



Rudders in Composite Materials

September 2013

**Guidance Note
NI 590 DT R00 E**

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MARINE & OFFSHORE DIVISION

GENERAL CONDITIONS

ARTICLE 1

1.1. - BUREAU VERITAS is a Society the purpose of whose Marine & Offshore Division (the "Society") is the classification ("Classification") of any ship or vessel or offshore unit or structure of any type or part of it or system therein collectively hereinafter referred to as a "Unit" 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.

The Society:

- "prepares and publishes Rules for classification, Guidance Notes and other documents ("Rules");
- "issues Certificates, Attestations and Reports following its interventions ("Certificates");
- "publishes Registers.

1.2. - The Society also participates in the application of National and International Regulations or Standards, in particular by delegation from different Governments. Those activities are hereafter collectively referred to as "Certification".

1.3. - The Society can also provide services related to Classification and Certification such as ship and company safety management certification; ship and port security certification, training activities; all activities and duties incidental thereto such as documentation on any supporting means, software, instrumentation, measurements, tests and trials on board.

1.4. - The interventions mentioned in 1.1., 1.2. and 1.3. are referred to as "Services". The party and/or its representative requesting the services is hereinafter referred to as the "Client". The Services are prepared and carried out on the assumption that the Clients are aware of the International Maritime and/or Offshore Industry (the "Industry") practices.

1.5. - The Society is neither and may not be considered as an Underwriter, Broker in ship's sale or chartering, Expert in Unit's valuation, Consulting Engineer, Controller, Naval Architect, Manufacturer, Ship-builder, Repair yard, Charterer or Shipowner who are not relieved of any of their expressed or implied obligations by the interventions of the Society.

ARTICLE 2

2.1. - Classification is the appraisal given by the Society for its Client, at a certain date, following surveys by its Surveyors along the lines specified in Articles 3 and 4 hereafter on the level of compliance of a Unit to its Rules or part of them. This appraisal is represented by a class entered on the Certificates and periodically transcribed in the Society's Register.

2.2. - Certification is carried out by the Society along the same lines as set out in Articles 3 and 4 hereafter and with reference to the applicable National and International Regulations or Standards.

2.3. - It is incumbent upon the Client to maintain the condition of the Unit after surveys, to present the Unit for surveys and to inform the Society without delay of circumstances which may affect the given appraisal or cause to modify its scope.

2.4. - The Client is to give to the Society all access and information necessary for the safe and efficient performance of the requested Services. The Client is 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.

ARTICLE 3

3.1. - The Rules, procedures and instructions of the Society take into account at the date of their preparation the state of currently available and proven technical knowledge of the Industry. They are a collection of minimum requirements but 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.

Committees consisting of personalities from the Industry contribute to the development of those documents.

3.2. - The Society only is qualified to apply its Rules and to interpret them. Any reference to them has no effect unless it involves the Society's intervention.

3.3. - The Services of the Society are carried out by professional Surveyors according to the applicable Rules and to the Code of Ethics of the Society. Surveyors have authority to decide locally on matters related to classification and certification of the Units, unless the Rules provide otherwise.

3.4. - 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.

ARTICLE 4

4.1. - The Society, acting by reference to its Rules:

- "reviews the construction arrangements of the Units as shown on the documents presented by the Client;
- "conducts surveys at the place of their construction;
- "classes Units and enters their class in its Register;
- "surveys periodically the Units in service to note that the requirements for the maintenance of class are met.

The Client is to inform the Society without delay of circumstances which may cause the date or the extent of the surveys to be changed.

ARTICLE 5

5.1. - The Society acts as a provider of services. This cannot be construed as an obligation bearing on the Society to obtain a result or as a warranty.

5.2. - The certificates issued by the Society pursuant to 5.1. here above are a statement on the level of compliance of the Unit to its Rules or to the documents of reference for the Services provided for. In particular, the Society does not engage in any work relating to the design, building, production or repair checks, neither in the operation of the Units or in their trade, neither in any advisory services, and cannot be held liable on those accounts. Its certificates 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.

5.3. - The Society does not declare the acceptance or commissioning of a Unit, nor of its construction in conformity with its design, that being the exclusive responsibility of its owner or builder.

5.4. - The Services of the Society cannot create any obligation bearing on the Society or constitute any warranty of proper operation, beyond any representation set forth in the Rules, of any Unit, equipment or machinery, computer software of any sort or other comparable concepts that has been subject to any survey by the Society.

ARTICLE 6

6.1. - The Society accepts no responsibility for the use of information related to its Services which was not provided for the purpose by the Society or with its assistance.

6.2. - If the Services of the Society or their omission cause to the Client a damage which is proved to be the direct and reasonably foreseeable consequence of an error or omission of the Society, its liability towards the Client is limited to ten times the amount of fee paid for the Service having caused the damage, provided however that this limit shall be subject to a minimum of eight thousand (8,000) Euro, and to a maximum which is the greater of eight hundred thousand (800,000) Euro and one and a half times the above mentioned fee. These limits apply regardless of fault including breach of contract, breach of warranty, tort, strict liability, breach of statute, etc.

The Society bears no liability for indirect or consequential loss whether arising naturally or not as a consequence of the Services or their omission such as loss of revenue, loss of profit, loss of production, loss relative to other contracts and indemnities for termination of other agreements.

6.3. - All claims are to be presented to the Society in writing within three months of the date when the Services were supplied or (if later) the date when the events which are relied on were first known to the Client, and any claim which is not so presented shall be deemed waived and absolutely barred. Time is to be interrupted thereafter with the same periodicity.

ARTICLE 7

7.1. - Requests for Services are to be in writing.

7.2. - Either the Client or the Society can terminate as of right the requested Services after giving the other party thirty days' written notice, for convenience, and without prejudice to the provisions in Article 8 hereunder.

7.3. - The class granted to the concerned Units and the previously issued certificates remain valid until the date of effect of the notice issued according to 7.2. here above subject to compliance with 2.3. here above and Article 8 hereunder.

7.4. - The contract for classification and/or certification of a Unit cannot be transferred neither assigned.

ARTICLE 8

8.1. - The Services of the Society, whether completed or not, involve, for the part carried out, the payment of fee upon receipt of the invoice and the reimbursement of the expenses incurred.

8.2. - Overdue amounts are increased as of right by interest in accordance with the applicable legislation.

8.3. - The class of a Unit may be suspended in the event of non-payment of fee after a first unfruitful notification to pay.

ARTICLE 9

9.1. - The documents and data provided to or prepared by the Society for its Services, and the information available to the Society, are treated as confidential. However:

- "Clients have access to the data they have provided to the Society and, during the period of classification of the Unit for them, to the classification file consisting of survey reports and certificates which have been prepared at any time by the Society for the classification of the Unit ;
- "copy of the documents made available for the classification of the Unit and of available survey reports can be handed over to another Classification Society, where appropriate, in case of the Unit's transfer of class;
- "the data relative to the evolution of the Register, to the class suspension and to the survey status of the Units, as well as general technical information related to hull and equipment damages, may be passed on to IACS (International Association of Classification Societies) according to the association working rules;
- "the certificates, documents and information relative to the Units classed with the Society may be reviewed during certifying bodies audits and are disclosed upon order of the concerned governmental or inter-governmental authorities or of a Court having jurisdiction.

The documents and data are subject to a file management plan.

ARTICLE 10

10.1. - Any delay or shortcoming in the performance of its Services by the Society arising from an event not reasonably foreseeable by or beyond the control of the Society shall be deemed not to be a breach of contract.

ARTICLE 11

11.1. - In case of diverging opinions during surveys between the Client and the Society's surveyor, the Society may designate another of its surveyors at the request of the Client.

11.2. - Disagreements of a technical nature between the Client and the Society can be submitted by the Society to the advice of its Marine Advisory Committee.

ARTICLE 12

12.1. - Disputes over the Services carried out by delegation of Governments are assessed within the framework of the applicable agreements with the States, international Conventions and national rules.

12.2. - Disputes arising out of the payment of the Society's invoices by the Client are submitted to the Court of Nanterre, France, or to another Court as deemed fit by the Society.

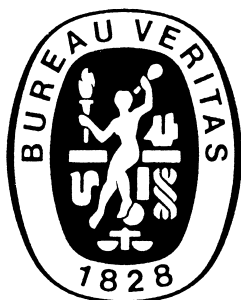
12.3. - Other disputes over the present General Conditions or over the Services of the Society are exclusively submitted to arbitration, by three arbitrators, in London according to the Arbitration Act 1996 or any statutory modification or re-enactment thereof. The contract between the Society and the Client shall be governed by English law.

ARTICLE 13

13.1. - These General Conditions constitute the sole contractual obligations binding together the Society and the Client, to the exclusion of all other representation, statements, terms, conditions whether express or implied. They may be varied in writing by mutual agreement. They are not varied by any purchase order or other document of the Client serving similar purpose.

13.2. - The invalidity of one or more stipulations of the present General Conditions does not affect the validity of the remaining provisions.

13.3. - The definitions herein take precedence over any definitions serving the same purpose which may appear in other documents issued by the Society.



GUIDANCE NOTE NI 590

Rudders in Composite Materials

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SECTION 1

GENERAL APPROACH

1 General

1.1 Application

1.1.1 The requirements of this Guidance Note apply to rudder stock, rudder blade and flap, rudder trunk and rudder horn built in composite materials.

1.1.2 The purpose of this Guidance Note is to define and specify:

- a methodology to assess scantling of rudders
- the requirements for the manufacture inspections and tests

for rudders, made totally or partially in composite materials.

This Guidance Note is to be applied in addition to the Rule Notes:

- NR467 Rules for the Classification of Steel Ships, Pt B, Ch 10, Sec 1, and
- NR546 Hull in Composite Materials and Plywood.

Note 1: As a general rule, this Guidance Note is not applicable to rudder built in composite materials for ship classed with the service notation **yacht** and **charter yacht**, where the NR500 Rules for the Classification and the Certification of Yachts, is applicable.

1.1.3 General arrangement of rudder (effective means to support the weight of rudder, to prevent the rudder from lift, to prevent water from entering the steering gear compartment,...) are to be as defined in NR467, Pt B, Ch10, Sec 1.

The elements made of steel in the rudder arrangement are not covered by this Guidance Note and are to be in accordance with NR467, Pt B, Ch 10, Sec 1.

1.1.4 The steering gear systems are not covered by this Guidance Note and are to be as defined in NR467, Pt C, Ch 1, Sec 11.

1.1.5 As a general rule, elements of the rudder system which are in direct contact with the ice, for ships having an additional notation for navigation in ice, are not to be in composite materials.

1.2 Surveys for the maintenance of class

1.2.1 In addition to the extend and scope of the periodical in-service surveys to be carried out according to NR467, Part A, an inspection plan for in-service surveys of composite rudder parts is to be provided by the manufacturer, including the:

- frequency of survey
- list of items to be inspected including acceptance criteria of elements checked,

- repair procedure, in case of wear/damage of rudder components,
- monitoring system, if provided, to assess the rudder stock deformation, the conical coupling pressure,...

Attention is drawn to special requirements from the ship Flag Administration which may be taken into account and not included in this Guidance Note.

1.3 Documentation to be submitted

1.3.1 The plan showing the structural arrangement of the rudder, the scantling of the rudder stock and rudder blade, the connections, the reinforcements in way of bearings,... are to be submitted to the Society for approval.

In addition to the structural drawings, the following information are to be submitted:

- Raw materials: technical specifications of suppliers with indication of the types, trademark and references of the raw materials, specifying:
 - for resins and adhesives: system (polyester, vinylester or epoxy), density, Young modulus, shear modulus, Poisson coefficient, breaking strength and elongation at break
 - for reinforcements (unidirectional reinforcements, woven roving, 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-wrap distribution
 - for core materials: type and quality, density, tensile, compression and shear breaking stresses and elasticity moduli.
- Laminate: arrangement of the laminates for the various elements (thickness, definition of the successive layers of reinforcement, mass of reinforcement per square meter in layers, proportion in mass or in volume of reinforcement of each layer, directions of roving layers and unidirectional reinforcements, dimension of lap joints between layers).
- Manufacturing process: see [2.3].

2 Materials and manufacturing process

2.1 General

2.1.1 The mechanical characteristics of a composite structure are directly depending on the type of raw materials used and the manufacturing process adopted for the building.

The present article defines the requirements regarding the homologation of raw materials and the construction process survey of rudder built in composite material.

2.2 Materials

2.2.1 General

The raw materials considered are:

- thermoset resin's systems
- glass, carbon or para-aramid based reinforcement fabrics.
- core materials

Other raw materials may be considered, provided their specifications are submitted to the Society for acceptance.

General informations on the "state of the art" about main raw materials and minimum rule mechanical characteristics are given in the NR546.

2.2.2 Certification of raw material

As a general rule, the main raw materials (resins, reinforcement fabrics and cores) used for rudder elements put on board are to be certified by the Society.

The process of raw material approval is described in the NR546, Sec 10, [2].

2.3 Construction survey

2.3.1 General

During the manufacturing process of the rudder elements, survey at yard and mechanical test are to be carried out by the Society.

The manufacturing process considered are lay-ups (spray and hand), vacuums (infusion), prepreg and winding.

Other manufacturing process may be accepted on a case by case basis.

2.3.2 Mechanical test

Mechanical and physico-chemical tests are to be performed on test samples produced by the shipyard and representative of the construction of the rudder elements (same raw materials, same laminate lay-up and same construction process).

These tests are to be defined on a case by case basis by the Society, and the results are to be compared with the theoretical properties of the laminates characteristics defined in this Guidance Note.

The general requirements about mechanical tests are defined in the NR546, Section 10.

Where deemed necessary by the Society, prototype model of a set of elements of the rudder may be requested to be tested.

2.3.3 Construction survey

Inspections at yard during the rudder elements construction are defined in the NR546, Section 10.

3 Design loads and stress analysis

3.1 Design loads

3.1.1 The rudder force C_R , in N, applied to the rudder is to be obtained as defined in the NR467, Pt B, Ch 10, Sec 1, taking into account the maximum ahead and astern speed of the ship, the location of the rudder in relation to the propeller jet and the shape of the rudder blade.

The forces acting on the rudder blade may induce in the rudder structure the following loads:

- bending moment, torque and shear force in the rudder stock
- bending moment, torque and shear force in the rudder blade and in the flat
- bending moment, torque and shear force in the rudder trunk
- support forces at pintle and rudder stock bearings
- bending moment, torque and shear force in the rudder horn.

These moments, shear force and support forces are defined in the NR467, Pt B, Ch 10, App 1 in relation to the type of rudder.

Bending moment, torque and shear force applied to the rudder structure may be defined by direct calculation to be submitted to the Society.

Note 1: Where rudder is supported by a rudder horn, a direct calculation taking into account the elastic support of the rudder horn may be considered to determine the bending moment and shear force applied to the rudder stock.

3.2 Stress analysis

3.2.1 Stress calculation

For each element of the rudder built in composite material (rudder stock, blade and flap, trunk or horn), the stress analysis is carried out taking into account:

- the moments and forces defined in [3.1.1]
- the geometry of the considered element
- the global rigidity of laminates of the considered element.

Strains and curved deformation of laminates of the considered element are to be calculated at the laminate median plan and allow to estimate the stresses in the layers of the laminate.

The mechanical characteristics of the individual layers and of the laminates are to be calculated as defined in the NR546, or by an equivalent method.

Steps of the calculation and associated Rules Note of the Society necessary to carry out these calculations are given in Tab 1.

3.2.2 Safety coefficients

For each layer of the different laminates of the element considered, the safety coefficients, equal to the ratio between the applied stress and the theoretical breaking stresses of the layer as defined in the NR546, are to be calculated. These safety coefficients are to be at least equal to the minimum rules safety coefficients as defined in [11].

Table 1 : Steps for stresses calculation

Steps		Calculation	Reference
1	Force and torque acting on the rudder	Rudder force C_R and force per unit length acting on the rudder body in relation with the type of rudder	NR467, Ch 10, Sec 1 and Ch10, App 1
		Rudder torque applied to the rudder stock	NR467, Ch 10, Sec 1
		Bending moments, shear forces, support forces and torsion moments applied to the different elements of the rudder	NR467, Ch 10, App 1
2	Laminate characteristics of the elements of the rudder	Geometric characteristics, rigidity and theoretical breaking stresses of individual layers	NR546, Sec 5
		Description of the laminate (position of the individual layers, orientation of the reinforcements)	NR546, Sec 6
		Global elastic coefficients and mechanical characteristics of the laminate in the axis the element of the rudder	NR546, Sec 6
3	Element of the rudder	Calculation of the sections and the rigidities of the element of the rudder under consideration (rudder stock, blade or flap, trunk, horn)	[4]
		Strains deformation of the median plan of each laminates of the considered elements under loads calculated in step 1	[5] to [10]
4	Laminate stress analysis	Calculation of the stresses for each individual layer in its own local axis	NR546, Sec 6
		Calculation of the safety coefficients for each individual layer	[11]

4 Section characteristics of rudder elements

4.1 General

4.1.1 As a general rule, the bending rigidity $E_x I_x$, the torsional rigidity $G_{xy} I_T$ and the effective shear rigidity $G_{xy} S$ of the element of the rudder are to be determined by direct calculation.

For circular or rectangular hollow profiles, formulae defined in [4.2] may be used, instead of determination by direct calculation.

4.2 Calculation of element rigidity

4.2.1 Elastic coefficient of laminate

The following moduli, in N/mm^2 , which characterize the laminate, are to be calculated as defined in the NR546, Sec 6, [2]:

- E_x tensile modulus in the direction X of the laminate
- E_y tensile modulus in the direction Y of the laminate
- G_{xy} shear plane modulus in the plane of the laminate.

4.2.2 Circular hollow profile rigidity

The bending and torsional rigidity, the effective shear rigidity and the tensile rigidity of a circular hollow profile are to be calculated as follows:

- bending rigidities, in Nmm^2 , according to the two main axes:

$$E_x I_x = \frac{E_x \pi (D^4 - d^4)}{64}$$

- torsional rigidity, in Nmm^2 :

$$G_{xy} I_T = \frac{G_{xy} \pi (D^4 - d^4)}{32}$$

- effective shear rigidity, in N:

$$G_{xy} S = \frac{G_{xy} \pi (D^2 - d^2)}{8}$$

- tensile rigidity, in N:

$$E_x A_x = \frac{\pi}{4} (D^2 - d^2) E_x$$

where:

D, d : Respectively the outer and inner diameter, in mm, of the circular hollow profile.

4.2.3 Rectangular hollow profile rigidity

The bending rigidity, the torsional rigidity, the effective shear rigidity and the tensile rigidity of a rectangular hollow profile are to be calculated as follows:

- bending rigidity $E_{x1} I_x$, in Nmm^2 , and effective shear rigidity $G_{xy1} S_x$, in N, according to X axis:

$$E_{x1} I_x = 2 \left[\left(\frac{B_x e_x^3}{12} + B_x e_x v_y^2 \right) E_{x1} + \frac{e_y B_y^3}{12} E_{x2} \right]$$

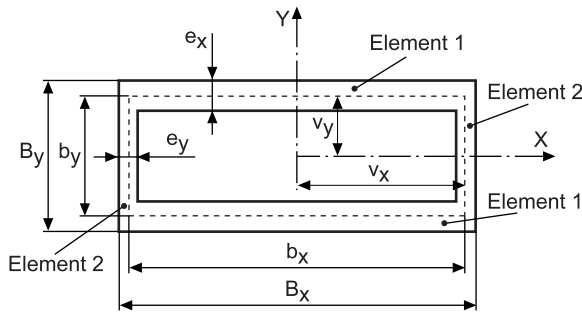
$$G_{xy1} S_x = 2 G_{xy1} B_x e_x$$

where:

E_{x1} , G_{xy1} : Young modulus and shear modulus, in N/mm^2 calculated in the element 1 as shown on Fig 1, in accordance with NR546, Sec 6, [2]

E_{x2} : Young modulus, in N/mm^2 calculated in the element 2 as shown on Fig 1, in accordance with NR546, Sec 6, [2]

Figure 1 : Rectangular hollow profile dimensions



---- Position of median plan of element 1 & element 2

- bending rigidity $E_{x2}I_y$, in Nmm^2 , and effective shear rigidity $G_{xy2}S_y$, in N, according to Y axis:

$$E_{x2}I_y = 2 \left[\left(\frac{B_y e^3}{12} + B_y e_y v^2 \right) E_{x2} + \frac{e_x B_x^3}{12} E_{x1} \right]$$

$$G_{xy2}S_y = 2 G_{xy2} B_y e_y$$

where:

E_{x1} , G_{xy} : Young modulus and shear modulus calculated in the element 1 as shown on Fig 1, in accordance with NR546, Sec 6, [2]

E_{x2} : Young modulus calculated in the element 2 as shown on Fig 1, in accordance with NR546, Sec 6, [2]

- torsional rigidity, in Nmm^2 :

$$G_{xy}I_T = \frac{2(b_x b_y)^2}{\frac{b_x}{e_x} G_{xy1} + \frac{b_y}{e_y} G_{xy2}} G_{moy}^2$$

where:

$$G_{moy} = \frac{G_{xy1} b_x e_x + G_{xy2} b_y e_y}{b_x e_x + b_y e_y}$$

G_{xy1} , G_{xy2} : Shear moduli, in N/mm^2 , respectively calculated in accordance with NR546, Sec 6, [2], in the element 1 and the element 2 (see Fig 1).

- tensile rigidity, in N:

$$E_x A_x = 2(B_x e_x + B_y e_y) E_{moy}$$

where:

$$E_{moy} = \frac{B_x e_x E_{x1} + B_y e_y E_{x2}}{B_x e_x + B_y e_y}$$

5 Rudder stock scantling

5.1 Scantling criterion

5.1.1 General

The scantling of the rudder stock is based for a state of stress in each layer of the laminate making up the rudder stock, induced by torque moment M_{TR} , bending moment M_b and shear force F.

The values of the moments, in KNm , and the shear forces, in N, and the combination of these moments and shear force according to the section of the rudder stock under consideration are defined in the NR467, Part B, Ch 10, App 1.

As a general rule, the requirements to rudder stock scantling are applicable regardless of liners generally provided in way of bearings, cone couplings,...

The stresses in the individual layers of the laminates making up the rudder stock are to be calculated as defined in the NR546, Section 6, taking into account the strains defined in [5.1.2].

The scantling criteria are based on safety coefficients as defined in [11].

5.1.2 Rudder stock strains

The rudder stock laminate strains, calculated at the median plan of the laminates, at the section considered of the rudder stock may be estimated as follows:

- Shear strain, in %, in the plan of the rudder section induced by the torque moment:

$$\gamma_{xy} = \frac{M_{TR} V_{mp}}{G_{xT} I_T} 10^8$$

where:

M_{TR} : Torque moment, in KNm

V_{mp} : Distance, in mm, between the torsion centre of the rudder stock profile and the median plan of the laminate

$G_{xT} I_T$: Torsional rigidity, in Nmm^2 , as defined in [4].

- Bending strain, in %, in the median plan of the laminates making up the rudder stock induced by the bending moment:

$$\epsilon_{xi} = \frac{M_b V_{mp}}{E_{xi} I_i} 10^8$$

where:

M_b : Bending moment, in KNm

V_{mp} : Distance, in mm, between the bending centre of the rudder stock profile and the median plan of the laminate

$E_{xi} I_i$: Bending rigidity, in Nmm^2 , as defined in [4].

Note 1: The strain analysis of each layer of the laminate of the rudder stock may be carried out by the analysis of an equivalent sandwich having the same lay-up than the rudder stock with a core thickness equal to d_s and with a width of one meter, loaded by a bending moment M'_B , in $KN.m$, equal to:

$$M'_B = \frac{I_i}{I_s} M_B$$

where:

I_i : Inertia of the rudder stock

I_s : Inertia of the equivalent sandwich of one meter width.

- Shear strain perpendicular to the rudder section induced by the shear force:

$$\gamma_{xz} = \frac{F}{G_{xyi} S_i} 10^3$$

where:

F : Shear force, in KN

$G_{xyi} S_i$: Effective shear rigidity, in N, as defined in [4].