore, river bed or sea bed or not, whether operated or located at sea or in inland waters or partly on land, including submarines, hovercrafts, drilling rigs, offshore installations of any type and of any purpose, their related and ancillary equipment, subsea or not, such as well head and pipelines, mooring legs and mooring points or otherwise as decided by the Society.

3. SCOPE AND PERFORMANCE

- 3.1 Subject to the Services requested and always by reference to the Rules, the Society shall:
- review the construction arrangements of the Unit as shown on the documents provided by the Client;
 - conduct the Unit surveys at the place of the Unit construction;
 - class the Unit and enter the Unit's class in the Society's Register;
 - survey the Unit periodically in service to note whether the requirements for the maintenance of class are met.
- The Client shall inform the Society without delay of any circumstances which may cause any changes on the conducted surveys or Services.
- 3.2 The Society will not:
- declare the acceptance or commissioning of a Unit, nor its construction in conformity with its design, such activities remaining under the exclusive responsibility of the Unit's owner or builder;
 - engage in any work relating to the design, construction, production or repair checks, neither in the operation of the Unit or the Unit's trade, neither in any advisory services, and cannot be held liable on those accounts.

4. RESERVATION CLAUSE

- 4.1 The Client shall always: (i) maintain the Unit in good condition after surveys; (ii) present the Unit for surveys; and (iii) inform the Society in due time of any circumstances that may affect the given appraisalment of the Unit or cause to modify the scope of the Services.
- 4.2 Certificates are only valid if issued by the Society.
- 4.3 The Society has entire control over the Certificates issued and may at any time withdraw a Certificate at its entire discretion including, but not limited to, in the following situations: where the Client fails to comply in due time with instructions of the Society or where the Client fails to pay in accordance with clause 6.2 hereunder.
- 4.4 The Society may at times and at its sole discretion give an opinion on a design or any technical element that would 'in principle' be acceptable to the Society. This opinion shall not presume on the final issuance of any Certificate or on its content in the event of the actual issuance of a Certificate. This opinion shall only be an appraisal made by the Society which shall not be held liable for it.

5. ACCESS AND SAFETY

- 5.1 The Client shall give to the Society all access and information necessary for the efficient performance of the requested Services. The Client shall be the sole responsible for the conditions of presentation of the Unit for tests, trials and surveys and the conditions under which tests and trials are carried out. Any information, drawing, etc. required for the performance of the Services must be made available in due time.
- 5.2 The Client shall notify the Society of any relevant safety issue and shall take all necessary safety-related measures to ensure a safe work environment for the Society or any of its officers, employees, servants, agents or subcontractors and shall comply with all applicable safety regulations.

6. PAYMENT OF INVOICES

- 6.1 The provision of the Services by the Society, whether complete or not, involve, for the part carried out, the payment of fees thirty (30) days upon issuance of the invoice.

6.2 Without prejudice to any other rights hereunder, in case of Client's payment default, the Society shall be entitled to charge, in addition to the amount not properly paid, interests equal to twelve (12) months LIBOR plus two (2) per cent as of due date calculated on the number of days such payment is delinquent. The Society shall also have the right to withhold Certificates and other documents and/or to suspend or revoke the validity of Certificates.

- 6.3 In case of dispute on the invoice amount, the undisputed portion of the invoice shall be paid and an explanation on the dispute shall accompany payment so that action can be taken to solve the dispute.

7. LIABILITY

- 7.1 The Society bears no liability for consequential loss. For the purpose of this clause consequential loss shall include, without limitation:
- Indirect or consequential loss;
 - Any loss and/or deferral of production, loss of product, loss of use, loss of bargain, loss of revenue, loss of profit or anticipated profit, loss of business and business interruption, in each case whether direct or indirect.
- The Client shall defend, release, save, indemnify, defend and hold harmless the Society from the Client's own consequential loss regardless of cause.
- 7.2 Except in case of wilful misconduct of the Society, death or bodily injury caused by the Society's negligence and any other liability that could not be, by law, limited, the Society's maximum liability towards the Client is limited to one hundred and fifty per-cents (150%) of the price paid by the Client to the Society for the Services having caused the damage. This limit applies to any liability of whatsoever nature and howsoever arising, including fault by the Society, breach of contract, breach of warranty, tort, strict liability, breach of statute.
- 7.3 All claims shall be presented to the Society in writing within three (3) months of the completion of Services' performance or (if later) the date when the events which are relied on were first discovered by the Client. Any claim not so presented as defined above shall be deemed waived and absolutely time barred.

8. INDEMNITY CLAUSE

- 8.1 The Client shall defend, release, save, indemnify and hold harmless the Society from and against any and all claims, demands, lawsuits or actions for damages, including legal fees, for harm or loss to persons and/or property tangible, intangible or otherwise which may be brought against the Society, incidental to, arising out of or in connection with the performance of the Services (including for damages arising out of or in connection with opinions delivered according to clause 4.4 above) except for those claims caused solely and completely by the gross negligence of the Society, its officers, employees, servants, agents or subcontractors.

9. TERMINATION

- 9.1 The Parties shall have the right to terminate the Services (and the relevant contract) for convenience after giving the other Party thirty (30) days' written notice, and without prejudice to clause 6 above.
- 9.2 In such a case, the Classification granted to the concerned Unit and the previously issued Certificates shall remain valid until the date of effect of the termination notice issued, subject to compliance with clause 4.1 and 6 above.
- 9.3 In the event where, in the reasonable opinion of the Society, the Client is in breach, or is suspected to be in breach of clause 16 of the Conditions, the Society shall have the right to terminate the Services (and the relevant contracts associated) with immediate effect.

10. FORCE MAJEURE

- 10.1 Neither Party shall be responsible or liable for any failure to fulfil any term or provision of the Conditions if and to the extent that fulfilment has been delayed or temporarily prevented by a force majeure occurrence without the fault or negligence of the Party affected and which, by the exercise of reasonable diligence, the said Party is unable to provide against.
- 10.2 For the purpose of this clause, force majeure shall mean any circumstance not being within a Party's reasonable control including, but not limited to: acts of God, natural disasters, epidemics or pandemics, wars, terrorist attacks, riots, sabotages, impositions of sanctions, embargoes, nuclear, chemical or biological contaminations, laws or action taken by a government or public authority, quotas or prohibition, expropriations, destructions of the worksite, explosions, fires, accidents, any labour or trade disputes, strikes or lockouts.

11. CONFIDENTIALITY

- 11.1 The documents and data provided to or prepared by the Society in performing the Services, and the information made available to the Society, are treated as confidential except where the information:
- is properly and lawfully in the possession of the Society;
 - is already in possession of the public or has entered the public domain, otherwise than through a breach of this obligation;
 - is acquired or received independently from a third party that has the right to disseminate such information;
 - is required to be disclosed under applicable law or by a governmental order, decree, regulation or rule or by a stock exchange authority (provided that the receiving Party shall make all reasonable efforts to give prompt written notice to the disclosing Party prior to such disclosure).
- 11.2 The Parties shall use the confidential information exclusively within the framework of their activity underlying these Conditions.
- 11.3 Confidential information shall only be provided to third parties with the prior written consent of the other Party. However, such prior consent shall not be required when the Society provides the confidential information to a subsidiary.
- 11.4 Without prejudice to sub-clause 11.1, the Society shall have the right to disclose the confidential information if required to do so under regulations of the International Association of Classifications Societies (IACS) or any statutory obligations.

12. INTELLECTUAL PROPERTY

- 12.1 Each Party exclusively owns all rights to its Intellectual Property created before or after the commencement date of the Conditions and whether or not associated with any contract between the Parties.
- 12.2 The Intellectual Property developed by the Society for the performance of the Services including, but not limited to drawings, calculations, and reports shall remain the exclusive property of the Society.

13. ASSIGNMENT

- 13.1 The contract resulting from to these Conditions cannot be assigned or transferred by any means by a Party to any third party without the prior written consent of the other Party.
- 13.2 The Society shall however have the right to assign or transfer by any means the said contract to a subsidiary of the Bureau Veritas Group.

14. SEVERABILITY

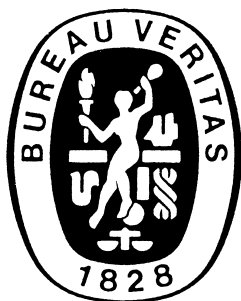
- 14.1 Invalidity of one or more provisions does not affect the remaining provisions.
- 14.2 Definitions herein take precedence over other definitions which may appear in other documents issued by the Society.
- 14.3 In case of doubt as to the interpretation of the Conditions, the English text shall prevail.

15. GOVERNING LAW AND DISPUTE RESOLUTION

- 15.1 These Conditions shall be construed and governed by the laws of England and Wales.
- 15.2 The Parties shall make every effort to settle any dispute amicably and in good faith by way of negotiation within thirty (30) days from the date of receipt by either one of the Parties of a written notice of such a dispute.
- 15.3 Failing that, the dispute shall finally be settled under the Rules of Arbitration of the Maritime Arbitration Chamber of Paris ("CAMP"), which rules are deemed to be incorporated by reference into this clause. The number of arbitrators shall be three (3). The place of arbitration shall be Paris (France). The Parties agree to keep the arbitration proceedings confidential.

16. PROFESSIONAL ETHICS

- 16.1 Each Party shall conduct all activities in compliance with all laws, statutes, rules, economic and trade sanctions (including but not limited to UN sanctions and EU sanctions) and regulations applicable to such Party including but not limited to: child labour, forced labour, collective bargaining, discrimination, abuse, working hours and minimum wages, anti-bribery, anti-corruption, copyright and trademark protection, personal data protection (<https://personal.dataprotection.bureauveritas.com/privacypolicy>).
- Each of the Parties warrants that neither it, nor its affiliates, has made or will make, with respect to the matters provided for hereunder, any offer, payment, gift or authorization of the payment of any money, directly or indirectly, to or for the use or benefit of any official or employee of the government, political party, official or candidate.
- 16.2 In addition, the Client shall act consistently with the Bureau Veritas' Code of Ethics. <https://group.bureauveritas.com/group/corporate-social-responsibility>



RULE NOTE NR 546

NR 546

Hull in Composite Materials and Plywood, Material Approval, Design Principles, Construction and Survey

SECTION 1	GENERAL REQUIREMENTS AND CALCULATION PRINCIPLES
SECTION 2	SCANTLING CRITERIA AND HULL STRENGTH ANALYSIS
SECTION 3	MAIN STRUCTURE ARRANGEMENTS AND SPECIAL FEATURES
SECTION 4	RAW MATERIALS FOR LAMINATES
SECTION 5	INDIVIDUAL LAYERS FOR LAMINATES
SECTION 6	LAMINATE CHARACTERISTICS AND PANEL ANALYSIS
SECTION 7	STIFFENER ANALYSIS
SECTION 8	PLATE AND STIFFENER ANALYSIS FOR PLYWOOD STRUCTURE
SECTION 9	SCANTLING OF PILLARS IN COMPOSITE MATERIALS
SECTION 10	COMPOSITE SHAFT LINE
SECTION 11	HULL CONSTRUCTION, SURVEY, TANK TESTS AND MECHANICAL TESTS AND RAW MATERIAL HOMOLOGATION
APPENDIX 1	RAW MATERIAL HOMOLOGATION PROCEDURE

Section 1 General Requirements and Calculation Principles

1	General	9
1.1	Application	
1.2	Definitions	
2	Rule Note application	10
2.1	Hull in composite material	
2.2	Hull in plywood material	
3	Calculation principles of hull structure	10
3.1	General	
3.2	Calculation principles for panels	
3.3	Calculation principles for secondary and primary stiffeners	
3.4	Calculation principles for gluing structure connections	
4	Drawings and documents to be submitted	11
4.1	General	
4.2	Additional drawings and documents to be submitted for hull built in composite materials	
4.3	Additional drawings and documents to be submitted for hull built in plywood materials	

Section 2 Scantling Criteria and Hull Strength Analysis

1	Hull structure scantling criteria	13
1.1	General	
1.2	Types of stresses considered	
1.3	Minimum rule safety factors	
2	Local scantling analysis	14
2.1	Application	
2.2	Local loads	
3	Global strength scantling analysis	15
3.1	Application	
3.2	Global loads	
3.3	Global strength check	
4	Calculation of global strength for monohull ship	15
4.1	General	
4.2	Strain and stress in the transverse reference section	
4.3	Strength characteristics of the transverse reference section	
5	Calculation of global strength for multihull	16
5.1	General	
5.2	Global strength of superstructure platform catamaran	
6	Global strength and local scantling analysis	17
6.1	General	

Section 3 Main Structure Arrangements and Special Features

1	General	18
1.1	Application	
2	Structural continuity of hull girder	18
2.1	General principles for longitudinal hull girder	
2.2	General principles for platform of multihull	
3	Subdivision, compartment and access arrangements	18
3.1	General	
4	Arrangement of hull openings	18
4.1	General	
5	Bottom structure arrangements	18
5.1	General arrangement	
5.2	Longitudinal framing arrangement of single bottom	
5.3	Transverse framing arrangement of single bottom	
5.4	Double bottom arrangement	
6	Side structure arrangements	19
6.1	Framing system	
6.2	Stiffener arrangements	
6.3	Openings in the shell plating	
7	Deck structure arrangements	20
7.1	General	
7.2	Opening arrangements	
7.3	Pillar arrangement under deck	
7.4	Deck structure in way of lifesaving appliances	
8	Bulkhead structure arrangements	20
8.1	General	
8.2	Watertight bulkheads	
8.3	Non-tight bulkheads	
8.4	Bulkheads acting as pillars	
8.5	End stiffener connections	
9	Superstructure and deckhouse arrangements	21
9.1	Superstructure materials	
9.2	Connections of superstructures and deckhouses with the hull structure	
9.3	Structural arrangement of superstructures and deckhouses	
10	Other structures	22
10.1	Machinery spaces	
10.2	Bulwark	
10.3	Helicopter deck and platform	
10.4	Hull structure reinforcement for navigation in ice	
11	Special features	24
11.1	Bow doors, bow visors and inner doors	
11.2	Side doors and stern doors	
11.3	Hatch covers	
11.4	Rudders	
11.5	Water jet propulsion tunnel	
11.6	Foils and trim supports	

- 11.7 Propeller shaft bracket
- 11.8 Lifting appliances
- 11.9 Equipment in chain and anchor

Section 4 Raw Materials for Laminates

1	General	26
1.1	Application	
1.2	Definitions	
1.3	Certification of raw materials	
2	Resin systems	27
2.1	General	
2.2	Resin system types	
2.3	Resin mechanical characteristics	
3	Reinforcements	29
3.1	General	
3.2	Fibre types	
3.3	Reinforcement fabrics	
4	Core materials	31
4.1	General	
4.2	Foam cores	
4.3	Wood cores	
4.4	Honeycombs	
5	Structural adhesives	36
5.1	General	
5.2	Structural gluing joint characteristics	

Section 5 Individual Layers for Laminates

1	General	37
1.1	Application	
2	Geometrical and physical properties of an individual layer	37
2.1	Fibre/resin mix ratios	
2.2	Individual layer thickness	
2.3	Density of an individual layer	
3	Elastic coefficients of an individual layer	38
3.1	Unidirectional	
3.2	Woven roving	
3.3	Chopped strand mat	
3.4	Combined fabric	
4	In-plane rigidity and flexibility of an individual layer	40
4.1	In-plane characteristics	
5	In-plane theoretical individual layer breaking stresses	40
5.1	Definitions	

Section 6 Laminate Characteristics and Panel Analysis

1	Application	42
	1.1 General	
	1.2 Laminate calculation methodology	
2	Laminate basic characteristics	43
	2.1 General	
	2.2 Elastic coefficients of laminates	
	2.3 Matrix notation	
3	Laminate behaviour under bending moments, shear forces and in-plane forces	45
	3.1 General	
	3.2 Laminate behaviour under bending moments M_i and in-plane forces N_i	
	3.3 Laminate behaviour under out plane shear forces T_i	
4	Laminate behaviour under in-plane buckling	46
	4.1 General	
	4.2 Buckling of monolithic laminate	
	4.3 Buckling of sandwich laminate	
5	Rules analysis of panel under local loads	49
	5.1 General	
	5.2 Bending moments and transverse shear forces calculation for panel under sea or internal pressures	
	5.3 Bending moments and transverse shear forces for bottom panel under slamming loads	
	5.4 Bending moments and transverse shear forces for side shell panel under impact pressure	
	5.5 Bending moments and transverse shear forces calculation for deck panel under wheeled loads	
	5.6 Bending moments and transverse shear forces calculation for side shell panel under lateral ice loads	
6	Rule analysis of panel under global loads	53
	6.1 General	
7	Rule analysis of panel under global and local loads	53
	7.1 Application	

Section 7 Stiffener Analysis

1	General	55
	1.1 Application	
	1.2 Stiffener calculation methodology	
2	Stiffener basic characteristics	55
	2.1 General	
	2.2 Stiffener characteristics	
3	Stiffener behaviour under bending moments, shear forces and axial forces	57
	3.1 Stiffener behaviour under bending moment and shear forces	
	3.2 Stiffener behaviour under axial forces	

4	Rule analysis of stiffeners under local loads	58
4.1	General	
4.2	Bending moment and shear force calculation	
5	Rule analysis of stiffeners under global loads	60
5.1	General	
6	Rule analysis of stiffeners under global and local loads	61
6.1	Application	
7	Scantling of brackets at ends of secondary and primary stiffeners	61
7.1	General requirements	
8	Large openings in webs of primary stiffeners	62
8.1	Calculation methodology	
9	Analysis of specific stiffeners	63
9.1	Stiffeners made with plywood and composite materials	
9.2	Curved stiffeners	
10	Stiffener characteristics for 2D or 3D beam model	63
10.1	Stiffener parameters	
11	Stiffener connection with attached plate	66
11.1	Connection by bonded angle	
11.2	Connection by adhesive joint	

Section 8 Plate and Stiffener Analysis for Plywood Structure

1	Hull structure scantling criteria	68
1.1	General	
1.2	Local and global scantling analyses	
1.3	Minimum rule safety factors	
2	Material	70
2.1	Timber species	
2.2	Plywood	
2.3	Plywood certification	
3	Plywood panel scantling	71
3.1	Plywood under local loads	
3.2	Plywood under global loads	
3.3	Plywood under global and local loads	
3.4	Plywood panel combined with composite laminates	
4	Secondary and primary stiffener analysis and scantling approach	71
4.1	Plywood stiffener under local loads	
4.2	Plywood stiffener under global loads	
4.3	Plywood stiffener under global and local loads	
4.4	Plywood stiffener arrangement	
5	Working process and material	72
5.1	General	
5.2	Structural adhesives	

Section 9 Scantling of Pillars in Composite Materials

1	General	73
	1.1 Application	
2	Pillar basic characteristics	73
	2.1 General	
3	Pillar scantling	74
	3.1 Pillar scantling under compression load	
	3.2 Pillar scantling under compressive force and bending moment	
	3.3 Pillars in tanks	
4	Vertical bulkheads acting as pillar	76
	4.1 General	

Section 10 Composite Shaft Line

1	General	77
	1.1 Application	
	1.2 Operational conditions	
	1.3 Materials	
	1.4 Documents to be submitted	
2	Test and survey at works	78
	2.1 General	
3	Scantling check	78
	3.1 General	
4	Design check of shaft line under static loads	78
	4.1 Loads	
	4.2 Strain and stresses in the composite shaft line	
	4.3 Scantling criteria under static loads	
5	Buckling analysis	79
	5.1 General	
6	Design check of shaft vibration	80
	6.1 Critical speeds	
	6.2 Checking criteria	
7	Design check under fatigue	80
	7.1 General	
	7.2 Fatigue analysis methodology	
8	Shaft line coupling	81
	8.1 Scantling check of connection	
9	Calculation methodology proposal	81
	9.1 Static loads	

Section 11 Hull Construction, Survey, Tank tests and Mechanical Tests and Raw Material Homologation

1	General	83
	1.1 Scope	
2	Homologation and certification of raw materials	83
	2.1 General	
3	Structure design assessment	83
	3.1 General	
4	Mechanical tests on laminate test panels	83
	4.1 General	
	4.2 Mechanical type tests	
5	Hull construction and shipyard procedures	85
	5.1 Shipyard details and procedures	
	5.2 Materials	
	5.3 Laminating procedures	
	5.4 Non Destructive Testing (NDT)	
	5.5 Tank and weathertight structure testing	
6	Survey for unit production	87
	6.1 General	
7	Alternative survey scheme for production in large series	87
	7.1 General	
	7.2 Type approval	
	7.3 Quality system documentation	
	7.4 Manufacturing, testing and inspection plan (MTI plan)	
	7.5 Society's certificate	
	7.6 Other certification scheme for production in large series	

Appendix 1 Raw Material Homologation Procedure

1	General	90
	1.1 Application	
2	Design type approval of raw materials	90
	2.1 Approval test program	
3	Work's recognition	90
	3.1 General	
4	Equivalent raw material homologation process	90
	4.1 General	

SECTION 1

GENERAL REQUIREMENTS AND CALCULATION PRINCIPLES

1 General

1.1 Application

1.1.1 General scope of application

The requirements of this Rule Note are applicable to ships having their hull and superstructure totally or partly made of composite materials or plywood.

The purpose of this Rule Note is to define the general requirements for hull scantling and arrangements, with respect to:

- raw material
- methodology of composite and plywood calculation
- hull structure calculation approach
- classification and /or certification process.

1.1.2 Other applicable Rules

The requirements of this Rule Note apply in addition to the following Society Rules for the classification and/or certification of ships, in particular the requirements concerning:

- Classification and surveys:

NR467, Part A: Rules for the Classification of Steel Ships, Classification and Surveys
- Loading cases and scantling safety factors:
 - NR600: Hull Structure and Arrangement for the Classification of Cargo Ships less than 65 m and Non Cargo Ships less than 90 m
 - NR500: Rules for the Classification and the Certification of Yachts.
- Subdivision, compartment and access arrangements and arrangement of hull openings, as applicable:
 - NR600: Hull Structure and Arrangement for the Classification of Cargo Ships less than 65 m and Non Cargo Ships less than 90 m, or
 - NR566: Hull arrangement, Stability and Systems for ships less than 500 GT
 - NR500: Rules for the Classification and the Certification of Yachts.

Other Rules Notes may be considered by the Society in accordance with the service notations and additional service features considered for the classification (see NR467, Part A).

1.1.3 Structural scopes not covered by Rules

The following structural aspects are not covered by the present Rules:

- structure deflection under loads
- structural response to vibrations induced by engines, propeller blades or water jet.

1.1.4 Exceptions

Ships with unusual design, materials, speed or service, or intended to carry special cargoes not provided by the Rules are examined on a case-by-case basis.

1.1.5 Working process and inspection at works

Inspections needed by the Society during ship hull construction within the scope of the classification and/or certification of ships built in unit production or in mass production are defined in Sec 11.

The homologation process of raw materials to grant the hull construction marks $\boxtimes$ or $\bullet$ within the scope of classification and/or certification is defined in Sec 11.

1.2 Definitions

1.2.1 General

In the present Rule Note, the meaning of the following terms is:

- Laminate:

material made from several individual layers. The term laminate is used for panel (hull, superstructure or bulkhead) and for basic stiffener elements (attached plating, web or flange)
- Composite structure:

used for panel, secondary or primary stiffeners
- Secondary stiffener:

stiffener supporting panels
- Primary stiffener:

stiffener supporting secondary stiffeners.

1.2.2 Platform of multihull

A platform of multihull is a strength structure connecting the hulls by primary cross transverse structure elements. These transverse elements may be cross beams or cross bulkheads.

The part of the platform directly exposed to sea effect is designed as platform bottom.

The upper part of the platform and the upper decks are defined as platform deck.

2 Rule Note application

2.1 Hull in composite material

2.1.1 The following steps are to be carried out within the scope of classification and/or certification of ships built in composite materials, from a structural point of view:

- raw materials: certification or equivalent process to grant the hull construction marks ☒ or • (see Sec 11)
- calculation of the theoretical mechanical characteristics of the laminates used for panels and for basic elements of stiffeners (flange, web and attached plating) as defined in Sec 5 (individual layers) and Sec 6 (laminates)
- mechanical sample tests representative of the hull's structure building to compare with the theoretical mechanical characteristics (see Sec 11)
- structure drawings examination
- preliminary survey of the yard and survey at work as defined in Sec 11.

2.1.2 The composite's structure characteristics are directly depending on the type of:

- resin
- fibre
- reinforcement fabric
- hull's manufacturing process.

All these particulars are taken into account in the present Rule Note to characterize the composite materials from a mechanical point of view.

2.1.3 The composite materials considered in this present Rule Note are basically those made from:

- thermoset resin's systems
- glass, carbon or para-aramid based reinforcement fabrics
- manufacturing processes as lay-ups (spray and hand), vacuums (infusion) or pre-pregs.

Composite materials made of other resin's systems, fibres or manufacturing processes may be accepted, provided their specifications are submitted to the Society for approval.

2.2 Hull in plywood material

2.2.1 The following steps are to be carried out within the scope of classification and/or certification of a ship built in plywood, from a structural point of view:

- plywood material certification or equivalent process for the assignment of the hull construction mark ☒ or • (see Sec 8, [2.3])
- structure drawings examination
- preliminary survey of the yard and survey at work as defined in Sec 11.

2.2.2 The plywood's characteristics are directly depending on the timber species, ply number and thickness of each ply.

These particulars are taken into account in the present Rule Note to characterize the plywood material from a mechanical point of view and for hull structure review (see Sec 8).

3 Calculation principles of hull structure

3.1 General

3.1.1 As a general rule, the review of hull structure is to be carried out under the effect of local loads (pressure and forces directly applied to the individual structural members).

When applicable according to Sec 2, [3.1.1], the review of hull structure is to be also carried out under global hull girder loads (forces and moments which result from effects of local loads acting on the ship as a whole and considered as a beam).

3.1.2 Global hull girder and local strength

As a rule, the global hull girder strength and the local strength are examined independently, as follows:

- the local scantling is examined on the basis of local permissible safety factors defined in relation to the type of local loads applied as defined in Sec 2, [2] and the type of structure element.
- the global scantling of the hull girder and of the platform of multihull is examined as defined in Sec 2, [3], on the basis of a minimum permissible safety factor and a buckling check of elements contributing to the global hull girder strength.

3.1.3 Particular case

A combination between the global hull girder stresses and the local stresses analysis may be carried out as defined in Sec 2, [6] when deemed necessary by the Society (see applicable Society Rules defined in [1.1.2]).

3.2 Calculation principles for panels

3.2.1 General

The scantling of composite and plywood panels are to be checked according to the methodology defined in Sec 6, Tab 1 and Sec 8, [3] respectively.

3.2.2 Panel buckling analysis

When panels are checked under global hull girder loads, a panel buckling analysis is to be carried out.

The two following buckling cases are to be considered:

- panel submitted to compression stress
- panel submitted to shear stress.

The plate panels to be checked under buckling criteria are mainly:

- a) Under compression due to longitudinal global loads (hull of monohull and floats of catamaran):
 - bottom and deck panels
 - side shell panels below strength deck and above bottom areas
- b) Under compression due to transverse global bending of catamaran induced by torsion (primary transverse structure of platform):
 - bottom and deck panels of platform
- c) Under shear:
 - side shell panels of monohull and floats of catamarans
 - primary cross transverse structure bulkheads of platform of catamarans.

3.3 Calculation principles for secondary and primary stiffeners

3.3.1 General

The scantling of composite and plywood secondary and primary stiffeners are to be checked according to the methodology defined in Sec 7, Tab 1 and Sec 8, [4] respectively.

3.3.2 Stiffener buckling analysis

When continuous stiffeners are checked under global hull girder loads, a stiffener buckling analysis is to be carried out.

The continuous stiffeners to be checked under buckling criteria are mainly:

- a) Due to longitudinal global loads (hull of monohull and floats of catamaran):
 - bottom and deck stiffeners
 - side shell stiffeners below strength deck and above bottom areas.
- b) Due to transverse global bending of catamaran induced by torsion (primary transverse structure of platform):
 - bottom and deck stiffeners of platform.

3.4 Calculation principles for gluing structure connections

3.4.1 General

Gluing structure connections are adhesive joints where structure elements are bonded by placing a layer of adhesive or resin system between the structure elements.

As a rule, adhesive structure connections are examined by direct calculation taking into account the shear force applied to the adhesive joints, the surface of the joint, the gluing joint characteristics defined in Sec 4, [5] and the safety factor defined in Sec 2, [1.3.5].

Where gluing structure connection are submitted to tension or out of plane forces (cleavage, peel...) due to the joint geometry, or where adhesive with shear elongation at break greater than 10% are used, the gluing structure connection is to be examined on a case by case basis.

4 Drawings and documents to be submitted

4.1 General

4.1.1 As a rule, the drawings and documents to be submitted for hull structure review are listed in the Rules for the classification of ships (see [1.1.2]).

Builder's quality systems checking the general production fabrication and process are to be submitted for review (see Sec 11).

4.2 Additional drawings and documents to be submitted for hull built in composite materials

4.2.1 Laminate

Following informations are to be specified on drawings:

- arrangement of the laminates for the various structural elements (thickness, definition of the successive layers of reinforcement specifying for each layer the mass per square meter of reinforcement, the proportion in mass or in volume of reinforcement, the directions of roving and unidirectional reinforcements, the dimension of lap joint between layers)
- direction of the laminates in relation with the ship structure
- details of the connections between various structural elements.

4.2.2 Individual layer

The technical specifications of suppliers with indication of the types, trademarks and references of the resins and gel-coats, reinforcements and core materials are to be specified.

These specifications are to give the following informations:

- for resins:
 - system (polyester, vinylester or epoxy), density, Young modulus, shear modulus, Poisson coefficient, breaking strength and elongation at break
- for reinforcements (unidirectional reinforcements, woven rovings, chopped strand mats):
 - fibre's quality (type, density and breaking strength, Young modulus and Poisson coefficient in fibre direction and normal to fibre direction), mass per square meter, thickness and, for woven roving, weft-warp distribution
- for core materials:
 - type and quality, density, tensile, compression and shear strengths and elasticity moduli.
- for adhesive used for structural joints:
 - adhesive system, density, Young modulus, shear modulus, Poisson coefficient, breaking strength and elongation at break in tensile and shear.

4.3 Additional drawings and documents to be submitted for hull built in plywood materials

4.3.1 Additional drawings and documents, as listed as follows, are to be submitted:

- plywood technical specification of the supplier with indication of wood species, bond type, total thickness, plies thicknesses, Young moduli and bending breaking stresses in the two main directions of the panels
- direction of plywood panels in relation with the ship structure
- panel joining and stiffener joining, indicating the structure continuity of strength.
- for adhesive used for structural joints:
adhesive system, density, Young modulus, shear modulus, Poisson coefficient, breaking strength and elongation at break in tensile and shear.

SECTION 2

SCANTLING CRITERIA AND HULL STRENGTH ANALYSIS

Symbols

C_V	: Rule partial safety factor taking into account the ageing effect on the laminates
C_F	: Rule partial safety factor taking into account the fabrication process and the reproducibility of the fabrication, directly linked to the mechanical characteristics of the laminates
C_R	: Rule partial safety factor taking into account the type and the direction of main stresses applied to the fibres of the reinforcement fabric of the laminates
C_{CS}	: Rule partial safety factor for combined stresses in the individual layers of the laminates
C_i	: Rule partial safety factor taking into account the type of loads (sea pressure, dynamic sea pressure or internal pressure)
C_{Buck}	: Rule partial safety factor for laminate panel buckling.

1 Hull structure scantling criteria

1.1 General

1.1.1 Scantling criteria for composite structure

The hull structure scantling criteria are based on the calculation principles defined in Sec 1, [3] and safety factors.

The actual safety factors are equal to the ratio between:

- the theoretical breaking stresses of each individual layers of laminates (defined in Sec 5, [5]) or, when applicable, the critical buckling stress of the whole laminate (defined in Sec 6, [4]) or the stiffener (defined in Sec 7, [3.2.2]), and
- the actual applied stresses induced by local or global loads.

The actual safety factors are to be greater than the minimum rule safety factors defined in [1.3].

Note 1: Breaking stresses directly deduced from mechanical tests may be taken over from theoretical breaking stresses defined in Sec 5 if mechanical test results are noticeably different from expected values.

1.1.2 Scantling criteria for plywood structure

The hull structure scantling criteria are defined in Sec 8.

1.2 Types of stresses considered

1.2.1 The different types of stresses considered to estimate the actual safety factors are:

- For main stresses analysis in each individual layer ("ply by ply" analysis):
 - Main tensile or compressive stresses σ_1 in the longitudinal direction of the fibre, mostly located in:
 - 0° direction of unidirectional tape
 - 0° and 90° directions of woven roving when the set of fibres are interweaved
 - Main tensile or compressive stresses σ_2 in the perpendicular direction of the fibre, mostly located in:
 - 90° direction of unidirectional tape or combined fabrics when the set of fibres are stitched together without criss-crossing of fibre
 - Main shear stresses parallel to the fibre located in the plane of the individual layer (τ_{12}) and/or between each individual layer (τ_{IL1} and τ_{IL2} , also designated as inter-laminar shear stresses).
- For combined stress analysis in each individual layer ("ply by ply" analysis):
 - Combined stresses calculated according to the Hoffman criterion
- For buckling analysis in the whole laminate:
 - Compression stresses in the longitudinal and transverse directions of the panel or structure element
 - Shear stresses in the plane of the panel or structure element.

1.3 Minimum rule safety factors

1.3.1 General

The minimum rule safety factors are defined in relation with partial safety factors C_V , C_F , C_R , C_i , C_{CS} and C_{Buck} .

These partial safety factors are to be taken equal, at least, to the minimum values defined in the applicable Society Rules for the classification and/or the certification of ships (see Sec 1, [1.1.2]).

1.3.2 Main stresses analysis in individual layers

The minimum rule safety factor SF in each layer is to fulfil the following condition:

$$SF \geq C_V \cdot C_F \cdot C_R \cdot C_i$$

1.3.3 Combined stresses analysis in individual layers

The minimum rule safety factor SF_{CS} , applicable to the combined stresses in each layer, is to fulfil the following condition:

$$SF_{CS} > SF_{CSiapp}$$

where:

$$SF_{CS} = C_{CS} \cdot C_V \cdot C_F \cdot C_i$$

SF_{CSiapp} : Equal to the positive value of:

$$SF_{CSiapp} = \frac{-b \pm \sqrt{b^2 + 4a}}{2a}$$

with:

$$a = \frac{\sigma_1^2}{|\sigma_{brc1} \sigma_{brt1}|} + \frac{\sigma_2^2}{|\sigma_{brc2} \sigma_{brt2}|} - \frac{\sigma_1 \sigma_2}{|\sigma_{brc1} \sigma_{brt1}|} + \frac{\tau_{12}^2}{\tau_{br12}^2}$$

$$b = \frac{\sigma_1(|\sigma_{brc1}| - |\sigma_{brt1}|)}{|\sigma_{brc1} \sigma_{brt1}|} + \frac{\sigma_2(|\sigma_{brc2}| - |\sigma_{brt2}|)}{|\sigma_{brc2} \sigma_{brt2}|}$$

σ_i, τ_{12} : Actual stresses, in N/mm², in the considered local ply axis induced by the loading case considered and calculated as defined in Sec 6 for panels and Sec 7 for stiffeners

$\sigma_{bri}, \tau_{br12}$: Ply theoretical breaking stresses, in N/mm², in the local ply axis, as defined in Sec 5, [5].

Note 1: The combined criterion SF_{CSiapp} is obtained from the following equation:

$$SF_{CSiapp}^2 \cdot F_{ij} \cdot \sigma_i \cdot \sigma_j + SF_{CSiapp} \cdot F_i \cdot \sigma_i > 1$$

1.3.4 Buckling stresses in the whole laminate

The minimum buckling rule safety factor SF_B , applicable to the whole laminate panel or stiffener is to fulfil the following condition:

$$SF_B \geq C_{Buck} \cdot C_F \cdot C_V \cdot C_i$$

1.3.5 Shear stress in gluing structural connections

The safety factor equal to the ratio between the theoretical shear breaking stresses of the gluing joint defined in Sec 4, [5.2] and the actual applied shear stress in the connection is to fulfil the following condition:

$$SF \geq 2,4 C_F C_i$$

where:

C_F, C_i : Coefficient defined in the applicable Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

Gluing structural connection are examined on a case by case basis when out of plane forces in the joint are expected to occur due to the joint geometry.

2 Local scantling analysis

2.1 Application

2.1.1 The local scantling of panels, secondary and primary stiffeners is to be reviewed according to the:

- local loads as defined in [2.2]
- rule analysis as defined in Sec 6 for panels and in Sec 7 for stiffeners
- minimum rule safety factors as defined in [1.3] for laminates and in Sec 8 for plywood structure.

2.2 Local loads

2.2.1 General

The rule local loads considered for the structure analysis are the external and internal loads defined in the applicable Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

As a general rule, the different types of local loads to be considered are:

a) sea pressures:

These static loads, induced by still water loads and wave loads are considered as uniform on the local structure (these loads are applied to bottom, side, deck and superstructure).

b) dynamic sea pressures:

The dynamic sea pressures are loads which have a duration shorter than the period of wave loads and are constituted by:

- bottom slamming loads: Non-uniform loads on the bottom structures where slamming may occur
- impact loads on side shell and cross deck of catamaran: These dynamic loads represent a wave impact on side shell and are considered as loads locally distributed on the structure as a column of water of 0,6 m diameter.

Note 1: Side shell primary stiffeners and cross deck primary stiffeners are, as a general rule, examined with sea pressures only, without taking into account the side shell and cross deck impacts.

c) local internal pressures:

Local internal pressures are loads induced by liquid cargoes, dry cargoes, accommodations, testing loads and flooding loads.

d) wheel loads on deck when applicable.

2.2.2 Local load point location

Unless otherwise specified, the local loads are to be calculated:

a) for sea pressures and local internal pressure on:

- panels: at the lower edge of the panel for monolithic panel, and at the middle of the panels for sandwich panel
- longitudinal stiffeners: at mid-span of the stiffeners
- transverse stiffeners: at the lower point (p_{slower}) and at the upper point (p_{supper}) of the stiffeners.

b) for dynamic sea pressures on:

- panels: at the middle of the panels
- longitudinal and transverse stiffeners: at mid-span of the stiffeners.

3 Global strength scantling analysis

3.1 Application

3.1.1 Global hull girder longitudinal strength

As a rule, the global hull girder longitudinal strength is to be examined as defined in [4], for monohull ships and for floats of catamarans, in the following cases:

- ships with length greater than 30 m, or
- ships having large openings in decks or significant geometrical structure discontinuity at bottom or deck, or
- ships with a transverse framing system, or
- ships with deck structure made of panels with small thicknesses and stiffeners with large spacings, or
- ships with important deadweight, or
- where deemed appropriate by the Society.

Note 1: For ships not covered by the above cases, the hull girder strength is considered satisfied when local scantlings are in accordance with requirements defined in Article [2].

3.1.2 Global transverse strength of catamaran

As a rule, the global transverse strength of catamaran is to be examined as defined in Article [5] for all types of catamaran.

3.1.3 Finite element calculation

The global strength analysis may also be examined with a Finite Elements Analysis submitted by the designer. In this case and where large openings are provided in side shell and/or in transverse cross bulkhead of catamaran, a special attention is to be paid to ensure a realistic modelling of the bending and shear strengths of the window jambs between windows.

3.2 Global loads

3.2.1 As a general rule, the different types of global loads to be considered and inducing overall bending moment and shear force acting on the hull and/or platform of catamaran are:

- Still water loads: the longitudinal distribution of ship lightweight, the weights carried in the ship and the buoyancy, and
- Wave loads: the distribution of wave loads in head sea and/or quartering sea conditions.

The global still water and waves loads, their combination and the calculation of the overall bending moment considered for the global hull structure rule analysis are defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

3.3 Global strength check

3.3.1 General

The global analysis check is to be successively carried out taking into account the minimum rule safety factors based on main stresses and combined stresses in individual layers, and on buckling stresses in the whole laminates (see [1.3]).

The global analysis check is to be carried out for the structure elements contributing to the overall hull girder strength in the following areas of the hull:

- in head sea condition (for monohull and multihull):
Along the ship from 0,30L to 0,7L from the aft end
- in quartering sea and digging in condition (for multihull only):
Along the float from aft to fore end, and in way of each primary transverse cross structure of the platform.

4 Calculation of global strength for monohull ship

4.1 General

4.1.1 Calculation of the hull girder strength characteristics is to be carried out taking into account all longitudinal continuous structural element of the hull.

A superstructure extending over at least 0,4 L may generally be considered as contributing to the longitudinal strength.

The transverse sectional areas of openings such as deck hatches, side shell ports, side shell and superstructure doors and windows in the members contributing to the longitudinal hull girder strength, are to be deduced from the considered transverse section.

Lightening holes, draining holes and single scallops in longitudinal stiffeners need not be deducted if their height is less than 0,25 h_{wv} , without being greater than 75 mm,

where:

h_{wv} : Web height, in mm, of the considered longitudinal.

4.2 Strain and stress in the transverse reference section

4.2.1 Strain and stress in the transverse reference section

The overall longitudinal bending strain ϵ_{Aref} in‰ and stress σ_{Aref} in N/mm², in any point of a transverse reference section are obtained from the following formulae:

$$\epsilon_{Aref} = \frac{M_v}{Z_{Aref} \cdot E_{ref}} \cdot 10^{-1}$$

$$\sigma_{Aref} = \frac{E_{ref}}{100} \cdot \epsilon_{Aref}$$

where:

M_v : Vertical overall longitudinal bending moment of the combination global loads in head sea condition, in kN·m, calculated as indicated in the applicable Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2])

- Z_{Aref} : Section modulus calculated for the reference section according to [4.3]
- E_{ref} : Arbitrary reference Young modulus value chosen for the transverse section, in N/mm².

4.2.2 Strain and stress in structure element

The overall longitudinal bending stress σ_A , in N/mm², and strain ε_A , in % in any point of a structure element of a transverse section, is obtained from the following formula:

$$\sigma_A = \frac{E_i}{100} \cdot \varepsilon_{Aref}$$

$$\varepsilon_A = \frac{\sigma_A}{100 E_i}$$

where:

- E_i : Actual Young modulus of the considered element contributing to the longitudinal strength, in N/mm², defined in Sec 6, [2.2.1] for laminate and in Sec 7, [2.2.3] for stiffener
- ε_{Aref} : Overall longitudinal bending strain as defined in [4.2.1], in %.

4.3 Strength characteristics of the transverse reference section

4.3.1 Where the members contributing to the longitudinal strength are made in various composite materials, the bending rigidity and the neutral axis of the hull girder transverse sections are to be calculated taking into account the different Young moduli of the longitudinal members.

A transverse reference section inertia of the hull girder is to be calculated, taking into account the different Young moduli of the members, by a modification of the thicknesses t_{ref} , in mm, obtained as follows:

$$t_{ref} = t \cdot \frac{E_i}{E_{ref}}$$

where:

- t : Actual thickness of the element considered, in mm
- E_i : Actual Young modulus of the element considered, in N/mm²
- E_{ref} : Arbitrary reference Young modulus value chosen for the transverse reference section, in N/mm².

4.3.2 Section modulus

The reference section modulus Z_{Aref} , in any point of a transverse section along the hull girder, is given, in m³, by the following formula:

$$Z_{Aref} = \frac{I_{Yref}}{|Z - N|}$$

where:

- I_{Yref} : Moment of inertia, in m⁴, of the transverse reference section considered, calculated with the arbitrary reference Young modulus E_{ref} with respect to the horizontal neutral axis

- z : Z co-ordinate, in m, of the considered point in the transverse section, above the base line
- N : Z co-ordinate, in m, of the centre of gravity of the transverse reference section, above the base line.

4.3.3 Section moduli at bottom and deck

The section moduli at bottom and at deck of the reference section are given, in m³, by the following formulae:

- at bottom:

$$Z_{ABref} = \frac{I_{Yref}}{N}$$

- at deck:

$$Z_{ADref} = \frac{I_{Yref}}{V_D}$$

where:

I_{Yref} , N : Defined in [4.3.2]

V_D : Vertical distance, in m, equal to:

$$V_D = z_D - N$$

z_D : Z co-ordinate, in m, of the deck above the base line.

4.3.4 Midship section moment of inertia

As a rule, the midship section moment of inertia about its horizontal neutral axis is to fulfil the following criteria:

$$\frac{M_v \times L_{WL}^2 \times 10^{-3}}{10 \times E_{ref} \times I_{Yref}} \leq 0.003 \times L_{WL}$$

where:

M_v , E_{ref} , I_{Yref} : As defined in [4.2.1] and [4.3.2]

L_{WL} : Waterline length of the ship, in m.

5 Calculation of global strength for multihull

5.1 General

5.1.1 Type of calculation approach for catamaran

The global strength of catamaran is to be examined:

- In head sea condition: according the methodology defined in Article [4]. The moment of inertia I_{Yref} is to be calculated for only one float. Platform between floats extending over at least 0,4 L is to be considered for the calculation of I_{Yref} . In this case, I_{Yref} is to be calculated with the area b_R and b_{WD} as defined as follow (see also Fig 1):

b_R : Breadth equal to 10% of the roof longitudinal length

b_{WD} : Breadth equal to 10% of the cross deck longitudinal length

and,

- In other sea condition: according to [5.2].

The global strength of multihulls having more than two floats are to be examined on a case-by-case basis.

5.2 Global strength of superstructure platform catamaran

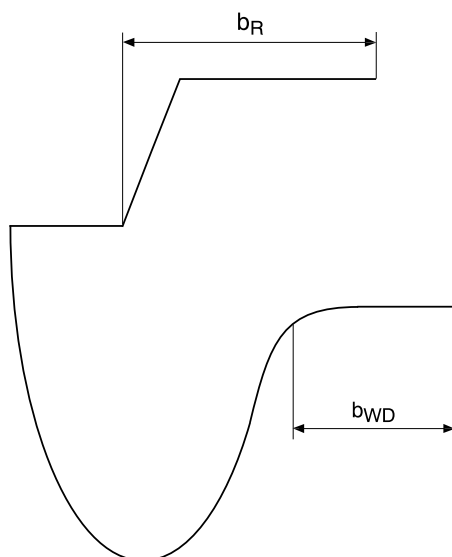
5.2.1 General

The global strength analysis of superstructure platform may be carried out by a beam model as defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]), taking into account the bending and shear stiffness of the different primary transverse bulkheads (and main beams) and of one float.

The transverses main beams are fixed in way of the inner side shell of the other float.

Any other justified global analysis may be considered.

Figure 1 : Hull girder strength area to be taken into account for continuous members (plates and stiffeners)



5.2.2 Main transverse cross deck model

Each resisting transverse member between floats is considered as a beam in the global model, taking into account:

- its bending inertia about an horizontal axis (depending mainly on the web height of the transverse cross beam or bulkhead, the roof deck thickness and the thickness of the underside of the cross deck) calculated according to [4.3]
- its vertical shear inertia (depending on the web height and thickness of the transverse cross beam or bulkhead)
- its span between inner side shells of the floats.

5.2.3 Float model

The float is modelled as a beam having, as far as possible, its:

- vertical and horizontal bending inertia calculated according to [4.3], and
- shear inertia, and
- torsional inertia about longitudinal float axis, close to the actual float values.

The transverse sections of the float to be considered are to take into account all the longitudinal continuous members (plates and longitudinal stiffeners) in the areas b_R and b_{WD} defined in [5.1.1].

5.2.4 Wave model loading

The vertical and horizontal forces loading the floats and to be considered in the beam model defined in [5.2.1] are defined in the applicable Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

As a rule, wave in quartering sea condition and digging in wave conditions are to be considered.

5.2.5 Strains and stresses in float and main transverse structure

The overall bending strain ϵ_{ref} in % and stresses σ_{Aref} in N/mm² are deduced from the beam model calculation in the float and in transverse cross beam and bulkhead.

The stress and stress in structure element are to be calculated as defined in [4.2.2].

6 Global strength and local scantling analysis

6.1 General

6.1.1 When deemed necessary by the Society, the hull scantling may be checked taking into account a combination between the global hull girder and local stresses.

6.1.2 Loads

The loads to be combined are as follow:

- local loads: Sea pressures as defined in [2.2.1]a) and internal loads as defined in [2.2.1] c) with the exception of testing and flooding loads.
- global loads:
 - For monohull: Still water loads as defined in [3.2.1] a) with wave loads in head sea condition.
 - For multihull: Still water loads with wave loads successively in head sea condition and in quartering sea condition.

Note 1: The global wave loads induced by slamming and/or digging in wave are not to be considered for the check of structure under combination between the global hull girder and local stresses.

6.1.3 Scantling criteria

The rule analysis of panels and stiffeners is to be carried out as defined in Sec 6, [7] and Sec 7, [6] respectively.

The hull structure scantling criteria are defined in Article [1].

6.1.4 Midship section moment of inertia

As a rule, the midship section moment of inertia about its horizontal neutral axis is to fulfil the criteria defined in [4.3.4].

SECTION 3

MAIN STRUCTURE ARRANGEMENTS AND SPECIAL FEATURES

1 General

1.1 Application

1.1.1 The requirements of the present Section apply to longitudinally and transversely framed structure arrangements of ships built in composite materials or plywood for:

- structural continuity of hull
- single and double bottoms
- sides and decks
- transverse and longitudinal structures
- superstructures and deckhouses
- special features.

Any other arrangement may be considered on a case-by-case basis.

Additional specific structure arrangements in relation to the service notation of the ship are to comply with the applicable requirements defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

1.1.2 Cut-out protections

As a rule, the edges of cut-outs in laminates are to be protected against water and moisture.

2 Structural continuity of hull girder

2.1 General principles for longitudinal hull girder

2.1.1 Attention is to be paid to the structural continuity:

- in way of changes in the framing system
- at the connections of primary and secondary stiffeners.

2.1.2 Longitudinal members contributing to the hull girder longitudinal strength are to extend continuously over a sufficient distance towards the ends of the ship.

Secondary stiffeners contributing to the hull girder longitudinal strength are generally to be continuous when crossing primary supporting members. Otherwise, the detail of connections is considered by the Society on a case-by-case basis.

2.1.3 Where stress concentrations may occur in way of structural discontinuity, adequate compensation and reinforcements are to be provided.

2.1.4 Openings are to be avoided, as far as practicable, in way of highly stressed areas.

Where necessary, the shape of openings is to be specially designed to reduce the stress concentration factors.

Openings are to be generally well rounded with smooth edges.

2.1.5 Primary supporting members are to be arranged in such a way that they ensure adequate continuity of strength. Abrupt changes in height or in cross-section are to be avoided.

2.2 General principles for platform of multihull

2.2.1 Attention is to be paid to the structural continuity of the primary transverse cross structure of the platform ensuring the global transversal resistance of the multihull.

The primary transverse cross structure of catamaran are generally to be continuous when crossing float structures.

The connection between the transverse cross structure of swath and struts are to be examined by direct calculation.

The general continuity principles defined in [2.1] also apply for the primary transverse cross structure of the platform.

3 Subdivision, compartment and access arrangements

3.1 General

3.1.1 Subdivision, compartment and access arrangements are to comply with the applicable requirements defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

4 Arrangement of hull openings

4.1 General

4.1.1 Arrangement of hull openings is to comply with the applicable requirements defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

5 Bottom structure arrangements

5.1 General arrangement

5.1.1 The bottom structure is to be checked by the Designer to make sure that it withstands the loads resulting from the dry-docking of the ship or the lifting by crane. These loading cases are not within the scope of the classification and/or certification.

5.1.2 Provision is to be made for the free passage of water from all the areas of the bottom to the suction, by means of scallops in floors and bottom girders.

5.1.3 Additional girders and floors may be fitted in the engine room to ensure adequate rigidity of the structure, according to the recommendations of the engine supplier.

5.1.4 If fitted, solid ballast is to be securely positioned. If necessary, intermediate girders and floors may be required.

5.1.5 Where flanges of floors and girders are at the same level, the web flange of the stiffer member is generally to be continuous. The continuity of the flange of the other member is also to be ensured.

5.1.6 As a rule, bottom girders are to be fitted in way of each line of pillars. If it is not the case, local longitudinal members are to be provided.

5.2 Longitudinal framing arrangement of single bottom

5.2.1 As a general rule, hull with a longitudinally framed single bottom are to be fitted with a continuous or intercostal centre girder.

5.2.2 Where side girders are fitted locally in lieu of the centre girder, they are to be extended over a sufficient distance beyond the ends of the existing centre girder and an additional stiffening of the bottom in the centreline area may be required.

5.2.3 Centre and side girders are to be extended as far as possible towards the ends of the hull.

5.2.4 Longitudinal secondary stiffeners are generally to be continuous when crossing primary members.

Cut-outs fitted in web of floors for the crossing of bottom longitudinals are to be taken into account for shear analysis of floors.

5.3 Transverse framing arrangement of single bottom

5.3.1 In general, the height, in m, of floors at the centreline should not be less than $B/16$. In the case of ships with considerable rise of floor, this height may be required to be increased so as to ensure a satisfactory connection to the frames.

5.3.2 The ends of floors at side are to be located in line with side transverse members.

It may be accepted on a case-by-case basis that floors ends at side be connected on a primary longitudinal member of the side shell or of the bottom.

5.3.3 Openings and cut-outs in web of bottom girders for the crossing of floors are to be taken into account for the girder shear analysis.

5.4 Double bottom arrangement

5.4.1 Double bottom height

As a general rule, the double bottom height is to be:

- sufficient to ensure access to any part of the bottom, and
- not less than 0,76 m in way of the centre girder.

5.4.2 Where the height of the double bottom varies, the variation is generally to be made gradually and over an adequate length; the knuckles of inner bottom plating are to be located in way of floors.

Where such arrangements are not possible, suitable longitudinal structures, such as partial girders, longitudinal brackets etc., fitted across the knuckles are to be fitted.

5.4.3 Adequate continuity is to be provided between double bottom area and single bottom area.

5.4.4 Floors are to be provided:

- watertight in way of transverse watertight bulkheads
- reinforced in way of double bottom steps.

6 Side structure arrangements

6.1 Framing system

6.1.1 In a transverse framing system, structure of sides is made of transverse frames, possibly supported by horizontal stringers.

6.1.2 In a longitudinal framing system, structure of sides is made of longitudinal frames supported by vertical primary supporting members.

6.2 Stiffener arrangements

6.2.1 Secondary stiffeners are normally to be continuous through primary supporting members.

Otherwise, detail of the connection is examined by the Society on a case-by-case basis.

6.2.2 In general, the section modulus of tweendeck frames is to be not less than that required for frames located immediately above.

6.2.3 Transverse web frames and secondary side frames are to be adequately attached to floors and to deck beams.

In general, frames are to be continuous or bracketed to the bottom floors.

Scantlings of the brackets connecting frames to bottom floors and deck beams are to be examined by direct calculation as indicated in Sec 7, [4].

6.3 Openings in the shell plating

6.3.1 Openings in the side shell are to be well rounded at the corners and located, as far as practicable, well clear of superstructure ends.

6.3.2 Large size openings are to be adequately compensated by means of increased lamination. Such compensation is to be partial or total, depending on the stresses occurring in the area of the openings.

6.3.3 Secondary stiffeners cut in way of side shell openings are to be attached to local structural members supported by the continuous adjacent secondary stiffeners or by any other equivalent arrangement.

6.3.4 The laminate of sea chests is generally to be equal to that of the local adjacent shell plating.

6.3.5 Openings for stabilizer fins are considered by the Society on a case-by-case basis.

7 Deck structure arrangements

7.1 General

7.1.1 Adequate continuity of strength (deck laminates and longitudinal stiffeners) is to be ensured in way of:

- stepped strength decks
- changes in the framing system
- large openings.

7.1.2 Deck supporting structures under cranes and windlass are to be adequately stiffened.

7.1.3 Pillars or other supporting structures are generally to be fitted under heavy concentrated loads on decks.

7.1.4 Stiffeners are also to be fitted in way of the ends and corners of deckhouses and partial superstructures.

7.1.5 Beams fitted at deck hatch are to be effectively supported by at least two deck girders located at each side of the deck opening.

7.2 Opening arrangements

7.2.1 The deck openings are to be as much spaced apart as possible.

As practicable, they are to be located as far as possible from the highly stressed deck areas or from the stepped deck areas.

7.2.2 An increase of lamination plate or additional reinforcements may be requested where deck openings are located:

- close to the primary transverse cross structure of platform of multihull
- in areas of deck structural singularity (stepped deck...)
- in way of the fixing of out-fittings.

7.2.3 As a rule, all the deck openings are to be fitted with rounded corners. Generally, the corner radius is to be not less than 5% of the transverse width of the opening.

7.2.4 Corner radiusing, in the case of two or more openings athwart ship in one single transverse section, is considered by the Society on a case-by-case basis.

7.3 Pillar arrangement under deck

7.3.1 Pillars are to be connected to the inner bottom at the intersection of floors and bottom girders, and at deck at the intersection of deck beams and deck girders.

Where it is not the case, an appropriate local structure (partial floors, partial bottom girders, partial deck beams or partial deck girders) is to be fitted to support the pillars.

7.3.2 Local high density core in stiffeners may be required in way where pillars are attached at their heads and heels.

7.3.3 If tensile stress is expected in the pillar, a special attention is to be paid to the connection of the pillar with the structure under tensile loads.

7.3.4 In tanks and in spaces intended for products which procure explosive gases, solid or open section pillars are to be fitted.

7.3.5 Manholes may not be cut in the web of primary structure in way of the head and heel of pillars.

7.3.6 Local structural bulkheads may be considered as pillars, provided that their scantlings comply with Sec 9.

7.3.7 The scantlings of pillars are to comply with the requirements of Sec 9.

7.4 Deck structure in way of lifesaving appliances

7.4.1 The scantling of deck structure supporting launching appliances used for survival craft or rescue boats is to be determined by direct calculations, as defined in the Society Rules for the certification and/or certification of ships (see Sec 1, [1.1.2]).

As a general rule, the minimum rule safety factor applicable to combined stresses SF_{CS} , as defined in Sec 2, [1.3.3], in the primary structure is to be not less than:

$$SF_{CS} \geq 2 \cdot C_V \cdot C_F$$

where:

C_{CS} , C_V , C_F : Partial safety factors defined in Sec 2.

7.4.2 The attention is drawn on any possible specific requirement that could be issued by Flag Administration with respect to a structural fire protection.

8 Bulkhead structure arrangements

8.1 General

8.1.1 Bulkheads may be horizontally or vertically stiffened. Stiffening of horizontally framed bulkheads consists of horizontal secondary stiffeners supported by vertical primary supporting members.

Stiffening of vertically framed bulkheads consists of vertical secondary stiffeners which may be supported by horizontal stringers.

The structural continuity of vertical and horizontal primary supporting members with the surrounding supporting hull structures is to be carefully ensured.

8.1.2 As a general rule, transverse bulkheads are to be stiffened in way of bottom and deck girders, by vertical stiffeners in line with these girders, or by an equivalent system.

Where a deck girder is not continuous, the bulkhead vertical stiffener supporting the end of the deck girder is to be strong enough to sustain the bending moment transmitted by the deck girder.

8.2 Watertight bulkheads

8.2.1 Crossing through watertight transverse bulkheads of bottom, side shell or deck longitudinal stiffeners is to be watertight.

8.2.2 Ends of stiffeners of watertight bulkheads are to be aligned with the hull structure members, and are to be fitted with end brackets.

Where this arrangement is made impossible due to hull lines, any other solution may be accepted provided embedding of the bulkhead secondary stiffeners is satisfactorily achieved.

8.2.3 The secondary stiffeners of watertight bulkheads in the tweendecks may be snipped at ends, provided their scantling is increased accordingly.

8.2.4 Watertight doors

The scantling of watertight doors is to be not less than the adjacent bulkhead, taking into account their actual spacing.

Where bulkhead stiffeners are cut in way of watertight door, reinforced stiffeners are to be fitted to support the interrupted stiffeners.

8.3 Non-tight bulkheads

8.3.1 As a rule, non-tight bulkheads not acting as pillars are to be provided with vertical stiffeners being at a maximum:

- 0,9 m apart, for transverse bulkheads
- two frames apart, with a maximum of 1,5m, for longitudinal bulkheads.

8.3.2 Swash bulkheads

As a rule, the total area of openings in a tank swash bulkhead is to be between 10% and 30% of the total area of the swash bulkhead.

8.4 Bulkheads acting as pillars

8.4.1 As a rule, bulkheads acting as pillars (i.e. those designed to sustain the loads transmitted by a deck structure) are to be provided with vertical stiffeners.

8.4.2 A vertical stiffening member is to be fitted on the bulkhead in line with the deck primary supporting member transferring the loads from the deck to the bulkhead and is to be checked according to Sec 9.

8.5 End stiffener connections

8.5.1 Bulkhead stiffener end connections are to be determined by direct calculation taking into account the bending moment and shear force acting on the stiffeners, as defined in Sec 7.

9 Superstructure and deckhouse arrangements

9.1 Superstructure materials

9.1.1 Special attention is to be given to any specific requirements from the Flag Administration about the structural materials and the structural fire protection in the superstructures.

9.2 Connections of superstructures and deckhouses with the hull structure

9.2.1 Superstructure and deckhouse frames are to be fitted, as far as practicable, in way of deck structure and are to be efficiently connected.

Ends of superstructures and deckhouses are to be efficiently supported by bulkheads, diaphragms, webs or pillars.

Where hatchways are fitted close to the ends of superstructures, additional strengthening may be required.

9.2.2 Construction details

The vertical stiffeners of the superstructure and deckhouse walls of the first tier (directly located above the freeboard deck) are to be attached to the decks at their ends.

Efficient connections are to be provided at the lower end and, preferably, at the upper end of the vertical stiffeners of exposed front bulkheads of engine casings and superstructures.

9.2.3 Connection to the hull deck of the corners of superstructures and deckhouses is considered by the Society on a case-by-case basis. Where necessary, local reinforcements may be required.

9.2.4 As a general rule, the side plating at ends of superstructures is to be tapered into the side shell bulwark or the sheerstrake of the strength deck.

Where a raised deck is fitted, the local reinforcement in way of the step is to extend, as a general rule, over at least 3-frame spacings.

9.3 Structural arrangement of superstructures and deckhouses

9.3.1 Superstructures contributing to the hull girder longitudinal strength are to be examined on top of local scantling, taking into account the global strength analysis as defined in Sec 2, [3].

9.3.2 Web frames, transverse partial bulkheads and other equivalent strengthening of each superstructure tier are to be arranged, where practicable, in line with the transverse reinforced structure below.

Web frames are also to be arranged in way of large openings, tender davits, winches, provision cranes and other areas subjected to local loads.

9.3.3 Openings

All the openings in superstructures and deckhouses exposed to greenseas are to be fitted with sills or coamings as defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

The attention of the Shipowners, Shipyards and Designer is drawn on the fact that the flag Administration may request application of National Rules.

9.3.4 Sidescuttles, windows and skylights

Sidescuttles, windows and skylights arrangement and scantlings are to be as defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

9.3.5 Access and doors

Access openings cut in side plating of enclosed superstructures are to be fitted with doors having a strength equivalent to the strength of the surrounding structure.

Special consideration is to be given to the connection of doors to the surrounding structure.

Securing devices which ensure watertightness are to include tight gaskets, clamping dogs or other similar appliances, and are to be permanently attached to the bulkheads and doors. The doors are to be operable from both sides.

10 Other structures

10.1 Machinery spaces

10.1.1 General

The arrangements of hull structure in the machinery space as regards general strength are to be determined according to the relevant criteria defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

It is no substitute to machinery manufacturer's requirements which have to be dealt with at Shipyard diligence.

The Designer may propose arrangements and scantlings alternative to the Society Rules requirements, on the basis of direct calculations which are to be submitted to the Society for examination on a case-by-case basis.

The Society may also require such direct calculations to be carried out whenever deemed necessary.

10.1.2 Seatings of engines

The scantling of seatings of main engines and thrust bearings are to be adequate in relation to the weight and power of engines and the static and dynamic forces transmitted by the propulsive installation.

Transverse and longitudinal members supporting the seatings are to be located in line with floors and bottom girders.

Seatings are to be adequately connected to floors and girders.

10.2 Bulwark

10.2.1 General

The plating and secondary stiffeners are to be checked as defined for side shell in the applicable requirements of the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

The bending moment, in kNm, and the shear force, in kN, to take into account for the scantling check of vertical stays are to be calculated by direct calculation, taking into account the side shell loads defined in the Society Rules for the classification and/or certification of ships, or as defined in [10.2.2].

The analysis of vertical analysis is to be carried out as defined for stiffeners in Sec 7, taking into account the safety coefficient in relation with the external load considered.

10.2.2 The bending moment, in kNm, and the shear force, in kN, of stays at their connection to the deck structure in way of the lower part of the bulwark can be obtained by the following formulae:

- Bending moment: The greater value of

$$M = \frac{p_s s \ell^2}{2}$$

and:

- if $\ell \geq 0,6\text{m}$ and $s \geq 0,6\text{m}$:

$$M = 0,28 p_{ssmin} (\ell - 0,3)$$

- if $\ell \geq 0,6\text{m}$ and $s < 0,6\text{m}$:

$$M = 0,6 s p_{ssmin} (\ell - 0,3)$$

- if $\ell < 0,6\text{m}$:

$$M = \frac{p_{ssmin} s \ell^2}{2}$$

with s not taken greater than $0,6\text{m}$.

- Shear force: The greater value of

$$T = p_s s \ell$$

and:

- if $\ell \geq 0,6\text{m}$ and $s \geq 0,6\text{m}$:

$$T = 0,28 p_{ssmin}$$

- if $\ell \geq 0,6\text{m}$ and $s < 0,6\text{m}$:

$$T = 0,6 s p_{ssmin}$$

- if $\ell < 0,6\text{m}$:

$$T = p_{ssmin} s \ell$$

with s not taken greater than $0,6\text{m}$.

where:

p_s, p_{ssmin} : Sea pressure and impact pressure on side shell as defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2])

s : Spacing of stays, in m

ℓ : Length of stays, in m.

10.3 Helicopter deck and platform

10.3.1 Structure of the helicopter deck located on super-structure weather deck or on platform permanently connected to the hull structure is to be examined according to general arrangement, as applicable, and loading loads as defined in NR467, Pt B, Ch 8, Sec 11.

Where the acceleration at helicopter centre of gravity for upright and inclined ship conditions are not defined by the ship designer, values determined on the basis of NR467 are to be taken into account.

Landing area laminates, as well as secondary and primary stiffeners, are to be examined by direct calculations. It is to be checked that the safety factors, defined in Sec 2, [1], are at least equal to the minimum rule safety factors given in the Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]), multiplied by the following coefficients:

- 1,4 for landing area located above accommodation spaces
- 1,15 for landing area located outside a zone covering accommodation spaces
- 1,0 for emergency condition.

Attention is drawn on any possible specific requirement that could be issued by Flag Administration with respect to the structural fire protection and the use of composite materials.

10.4 Hull structure reinforcement for navigation in ice

10.4.1 General

The ice strengthening requirements defined in the present article are applicable to the hull structure of ships which have been assigned one of the following additional class notation:

- **YOUNG ICE 1**
- **YOUNG ICE 2**

The assignment of these additional class notations are subjected to the compliance with NR467, Pt A.

10.4.2 Owner's responsibility

It is the responsibility of the Owner to decide which ice class notation is the most suitable in relation to the expected service conditions of the ship.

The ice conditions for the assignment of additional class notation **YOUNG ICE 1** and **YOUNG ICE 2** are defined in NR467, Pt F, Ch 8, Sec 1.

As a guidance, the relation between these additional class notation and the associated ice conditions compatible with the strengthening defined in the present article are as follow:

- young ice (gray or whitish) having a maximum thickness of 30 cm)

- ice concentration:

- **YOUNG ICE 1:** Open ice (concentration between 6/10 th and 3/10 th)
- **YOUNG ICE 2:** Very open ice (concentration less than 3/10 th)

10.4.3 General structure scantling

The structure hull areas (longitudinal and vertical) to be strengthened are defined in NR467, Pt F, Ch 8, Sec 2.

The scantling formulae defined in the present article are based on simply supported hypothesis of the structure element.

10.4.4 Plate scantling

In addition to the analysis of side shell panels carried out in accordance with Sec 6, [5], the panels within the ice belt and subject to ice loads are to be checked according to Sec 6, [5.1.2] taking into account the following values of bending moment, in kN.m/m, and shear force, in kN/m:

- a) For transverse framing:

$$M_x = \frac{F_1 p_{PL} s^2}{8} 10^3$$

$$T_{yz} = \frac{F_1 p_{PL} s}{2} 10^3$$

- b) For longitudinal framing:

$$M_y = \frac{p_{PL} h (2s - h)}{8} 10^3$$

$$T_{xz} = \frac{p_{PL} h s}{2 F_2} 10^3$$

where:

- F_1 : Coefficient to be taken equal to:

$$F_1 = 1, 3 - \frac{4, 2}{\left(\frac{h}{s} + 1, 8\right)^2} < 1$$

- F_2 : Coefficient to be taken equal to:

$$F_2 = 1, 4 - \left(0, 4 \frac{h}{s}\right) > 1$$

- h : Height of load area, in m, as defined in NR467, Pt F, Ch 8, Sec 2

- s : Spacing, in m, of ordinary or primary stiffeners, as applicable

- p_{PL} : Ice pressure on the shell panel, in N/mm², equal to 0,75p

- p : Design ice pressure, in N/mm², as defined in NR467, Pt F, Ch 8, Sec 2, [3.2.2] calculated with:

- for **YOUNG ICE 1** $C_p = 0,6$ and
for **YOUNG ICE 2** $C_p = 0,3$
- Nominal ice pressure p_0 , in N/mm², equal to 3.

10.4.5 Stiffener scantling

In addition to the analysis of stiffeners carried out in accordance with Sec 7, [4], the stiffeners within the ice belt and subject to ice loads are to be checked according to Sec 7, [4.1.3] taking into account the following values of bending moment, in kN.m, and shear force, in kN:

a) For transverse stiffener:

$$M = \frac{p h s (2 \ell - h)}{8} 10^3$$

$$T = p s h 10^3$$

Note 1: Where less than 15% of the span of the stiffener is located within the ice strengthening hull area as defined in [10.4.3], the present check is not required.

b) For longitudinal stiffener:

$$M = \frac{p h \ell^2}{8} 10^3$$

$$T = \frac{p h \ell}{2} 10^3$$

where:

p : Design ice pressure, in N/mm², as defined in [10.4.4].

10.4.6 General structure arrangement

As a general rule, the local reinforcement of the side shell panel in the area of the ice belt and subject to ice loads is to be examined on a case-by-case basis.

In particular, when sandwich panels are used for side shell, designer is to submit the mechanical characteristics and is to justify the scantling of the sandwich to avoid excessive indentation of the sandwich and deterioration of strength and stiffness properties by collapse with the core crushing beneath the ice belt area due to local instability of the compressive face sheets.

Local monolithic side shell panels may be required in the ice belt area.

11 Special features

11.1 Bow doors, bow visors and inner doors

11.1.1 Application and general arrangement

The requirements application and the general arrangement of bow doors, bow visors and inner doors are to be in accordance with the Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

11.1.2 Plate and secondary stiffeners

Scantlings of the plates and secondary stiffeners of bow doors and bow visors are to be not less than scantlings of the plates and secondary stiffeners of hull fore part obtained according to the Society Rules for the classification of ships (see Sec 1, [1.1.2]) and to the general requirements defined in the present Rule Note.

11.1.3 Primary supporting members

Primary supporting member scantlings are to be determined by direct calculation in accordance with the Rules for the classification of ships (see Sec 1, [1.1.2]).

11.1.4 Securing and supporting devices

Securing and supporting devices are to be examined on a case by case by the Society and on the bases defined in [11.1.3]. A particular attention is to be drawn to the connection between metal devices and composite structure.

11.2 Side doors and stern doors

11.2.1 Application and general arrangement

The requirements application and the general arrangement of side doors and stern inner doors are to be in accordance with the Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

11.2.2 Plate and secondary stiffeners

Scantling of the plates and stiffeners of side doors and bow doors are to be not less than scantlings of the adjacent side shell obtained according to the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

11.2.3 Primary supporting members

Primary supporting member scantlings are to be determined by direct calculation in accordance with the Rules for the classification of ships (see Sec 1, [1.1.2]).

11.2.4 Securing and supporting devices

Securing and supporting devices are to be examined on a case by case by the Society and on the bases defined in [11.2.3]. A particular attention is to be drawn to the connection between metal devices and composite structure.

11.3 Hatch covers

11.3.1 General

General arrangement, securing devices, height of coamings and weathertightness where applicable and structure scantling for hatch covers located on exposed or non exposed decks are to be as defined by the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

11.4 Rudders

11.4.1 Rudder stock and rudder blade scantlings

Rudder stock and rudder blade scantlings are to be checked by direct calculations, taking into account the forces and torque acting on rudder as defined in the applicable requirements of the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

Where it is not specified otherwise, the safety factors to take into account to check the rudder blade and the rudder stock scantlings are those defined in Sec 2, [1.3], increased by a coefficient to be taken at least equal to 1,3.

11.4.2 Rudder horn and solepiece scantlings

Rudder horn and solepiece scantlings are to be checked by direct calculations, taking into account the forces and torque moments acting on rudder horn or solepiece as defined in the applicable requirements of the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

Where it is not specified otherwise, the safety factors to take into account to check the rudder horn and the solepiece scantlings are those defined in Sec 2, [1.3], increased by a coefficient to be taken at least equal to:

- 1,9 for the main stress safety factor
- 1,3 for the combined stress safety factor.

11.5 Water jet propulsion tunnel

11.5.1 The drawings of water jet ducts, ship supporting structure, thrust bearing, as well as shell openings and local reinforcements, are to be submitted for examination.

The pressure in water jet ducts, the forces and moments induced by the water jet to the ship structure and the calculation procedure from the designer are to be specified.

In no case the scantlings are to be taken less than the requirements defined in:

- the present Rule Note, for the surrounding hull structure
- NR396 Rules for the Classification of High Speed Craft, Ch 3, C3.9.2. In this case, the minimum rule safety factors to take into account for the structure check, as defined in Sec 2, [1.3], are to be the same than those considered for the hull bottom structure.

11.6 Foils and trim supports

11.6.1 Foils and trim tab supports are not covered within the scope of classification and/or certification.

Forces and moments induced by these elements, as well as the designer calculation, are to be submitted for the examination of the surrounding ship structure reinforcements.

As a general rule, attachment structure of foils to the ship structure are to be located within watertight compartments or equivalent.

11.7 Propeller shaft bracket

11.7.1 Propeller shaft bracket scantlings are to be checked by direct calculations, taking into account the forces acting on shaft bracket as defined in the applicable requirements of the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

Where it is not specified otherwise, the safety factors to take into account to check the shaft bracket scantling are those defined in Sec 2, [1.3], increased by a coefficient to be taken at least equal to:

- 1,8 for the main stress safety factor
- 1,5 for the combined stress safety factor.

11.8 Lifting appliances

11.8.1 As a rule, the permanently fixed parts of lifting appliances fitted into the hull, as well as the associated local reinforcements, are considered as integral part of the hull and are to be checked as defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

Local reinforcements and hull structure surrounding the crane pedestal are to be checked by direct calculations, taking into account the safety factors defined in Sec 2, [1.3].

11.9 Equipment in chain and anchor

11.9.1 The equipment in anchors and chains is to be as defined in the applicable Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]) in relation of the navigation notation or service notation granted to the ship.

SECTION 4 RAW MATERIALS FOR LAMINATES

1 General

1.1 Application

1.1.1 The mechanical characteristics of laminates used for composite structure depend on raw materials' characteristics.

The present Section gives general informations on the "state of the art" about the main raw materials used for laminates in composite boat building.

1.2 Definitions

1.2.1 The raw materials, used in boat building, are of four main types: resin systems, reinforcements, core materials and adhesives.

1.2.2 Resin systems

Resin systems (or matrix) are thermoset resins (initial liquid, hard and stiff cross linked material that does not return liquid when cured). Resin is used to:

- link reinforcements together
- protect reinforcements from impact, moisture and abrasion
- spread loads through reinforcements' layers.

Resin systems dealt with in this Section are polyester, vinylester and epoxy systems (see Article [2]).

1.2.3 Reinforcements

Reinforcement fabrics are used to improve mechanical characteristics of laminates.

Reinforcement fabrics may be constructed with interlaced yarns or without interlacing, named respectively woven rovings and stitched rovings.

Reinforcement fabrics dealt with in this Section are made of continuous yarns, manufactured with glass, carbon or paraaramid fibres (see Article [3]).

1.2.4 Core materials

Core materials are used in laminate sandwich to improve global moment of inertia of the whole laminate. Sandwich laminates are made of two reinforced faces also named skins, separated by and jointed to a core.

Core materials dealt with in this Section are synthetic foams, natural cores and honeycombs (see Article [4]).

1.2.5 Adhesives

Adhesive materials are generally considered as resin systems and are used to bond together different composite structures or to bond skins to core in sandwich laminates (see Article [5]).

1.2.6 Other raw materials

Other raw materials than those described in [2] to [5] may be considered by the Society on a case by case basis. In this case, the following informations are to be submitted by the manufacturer or the shipyard for examination:

- use restriction of raw materials as defined in [1.3.1]
- values of mechanical characteristics as defined in:
 - for resins and adhesives systems: Tab 1
 - for fibres: Tab 2
 - for core materials: Tab 3
 - for structural adhesives: Article [5]
- methodology or mechanical tests on individual layers to estimate the elastic coefficients (see Sec 5, [3]) and the breaking stresses (see Sec 5, [5]) of the individual layers.

As a rule, raw materials are to be certified as defined in [1.3.2]. However, mechanical tests on laminate panels as defined in Sec 11, [4] and possibly specific mechanical tests on raw materials in order to define the elastic coefficients and breaking stresses may be considered as equivalent to the raw material homologation process.

1.3 Certification of raw materials

1.3.1 Use restriction of raw materials

Raw materials are to be used within the limits fixed by the manufacturer, taking into account the compatibility between the different materials and the laminating process. In this respect, the Surveyor may ask any useful justification to be submitted, such as:

- technical data sheet of main raw materials (resin, reinforcement fabrics and cores)
- manufacturer guarantee for raw materials used in naval construction (stability regarding ageing in marine environment, resistance to hydrolysis...)
- type and proportion of catalyst, hardener and accelerator recommended by the manufacturer to be adjusted in the different circumstances of conditions of work (ambient atmosphere, i.e. temperature, relative humidity)
- type approval certificate granted by a recognized Society.

1.3.2 Certification of raw materials

As a general rule, the main raw materials (resins, reinforcement fabrics and cores) used in the laminates for the construction of ships built in composite materials are to be certified within the scope of the classification and/or certification and, in particular, for the assignment of the construction marks $\boxtimes$ or $\bullet$.

This process of raw material approval is described in Sec 11, [2].

2 Resin systems

2.1 General

2.1.1 Manufacturing and curing process

As a general rule, thermoset resin systems used in ship-building are obtained from a synthetic resin, also named polymer, made of long unsaturated chains of molecules.

The process, which allows to modify the arrangement of molecular chains from free independent chains to a three dimensional linked chains network, is called polymerisation or curing process.

This chemical reaction is observed where resin goes from its liquid state to its solid state. This reaction is accompanied by a heat discharge and is irreversible for thermoset resins.

The three dimensional network is obtained by different curing processes, according to the type of synthetic resins:

- for polyester and vinylester: by mixing synthetic resin with an unsaturated monomer (e.g. styrene) which creates the chemical links. In this case, the chemical reaction needs a catalyst to start the polymerisation process
- for epoxy: by adding a hardener which promotes the polymerisation process. In this case, macromolecules chains are directly linked to each other.

These two different chemical processes have an important effect on mechanical characteristics of the final resin system and particularly on the volumetric shrinkage during the polymerisation (source of stress concentration in the final laminate between resin and fibre).

2.1.2 Glass Transition Temperature (T_g)

The state of polymerisation may be appraised by measuring the "Glass Transition Temperature" (T_g). This is the approximate temperature at which the number of chemical links between molecular chains is significant to change mechanical properties of a cured resin.

The more polymerized is the resin, i.e. the greater is the number of chemical links between macromolecules chains, the higher is the value of T_g.

Where T_g is measured, it is necessary to indicate the reference of the test method, since the measured value of T_g may vary from one method to another.

For epoxy resin systems in particular, T_g may be increased after the resin polymerisation by a post cure with an additional rise of temperature.

2.1.3 Speed of polymerisation

The speed of polymerisation process may be controlled:

- either by the amount of accelerators for polyester and vinylester resin systems, or
- by the amount of a hardener for epoxy resin systems, or
- by a controlled rise of temperature speed.

2.1.4 Resin system reference

The resin systems may be affected by:

- the chemical formulation of polymers used (basic resins, unsaturated monomers, catalysts or hardeners)
- the polymerisation process and the additive products used such as thixotropic or coloured agents.

2.2 Resin system types

2.2.1 Polyester resin systems

Polyester resin systems are the result of mixing unsaturated polyester resin with an unsaturated monomer (also called co-polymer), a catalyst and sometime an accelerator. This reaction is named co-polymerisation.

The functions of these mixed elements are:

- Monomer: the unsaturated monomer, generally styrene, is used to reduce the initial viscosity of the resin before polymerisation and to create the chemical links between chains of polyester macromolecules. The chemical reactive sites, and so the chemical links, are located all along the macromolecules chains of polyester.

This chemical reaction between polyester and styrene leads to the emission of styrene over, not used in the polymerisation. The global chemical polymerisation is stopped where all the styrene over emission is fully completed or where reactive sites of polyester are fully linked.

- Catalyst: generally of organic peroxide chemical family, the catalyst is used to initiate the reaction between polyester and monomer. It does not take part in the chemical reaction.

The catalyst proportion and its homogeneous mixing with the polyester/styrene resin before moulding are the main parameters.

Too low proportion of catalyst may result in an incomplete polymerisation reaction, which may affect the mechanical properties of the final laminate. The catalyst proportion is to be defined by the resin manufacturer.

- Accelerator: an accelerator may also be added to control the chemical speed of reaction, according to the workshop environment (temperature for example).

Because the accelerator has no influence to initiate the polymerisation reaction, as long as there is no catalyst, it may be directly added by the manufacturer in the polyester resin system. This type of resin is called pre-accelerated.

The polymerisation is carried out at room temperature and goes with an exothermic heat temperature.

The chemical network after polymerisation may be represented by Fig 1.

Two types of polyester resins are used in boat building: orthophtalic and isophtalic.

The mechanical characteristics and the water absorption resistance of isophtalic polyester resin are higher than those of orthophtalic polyester resin. Isophtalic polyester resin is, then, generally used for gelcoats and in the first layers located after the gelcoat.

The main physical characteristics of polyester resin systems are:

- a high volumetric shrinkage during polymerisation due to the great number of chemical links along polyester macromolecules and to styrene emission
- a moderate breaking strain due to the location of chemical links along polyester macromolecules
- a water absorption sensitivity due to ester functions in polyester macromolecules.