

# STANDARD

DNVGL-ST-0412

Edition December 2016

## **Design and construction of large modern yacht rigs**

The electronic pdf version of this document, available free of charge from <http://www.dnvgl.com>, is the officially binding version.



## FOREWORD

DNV GL standards contain requirements, principles and acceptance criteria for objects, personnel, organisations and/or operations.

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Any comments may be sent by e-mail to [rules@dnvgl.com](mailto:rules@dnvgl.com)

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## CHANGES – CURRENT

This is a new document.

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# SECTION 1 DESIGN AND CONSTRUCTION OF LARGE MODERN YACHT RIGS

## 1.1 General

### 1.1.1 Scope

**1.1.1.1** This standard applies to sailing yachts of  $L > 24$  m.

**1.1.1.2** Scope of this standard is the structural integrity of one- or multiple-masted, Bermudian rigged monohull or multihull sailing yachts with spars made of carbon fibre reinforced plastics (CRP) or aluminium alloy; including the dimensioning of standing rigging, mast and boom sections as well as local construction in way of fittings structurally attached to the spars.

**1.1.1.3** For other rigged sailing yachts, the principles presented in the following shall be used as a general guidance. Any detailed analysis which is leading to different reserve or reduction factors can be submitted on the basis of an equivalent safety.

**1.1.1.4** Upon request, the performance on construction can be supervised by DNV GL. Basis for this is a relevant shop approval for the typical construction techniques. The survey will be carried out in periodical intervals where an assessment is made whether the product under supervision is built in accordance with approved documentation and the societies standards by random control.

## 1.2 Certification and verification systematics

### 1.2.1 General

**1.2.1.1** The relation between the customer and DNV GL is regulated in an agreement signed by both parties. The agreement specifies the scope of the service, the fee, terms of payment and legal obligations.

**1.2.1.2** The certification service is performed on the basic assumption that all parties involved (designer, builder/yard, manufacturer, design-owner, sub-contractor, owner, etc.) fulfil their individual obligations. The certification service is not performed in substitution of other parties' role or obligations. Nothing contained in DNV GL services, certificate, report or document issued in connection with or pursuant to these requirements, shall relieve any designer, engineer, builder, manufacturer, yard, seller, owner, operator or other parties from any obligations or consequences of default whatsoever. In particular, compliance with the requirements does not imply acceptance or commissioning of a craft. This is the exclusive responsibility of the owner.

### 1.2.2 Procedure

#### 1.2.2.1 General

**1.2.2.1.1** The certification/verification procedures are based on modules. These procedures (modules) cover the design phase, the manufacturing phase or both. The procedures are based on the modules specified in the agreement.

**1.2.2.1.2** Application for certification/verification shall be sent to the undersigned DNV GL office and include:

- name and address of the applicant
- name and address of the builder (yard, manufacturer) craft specification and type designation

- chosen procedure(s)/module(s)
- technical documentation.

1.2.2.1.3 The applicant has to be authorised by the owner of the design to act on his behalf.

1.2.2.1.4 If the applicant subcontract design or production, the applicant remains responsible for the execution of conformity assessment for all technical documentation, sub-supplies and the finished rig.

1.2.2.1.5 Any subcontracting will be subject to separate agreement, handling and approval.

1.2.2.1.6 DNV GL decides the extent of examinations, tests and inspections required to complete the relevant procedure (module) in each case.

## 1.2.3 Technical documentation

### 1.2.3.1 General requirements

1.2.3.1.1 All documents submitted to DNV GL shall be in English language.

1.2.3.1.2 The drawings shall contain all data necessary for assessment and approval. Where deemed necessary, calculations and descriptions of the yacht's elements shall be submitted. Any non-standard symbols used shall be explained in a key list. All documents shall show the project name, drawing number and revision number.

1.2.3.1.3 Submitted documentation about performed calculations shall contain all necessary information concerning reference documents, literature and other sources. The calculations shall be compiled in a way which allows identifying and checking all steps. Handwritten, easily readable documents are acceptable. Where appropriate, results of calculations shall be presented in graphic form. A written conclusion shall be provided.

1.2.3.1.4 DNV GL reserves the right to inquire additional documentation if the submitted is insufficient for an assessment of the rig or essential parts thereof. This may especially be the case for components related to new developments and/or which have not been tested on board to a sufficient extent.

### 1.2.3.2 Guidance for submission of documents

1.2.3.2.1 Upon request the list of required documents to be submitted will be provided by DNV GL

1.2.3.2.2 Drawings shall be submitted in pdf format in general. The documents to be submitted for plan approval are listed below. For the purpose of submission, DNV GL provides a digital platform called MYDNVGL.

#### 1.2.3.2.3 General information

- list of submitted drawings (title, drwg.no., date of latest revision)
- general arrangement, deck plan, sail plan
- technical specification (main dimensions, displacement, etc.)
- DNV GL rig input sheet.

1.2.3.2.4 Relate to [App.A](#) for the scope of documents and information required for certification listed for each of the different certification modules.

## 1.2.4 Certificate/statement of compliance

### 1.2.4.1 General

**1.2.4.1.1** The issuing of a certificate or statement of compliance is based on the chosen modules/ package specified in the agreement.

**1.2.4.1.2** The type of certificate to be issued by DNV GL for compliance will be:

- product certificate.

**1.2.4.1.3** The certificate/statement of compliance shall contain the following information as applicable:

- the name and address of the builder (yard, manufacturer)
- the identification of the product- craft type designation and reference to owner of the design
- reference to the standard and regulations applied
- scope of work
- specification of exemptions or equivalent standards
- date of issue and signatures.

## 1.3 Design and construction principles

### 1.3.1 General

**1.3.1.1** Generally, the basic value for all following evaluations is the static righting moment (RM) of the yacht at full displacement with a heel angle corresponding to the safe working angle (SWA).

**1.3.1.2** The safe working angle (SWA), which will be referred to in the following, generally represents a heeling angle of 25°. However, other angles may be defined as SWA in agreement with DNV GL. DNV GL reserves the right to assess the SWA according to the relevant characteristics of the yacht under sail according to [Table 1-1](#) or special characteristics such as canting keel.

**1.3.1.3** Large cruising catamarans require a different approach defining a basic design parameter. Where the righting moment is a very common value for monohulls, this is not so for "heavy" cruising catamarans. These vessels often provide excessive stability which makes it impractical to work from. Rather a more direct, yet conservative, approach is taken by using the wind pressure directly.

### 1.3.2 Load cases

#### 1.3.2.1 Ordinary sailing conditions

Upwind beating, reaching and broad reaching under appropriate sail configurations for light, moderate, strong and stormy wind conditions, such as:

- full main, working jib, genoa I or reacher
- several reef stages main, working jib, reefed jib, stay sail
- spinnaker only
- others and special configurations for special rigs.

**Table 1-1 Yacht characteristics**

Category	Displacement characteristics	Typical purpose characteristics	Typical handling characteristics
I	Motor sailer/heavy cruiser	Ocean going	Handled by owner/crew
II	Mid displacement	Offshore	Short-handed
III	Light displacement	Coastal pleasure cruises/club racing	Short-handed or handled by crew
IV	Ultra light displacement	Racing	Handled by professional crew

### 1.3.2.2 Extreme conditions

Extreme conditions may need to be defined in special cases, depending on the boat size and type and other configurations.

## 1.3.3 Determination of rig loads

### 1.3.3.1 Pretensioning of rig

The pretensioning of the rigging shall be specified by the designer, otherwise pretensioning is set to avoid slack leeward cap shrouds with an appropriate reserve, when sailing at heeling angles at or below the SWA.

### 1.3.3.2 Transverse sail forces

#### 1.3.3.2.1 Monohulls

Transverse forces are determined from righting moment:

Each sail's contribution to the resultant heeling moment is assumed to be proportional to the sail's area and the distance of its centre of effort above the underwater body's centre of lateral resistance, see [Figure 1-1](#). The sum of these heeling moments is set equal to the vessel's righting moment under the conditions and specific sail configurations being evaluated:

Transverse force from mainsail:

$$F_{tm} = \frac{RM_{design}}{\frac{CoE_m \cdot CLR}{A_m \cdot SFC_m} + \frac{A_f \cdot SFC_f}{A_m \cdot SFC_m} \cdot CoE_f \cdot CLR} \text{ [N]}$$

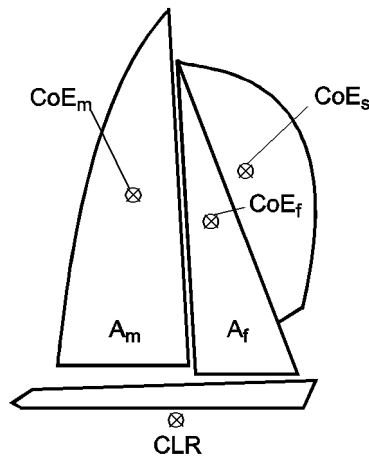
Transverse force from foresail:

$$F_{tf} = \frac{A_f \cdot SFC_f}{A_m \cdot SFC_m} \cdot F_{tm} \text{ [N]}$$

Transverse force from spinnaker when broaching:

$$F_{ts} = \frac{RM_{Design}}{CoE_s \cdot CLR} \text{ [N]}$$





**Figure 1-1 Centres of effort**

$RM_{Design}$  = righting moment as defined in [1.3.1] [Nm]

$CoE_{m/f/s}$  = centre of effort of respective sail:

$CoE_m = 0.39 P$  above gooseneck [m] (default)

$CoE_f = 0.39 I$  above foot [m] (default)

$CoE_s = 0.59 I$  above deck [m] (default)

$CLR$  = the centre of lateral resistance of the underwater body (including appendages) [m]

$A_m$  = mainsail area, projected laterally [m<sup>2</sup>]

$A_f$  = foresail area, projected laterally [m<sup>2</sup>]

$P$  = mainsail hoist [m]

$E$  = foot of mainsail [m]

$I$  = height of fore triangle [m]

$SFC_m$  = side force coefficient mainsail

= 0.9

$SFC_f$  = side force coefficient foresail

= 1.1

#### 1.2.3.2.1.1 Estimation of corresponding apparent wind speed for upwind cases

$$v_a = \sqrt{\frac{F_{t(m/f)}}{SFC_{m/f} \cdot A_{m/f} \cdot 0.5 \cdot \rho}} \text{ [m/s]}$$

where:

$\rho$  = density of air [kg/m<sup>3</sup>].

#### 1.3.3.2.2 Multiple-mast rig

For a multiple-mast rig a conservative assumption of the proportioning of righting moment shall be made:

For all relevant sail configurations, the fractions of sail area moments (SAM) for each mast from the total SAM shall be determined to find the design righting moment for each mast.

The sail area moment is defined as:

$$SAM = A \cdot \overline{CoE \cdot CLR} \text{ [m}^3\text{]}$$

where:

$A$  = projected sail area.

The sail area moment for each mast is defined as:

$$SAM_i = \sum_{j=1}^n (A_j \cdot \overline{CoE_j \cdot CLR}) \text{ [m}^3\text{]}$$

where:

$i$  = index for specific mast

$j$  = index for specific sail on specific mast.

The fraction of each mast from the total sail area moment is defined as:

$$f_i = \frac{SAM_i}{\sum_{i=1}^n SAM_i}$$

The design righting moment  $RM_{\text{design}}$  for each mast shall be taken the lower of:

- $RM_{\text{design}} = 1.0 \cdot (RM \text{ at SWA})$
- $RM_{\text{design}} = 1.56 \cdot f \cdot (RM \text{ at SWA}).$

Windage of masts and rigging (and equipment) and therewith contribution to (each) SAM and/or (OTM) may be taken into account.

$OTM$  = overturning moment, see [1.3.3.2.3].

#### 1.3.3.2.3 Multihulls

The relevant apparent wind speed, resulting from the true wind speed and the predicted boat speed is used to calculate the pressure forces for a rig.

$$AWS_o = TWS + \cos(TWA) \cdot BS$$

where:

$TWS$  = true wind speed

$TWA$  = true wind angle

$BS$  = boat speed.

This operational wind speed  $AWS_o$  is defining the safe operational limits for the vessel, equivalent to a safe working heel angle on monohulls, which may not be exceeded. The operational limits of a rig need to be defined precisely and followed diligently.

The design wind speed, which a rig is designed to, needs to be determined conservatively. As a catamaran does not "heel away" from wind forces, a gust factor is introduced as a buffer, which acts as a multiplier on TWS (true wind speed).

The design wind speed is calculated using the above equation with the true wind speed multiplied by factor of 1.25:

$$AWS_D = 1.25 \cdot TWS + \cos(TWA) \cdot BS$$

From this wind speed the sail pressure forces are calculated using the equation:

$$F = \frac{\rho}{2} \cdot AWS_D^2 \cdot A \cdot c_S$$

where:

$\rho$  = density of air.

The side force coefficient  $c_S$  for a mainsail is generally 0.9, for a jib 1.1. These pressure forces are supposed to act at the sails centre of effort, where the assumptions for the locations are:

Mainsail 45% of mean height for sails with normal roach.

Headsail 39% of mean height of triangular sail.

Looking at a different angle of this approach, these sail pressure forces calculated from the design wind speed result in an overturning moment (OTM). If really required for reference, the OTM shall be calculated about the vessel's longitudinal axis, at an elevation which can be called "platform" of the rig, mostly deck or sheerline level.

What has been found from studies is that obviously the AWS is a conservative value to work with. While bearing away from upwind the allowable TWS gets higher and also the AWS gets slightly higher. But the OTMs stay rather constant or even get marginally smaller. So actually, for all "upwind sail" configurations, an AWS limit is conservative and serves well for dimensioning purposes. Downwind cases need to be looked at separately, at a certain OTM (guideline: similar to upwind) and a windpressure due to an AWS of 25 kn.

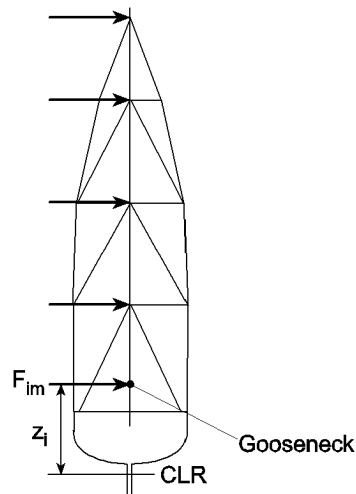
#### 1.3.3.2.4 Distribution of transverse sail forces of the mainsail

A set of point loads shall be calculated from  $F_{tm}$  acting on the mast as shown in Figure 1-2. The point load distribution shall be appropriate for the specified sail configuration and shall reproduce the equilibrium of moments. Table 1-2 shows examples of such point load distributions.

**Table 1-2 Possible approaches for mainsail load distribution, unreefed**

	Distribution factor $c_{im}$		
	3-spreader-rig	4-spreader-rig	5-spreader-rig
Clew <sup>1)</sup>	(0.25)	(0.25)	(0.25)
Gooseneck, tack	0.0	0.0	0.0
Spreader 1	0.05	0.0	0.0
Spreader 2	0.15	0.05	0.0
Spreader 3	0.25	0.15	0.05
Spreader 4	—	0.25	0.15

Spreader 5	—	—	0.25
Main headboard	0.30	0.30	0.30
1) Not applied on rig explicitly.			



**Figure 1-2 Mainsail load distribution**

$$F_{im} = c_{im} \cdot F_{tm} \text{ [N]}, \text{ where}$$

$$\frac{CoE_m \cdot CLR}{\sum_{i=1}^n (c_{im} \cdot z_i)} \stackrel{!}{=} 1$$

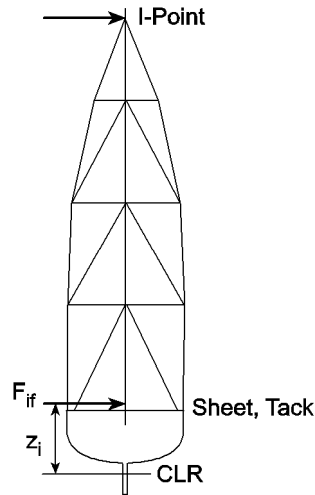
$F_{tm}$  = transverse force mainsail according to [\[1.3.3.2\]](#)

$c_{im}$  = distribution factor with:

$$\sum_{i=1}^n c_{im} = 1$$

$z_i$  = according to [Figure 1-2](#).

### 1.3.3.2.5 Distribution of transverse sail forces of the foresail



**Figure 1-3 Foresail point loads**

$$F_{if} = c_{if} \cdot F_{tf} \text{ [N]}, \text{ where}$$

$$\frac{CoE_f \cdot CLR}{\sum_{i=1}^3 (c_{if} \cdot z_i)} \stackrel{!}{=} 1$$

$F_{tf}$  = transverse force foresail according to [1.3.3.2]

$c_{if}$  = distribution factor with:

$$\sum_{i=1}^n c_{if} = 1$$

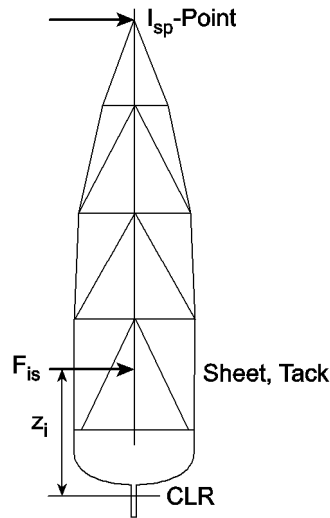
$z_i$  = according to Figure 1-3.

Table 1-3 shows an example of the foresail load distribution.

**Table 1-3 Approach for foresail load distribution**

	$c_{if}$
Tack <sup>1)</sup>	(0.3)
Clew <sup>1)</sup>	(0.3)
Head	0.4
1) Not applied on rig explicitly.	

### 1.3.3.2.6 Distribution of transverse sail forces of the spinnaker



**Figure 1-4 Spinnaker point loads**

$$F_{is} = c_{is} \cdot F_{ts} \text{ [N]}, \text{ where}$$

$$\frac{CoE_s \cdot CLR}{\sum_{i=1}^3 (c_{is} \cdot z_i)} \stackrel{!}{=} 1$$

$F_{ts}$  = transverse force spinnaker according to [1.3.3.2]

$c_{is}$  = distribution factor with:

$$\sum_{i=1}^n c_{is} = 1$$

$z_i$  = according to Figure 1-4.

Table 1-4 shows an example of spinnaker load distribution.

**Table 1-4 Approach for spinnaker load distribution**

	$c_{is}$
Tack <sup>1)</sup>	(0.3)
Clew <sup>1)</sup>	(0.3)
Head	0.4

1) Not applied on rig explicitly.

### 1.3.3.3 Self-weight forces

The self-weight of a rig induces additional internal forces in the rig, especially when a rig is heeled; the occurring forces are often of mentionable magnitude and need to be considered and applied to computational rig models aside the forces derived from righting moment or wind pressure.

### 1.3.3.4 Extreme loads

Extreme loads can be defined in each separate case, depending on special configurations.

## 1.3.4 Determination of working loads of running and standing rigging

### 1.3.4.1 Running rigging

The following approaches shall be seen as a general estimation of an initial calculation value. Care shall be taken, when configurations require modified approaches.

#### 1.3.4.1.1 Halyards

The working load of a halyard is generally generated by membrane forces in a sail. Its magnitude depends on the amount of sag of the leech including a preload due to hoisting. Determination of the halyard load shall be based on design righting moment and the following sail configuration:

Full main and 100% foresail (i.e. the foresail foot length equals  $J$ ).

$J$  = base of fore triangle [m].

1.3.4.1.1.1 Mainsail and/or mizzensail halyards:

$$F_{mhy} = 1.08 \cdot F_{ml} \text{ [N]}$$

where:

$F_{ml}$  = mainsail leech load

$$= \frac{F_{tm}}{8 \cdot s} \cdot f_r \text{ [N]}$$

$f_r$  = roach factor

$$= \frac{A_m}{0.5 \cdot P \cdot E}$$

$F_{tm}$  = according to [1.3.3.2]

$s$  = sag fraction

= 0.065 [-], (6.5% of leech length) for all categories.

1.3.4.1.1.2 Foresails (genoa, jib, staysail, etc.) halyards

$$F_{fhy} = 1.02 \cdot \frac{F_{tf}}{8 \cdot s} \text{ [N]}$$

where:

$F_{tf}$  = according to [1.3.3.2]

$s$  = sag fraction

= 0.045 [-], (4.5% of leech length).

#### 1.3.4.1.2 Boom outhaul

The force of the outhaul is generated by the horizontal component of the leech load and a force resultant from the sag of the sail foot.

$$F_{oh} = \cos\left(\arctan\left(\frac{P}{E}\right)\right) \cdot F_{ml} + F_{tm} \cdot \frac{E}{P \cdot 8 \cdot 0.05} \text{ [N]}$$

where:

$F_{ml}$  = according to [1.3.4.1.1.1]

$F_{tm}$  = transverse force from mainsail according to [1.3.3.2].

For  $P$  and  $E$  see [1.3.3.2.1].

#### 1.3.4.1.3 Mainsheet

The working load of the mainsheet is estimated by a given sag of the leech. Its vertical component  $F_{msv}$  is calculated by the equation:

$$F_{msv} = \frac{E}{X_{ms}} \cdot F_{ml} \text{ [N]}$$

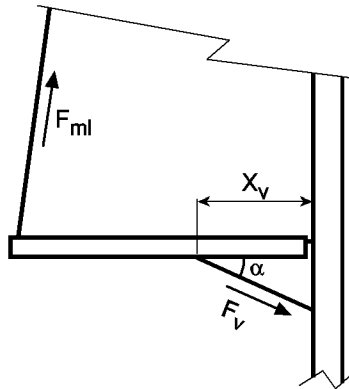
where:

$X_{ms}$  = sheet attachment point on boom aft of gooseneck [m]

$F_{ml}$  = according to [1.3.4.1.1.1].

#### 1.3.4.1.4 Vang

The maximum vang loads normally occur when reaching or running downwind. Base value for calculating the vang load is again the leech load of the mainsail which in turn is determined by the sag fraction specified below. By omitting the mainsheet load contribution the following equation for the vang load  $F_v$  results from force equilibrium according to Figure 1-5.



**Figure 1-5 Vang load determination**

$$F_v = \sin\left(\arctan\left(\frac{P}{E}\right)\right) \cdot F_{ml} \cdot \frac{E}{x_v \sin \alpha} \text{ [N]}$$

where:

$F_{ml}$  = according to [1.3.4.1.1.1]

$x_v$  = distance from gooseneck to boom vang fitting [m]

$\alpha$  = angle between vang and boom

$s$  = sag fraction (proposals)

= 0.25 [-], (25% of leech length) for category I, II

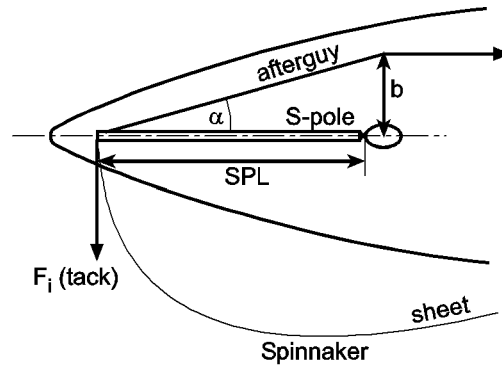
= 0.20 [-], (20% of leech length) for category III

= 0.15 [-], (15% of leech length) for category IV.



#### 1.3.4.1.5 Spinnaker pole

Normally, the maximum working compression of the spinnaker pole occurs under tight reaching condition, when the spinnaker pole points straight forward. The load induced is assumed to be generated by an interaction between afterguy and pole according to Figure 1-6.



**Figure 1-6 Spinnaker pole force**

Maximum working compression of spinnaker pole:

$$F_{sp} = \frac{F_i(tack)}{\tan \alpha} \text{ [N]}$$

where:

$F_i(tack)$  = relevant  $F_{is}$  according to [1.3.3.2.6]

$\alpha$  =  $\arctan\left(\frac{b}{SPL}\right)$

$b$  = distance of deflection sheave from centre line or length of jockey pole [m].

It shall be considered whether a supplement shall be made due to sheet loads (for rather flat spinnakers or gennakers).

#### 1.3.4.2 Standing rigging

DNV GL examines standing rigging sizes by calculating tensile forces and correlate them with the reserve factors according to [1.3.5.1]. Calculation method is geometric non-linear finite element analysis. The tensile forces determined this way are also called maximum working loads (MWL) under the conditions of this standard.

**Note:**

Working loads of longitudinal stays can be determined analytically (see [1.3.4.2.2]).

---e-n-d---o-f---n-o-t-e---

##### 1.3.4.2.1 Shrouds

Calculation of shroud working loads shall be based on the input specified in [1.3.1.2.3].

##### 1.3.4.2.2 Headstays

The working load is the resultant axial force due to sag of a sail-carrying headstay.

The sag is the maximum transverse deflection of a line under a lateral uniform load between its end points.

The values specified below are relevant for the load case of a full main combined with a jib of 100% forestay-triangle area or reefed main combined with staysail at SWA. The lateral load  $q$  is a uniform load equivalent to the force  $F_{tf}$  defined in [1.3.3.2.1], see Figure 1-7.

Headstay working load  $F_{hs}$ :

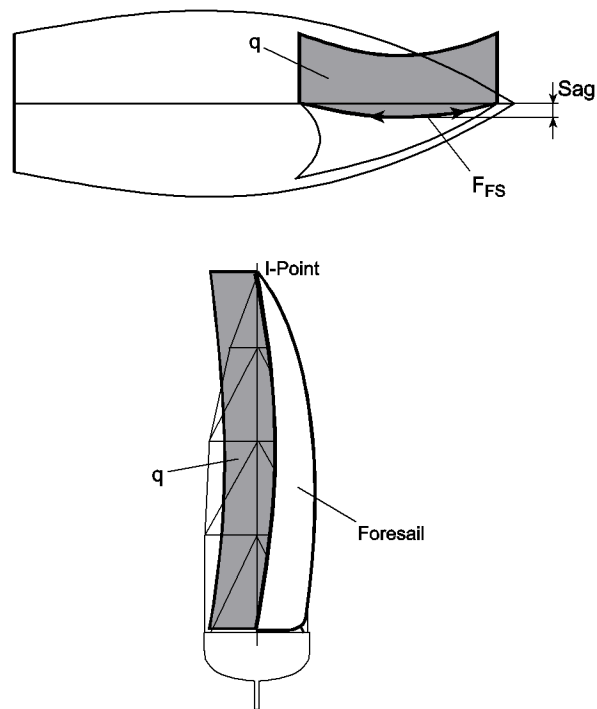
$$F_{hs} = \frac{q \cdot l_0}{8 \cdot s} \text{ [N]}$$

where:

$$q = \frac{F_{tf}}{l_0} \text{ [N/m]}$$

$l_0$  = stay length [m]

$s$  = the magnitude of sag  $s$  as a fraction of the stay length shall not be taken more than according to Table 1-5.



**Figure 1-7 Headstay load**

**Table 1-5 Headstay sag**

	Sag			
	Cat. IV	Cat. III	Cat. II	Cat. I
Primary headstay	0.7%	1.0%	1.5%	2.0%
Secondary headstay(s)	1.5%	2.5%	3.0%	5.0%

Deviations from these indexes can only be considered in well-founded cases, resulting from exceptional sail and/or design characteristics.

Working loads for non-sail-carrying headstays (inner forestays, baby stays) are not explicitly specified here. In this case, design criterion is the rig's required longitudinal stiffness dealt with in [1.3.5.2].

#### 1.3.4.2.3 Backstay(s)

For masthead rigs, backstay design load is obtained by opposing the forestay design load under equilibrium of moments about the mast base. In case of swept spreaders a contribution of cap shrouds may be considered.

#### 1.3.4.2.4 Runners, check stays, etc.

Runner and/or check stay design loads are obtained by opposing the forward longitudinal stays design loads under equilibrium of moments about the mast base.

Besides, runners may be necessary not only to control but also to support and stabilise the rig, see [1.3.5.2].

### 1.3.5 Global analysis

#### 1.3.5.1 Standing rigging

##### 1.3.5.1.1 General

Diagonal shrouds shall generally have a minimum angle to the mast centreline of 9°. If spreaders are swept, they shall be swept evenly, so that all shrouds are in plane on either side, when rig is unstressed. Spreader sweep angles between 5° and 9° are not advisable.

While dimensioning of standing rigging, global rig stiffness characteristics shall be considered, since in case of swept spreaders the "system stiffness" of the rig is also influenced by the dimensions and geometric arrangement of transverse rigging.

##### 1.3.5.1.2 Dimensioning of standing rigging made of steel rod

The following reserve factors (RF) are valid provided working loads in standing rigging have been calculated by static, geometric non-linear analysis. They are related to the ultimate break load specified by the manufacturer. If not explicitly mentioned, the following reserve factors are valid for Nitronic 50 Rod rigging.

###### 1.3.5.1.2.1 Transverse rigging and jumper

RF  $\geq$  2.5 on working loads determined according to [1.3.4.2].

###### 1.3.5.1.2.2 Fore and aft rigging, others

RF  $\geq$  2.0 on design load according to [1.3.4.2]

RF  $\geq$  2.5 on design load according to [1.3.4.2] generally for category I yachts.

##### 1.3.5.1.3 Dimensioning of standing rigging made of polymer fibre cables

For fibre rigging elements, such as PBO or carbon strand cables, the working load determined by static, geometric non-linear analysis using the approaches offered in this standard so far may not exceed the cable's maximum working load specified by the cable supplier. This maximum cable working load may be a DNV GL-certified value and thus/or be determined by the approach offered in DNVGL-CP-0413 class program for the type approval of carbon strand and PBO cable rigging for sailing yachts. In lack of such proof, the following reserve factors shall be used:

###### 1.3.5.1.3.1 Transverse rigging and jumper

RF  $\geq$  4.5 on working loads determined according to [1.3.4.2] including the self-weight effect.

#### 1.3.5.1.3.2 Fore and aft rigging, others

RF  $\geq$  3.6 on design load according to [1.3.4.2] and soft aramid rigging

RF  $\geq$  4.5 on design load according to [1.3.4.2] for category I yachts.

### 1.3.5.2 Stability analysis

The following stability evaluations are based on the determination of buckling modes. The reserve factors versus buckling do not necessarily represent a safety against the occurrence of this failure mode, because the applied method assumes ideal straightness of the mast and its alignment with the forces which is not the case in the realistic situation. Yet, the method provides a measure for assessing the rig's stiffness.

#### 1.3.5.2.1 Global stability and stiffness

Global buckling is called the longitudinal buckling of the whole rig-system fore and aft. The following reserve factors are applicable for an evaluation according to the Euler eigenmode method. The determination of mast compression levels is based on static, non-linear analysis.

RF  $\geq$  3.1 on each set of mast panel compressions (resulting from all relevant working loads according to [1.3.4]).

Global stiffness shall also be considered in case the yacht is driven with no mainsail, e.g. under engine, against heavy seaways.

#### 1.3.5.2.2 Local stability and stiffness

Local transverse buckling of the mast normally occurs as panel-buckling between transverse supports. Reserve factors are again applicable for an evaluation according to the Euler eigenmode method.

RF  $\geq$  2.6 on each set of mast panel compressions resulting from all relevant working loads according to [1.3.4].

#### 1.3.5.2.3 Shear stiffness of CRP-mast tubes

25% (by weight) of the mast's basic laminate lay-up shall have  $\pm 45^\circ$  fibre orientation to achieve a minimum shear and torsional stiffness. A stiffness correction of this content shall be taken into account in case of dissimilar moduli of fibres running in  $0^\circ$  and  $45^\circ$ .

See also [1.4.1.3] for minimum elastic properties of tubes.

However special considerations are required for furling masts with open sections.

#### 1.3.5.2.4 Thin wall buckling of the tube

Tube wall buckling shall be considered.

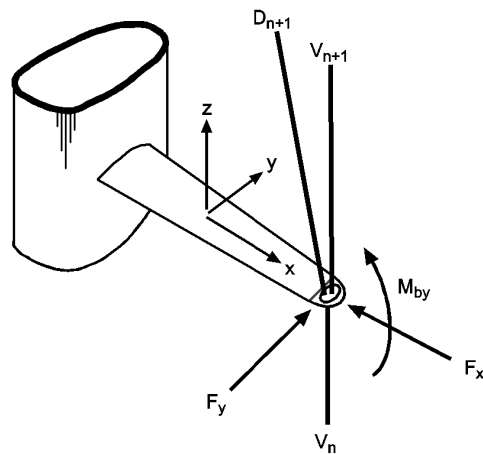
RF  $\geq$  3.0 on ultimate buckling stress or strain according to max. working compression in each wall panel resulting from load cases acc. to [1.3.2.1] (reserve factors are applicable for Roark and Young's theory of skin buckling under compression loads for curved, non-isotropic plates). Load concentrations shall be considered particularly in way of:

- mast step, especially when the mast can not be pitched
- D-tangs
- slots or halyard exits.

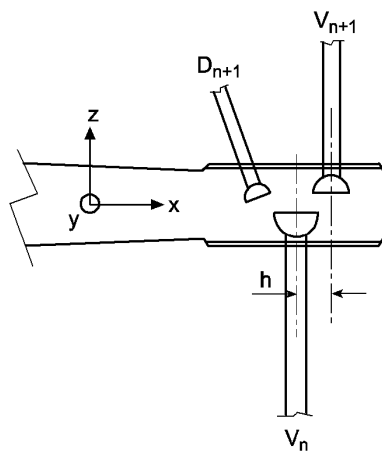
### 1.3.5.3 Spreader construction

Spreaders are subjected to axial, bending and shear loads. Each of the following scenarios described in [1.3.5.3.1] to [1.3.5.3.4] shall be considered. Proof of sufficient safety is based on "first principles" of engineering. In Figure 1-8 and Figure 1-9 relevant arrangements and coordinates are shown. Relevant allowable strains and stresses are defined in [1.3.9.1.2], [1.3.9.1.3] and [1.3.9.1.4]. The design loads shall be determined as follows:

### 1.3.5.3.1 Loading on windward side



**Figure 1-8 Forces on a spreader**



**Figure 1-9 Spreader end detail**

$F_x$  = load in x-direction, resulting from relevant components of 2.5 times the calculated shroud working loads [N]

$M_{by}$  = bending moment resulting from 2.5 times the calculated working loads of  $V_{n+1}$  with an offset of  $h$  (tip cup offset) [Nm]:

- for Navtec 528 Standard:  
Tip cup offset =  $0.6 \cdot \text{diam. } V_{n+1}$
- for Navtec 534/834:  $0.5 \cdot \text{diam. } V_{n+1}$
- for others: to be specified

Tip cup moments else from this approach may be considered if a variation of load cases has been calculated and the most conservative value resulting from combination of  $V_n$ ,  $V_{n+1}$  und  $D_{n+1}$ . This moment shall be multiplied by 2.5 for subsequent spreader calculations.

- $F_{ya}$  = load in y-direction at spreader tip generated by mast bent ( $F_{ya \max}$  on windward side):  
 =  $V1 \cdot 0.0055 \cdot k_1 \cdot k_2$  [N]  
 $V1$  = nominal break load or 2.5 times the calculated working load from  $V1$  [N]  
 $k_1$  = 0.7 for non-swept spreaders  
 = 1.0 for 20° spreader-rake, interpolate in-between  
 $k_2$  = distribution factor according to [Table 1-6](#)  
 $F_{yb}$  = sectional loads in y-direction  $F_y$  at spreader tips obtained from finite element analysis (FEA)  
 =  $2.5 \cdot F_y$  [N]

The sectional loads in the spreaders are combinations from design loads listed above.

**Table 1-6 Distribution factors**

$k_2$	3-spreaders-rig	4-spreaders-rig	5-spreaders-rig
Spreader 1	0.7	0.6	0.6
Spreader 2	1.0	0.9	0.8
Spreader 3	0.95	1.0	1.0
Spreader 4	—	0.96	0.95
Spreader 5	—	—	0.85

#### 1.3.5.3.2 Loading on leeward side

$F_{yc}$  = loads from mainsail pushing against each leeward spreader

$$F_{yc} = l_p \cdot E \cdot c_1 \cdot c_2 \cdot c_3 \cdot \frac{\rho}{2} \cdot v_{aws}^2 \text{ [N]}$$

where:

- $l_p$  =  $\frac{P}{n+1}$  [m]  
 $n$  = number of spreaders  
 $P$  = mainsail hoist, see [\[1.3.3.2.1\]](#)  
 $\rho$  = density of air [ $\text{kg}/\text{m}^3$ ]  
 $v_{aws}$  = design AWS according operational manual plus gust factor of 25%  
 $c_1$  = sail girth factor, see [Table 1-7](#)  
 $c_2$  = distribution factor, see [Table 1-8](#)  
 $c_3$  = overload factor  
 = 2.0  
 $E$  = foot of mainsail, see [\[1.3.3.2.1\]](#).

Choosing this method, all other design loads ( $F_x$ ,  $F_{ya}$  and  $M_{by}$ ) are assumed to be zero.

**Table 1-7 Girth factors**

$c_1$	3-spreader-rig	4-spreader-rig	5-spreader-rig
Spreader 1	0.75	0.8	0.83
Spreader 2	0.5	0.6	0.67
Spreader 3	0.25	0.4	0.5
Spreader 4	—	0.2	0.33
Spreader 5	—	—	0.17

**Table 1-8 Distribution factors**

$c_2$	3-spreader-rig	4-spreader-rig	5-spreader-rig
Spreader 1	0.5	0.5	0.4
Spreader 2	0.8	0.7	0.6
Spreader 3	1.0	0.9	0.8
Spreader 4	—	1.0	0.9
Spreader 5	—	—	1.0

#### 1.3.5.3.3 Spreader buckling

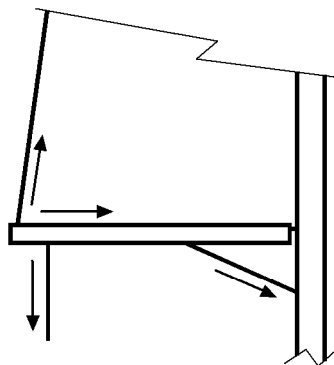
RF  $\geq$  1.1 for Euler-Buckling of spreader versus relevant design loads specified in [1.3.5.3.1].

#### 1.3.5.3.4 Spreader wall buckling

RF  $\geq$  1.1 for thin wall buckling of spreader versus relevant design loads specified in [1.3.5.3.1].

### 1.3.6 Booms

Booms are subjected to compression, bending, shear and torsion primarily through the loads from sheet, leech, outhaul and vang, see Figure 1-10.



**Figure 1-10 Forces on boom**

*Design loads:*

1.5 × release load for max. possible relief valve setting [N]

1.0 × max. working loads of all relevant sheets, lines, outhauls, etc. [N]

1.0 ×  $M_t$  (resulting torsional moment), see [Figure 1-12](#).

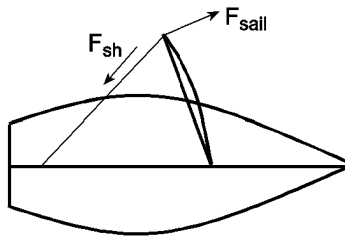
$$M_t = F_{sh} \cdot h + F_{sail} \cdot k \text{ [Nm]}$$

where:

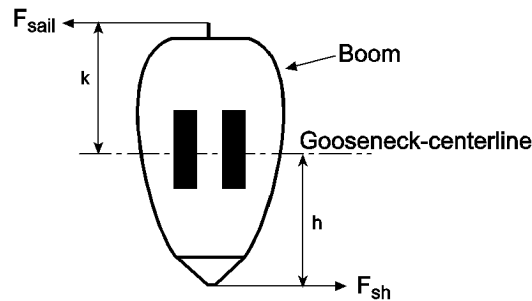
$F_{sh}$  = horizontal component of mainsheet load [N], see [Figure 1-11](#)

$F_{sail}$  = component of mainsail load acting at mainsail clew [N], see [Figure 1-11](#).

$$F_{sh} \approx F_{sail} = \frac{1}{3} \cdot \frac{\rho}{2} \cdot A \cdot v^2 \approx 75 \cdot A \text{ [N]}$$



**Figure 1-11 Mainsail clew**



**Figure 1-12 Boom section**

$v$  = apparent wind speed for design purpose = 19 m/s (35 kn)

$A$  = mainsail area [m<sup>2</sup>]

$\rho$  = density of air [kg/m<sup>3</sup>].

An appropriate combination of the above loads shall be assumed for the strength calculation.

It is strongly recommended to provide the vang with an overload relief valve. Otherwise the design load for the boom in respect of forces due to the vang shall be replaced by:

1.0 × breaking load of vang [N]



The requirements for allowable strains and stresses as defined in [1.3.9.1.2], [1.3.9.1.3] and [1.3.9.1.4] shall be met when applying the design loads. Also wall buckling of the boom shall be considered.

### 1.3.7 Mast step

A mast step is subjected to compression and shear forces. Especially for keel-stepped masts, shear is mainly generated by boom compression.

### 1.3.8 Mast-panel between maststep and upper-most spinnaker pole position (Panel 0)

If the loading of Panel 0 due to vang, spinnaker/jockey pole and boom has not been part of the global analysis, these loads shall be taken into account additionally when designing Panel 0. The resultant loads due to the following design loads shall be considered then:

Vang: resultant loads due to  $1.5 \times$  max. vang working-load according to [1.3.4.1.4] (for hydraulic device: vang load = release load at max. eased mainsheet)

Poles:  $2 \times$  resultant loads due to pole compression according to [1.3.4.1.5]

Gooseneck: resultant loads due to  $1.5 \times$  max. vang load (for hydraulic device: vang load = release load at max. eased mainsheet plus other relevant contributions (outhaul, mainsheet etc.)).

### 1.3.9 Local analysis

#### 1.3.9.1 Local analysis of components made of multi-axial-carbon fibre laminate or aluminium alloy

The reduction factors and allowable material strains and stresses in this standard are applicable for the following general engineering approaches (according to the classic laminate theory (CLT) for carbon fibre reinforced plastic). For 3-D finite element analysis the reduction factors shall be defined separately.

*Pin seating:*

— bearing stress/strain [MPa]:

$$\sigma_b = \frac{F}{t \cdot d} \quad \varepsilon_b = \frac{\sigma_b}{E}$$

— shear-out stress<sup>1</sup> (for CRP) [MPa]:

$$\tau_{st} = \frac{F}{2 \cdot t \cdot \left(e - \frac{d}{4}\right)} \quad \varepsilon_{st} = \frac{\tau_{st}}{G}$$

— tensile (hoop) stress [MPa]:

$$\sigma_{hs} = \frac{F}{t \cdot (b - d)} \quad \varepsilon_{hs} = \frac{\sigma_{hs}}{E}$$

where:

$F$  = design load according to [1.3.9.1.1] [N]

$t$  = plate thickness [mm]

$d$  = pin hole diameter/bushing diameter [mm]

$e$  = distance from pin centre to edge of component in direction of load [mm]

<sup>1</sup> Shear-out stress shall be considered for bolt-fastenings with an edge distance lower than  $2d$ . In any case, when plate material is not quasi-isotropic.

- $b$  = width of component perpendicular to direction of load [mm]
- $E$  = mean compressive modulus [MPa]
- $G$  = mean shear modulus [MPa].

This implies, that the construction allows for such simplifications, otherwise stress concentration factors (SCF) shall be incorporated. Index values for SCF are:

- SCF = 3.0 for holes around loaded pins
- SCF = 1.7 for holes in loaded isotropic or quasi-isotropic laminates.

Furthermore:

- Bending in bolt-connections shall be kept small by choosing an appropriate arrangement.
- Where pins introduce an un-symmetrical loading in a plate due to additional transverse loading (e.g. at forestay attachment), holes shall have a bushing and be clamped. (A clamped laminate is supported by a steel bushing inside a hole and at its cheeks with washers or plates connected to the bushing.)
- An efficient load transfer for local load introductions through bolt-connections in flat CRP-plates can be provided with a quasi-isotropic plate laminate with the following fractions of fibre-directions:
  - 0°: 30% - 50%
  - ±45°: 40% - 60%
  - 90°: ≥ 10%

For minimum elastic off-axis properties, relate also to [1.4.1.3].

#### 1.3.9.1.1 Design loads for structural joints, fittings attachments and connections

1.0 × breaking load of the relevant shroud or stay (usually used for steel rod rigging components)  
or

2.5 × calculated working load of the relevant stay or shroud (usually used for fibre rigging components)  
2.0 × calculated working load for headstays (usually used for fibre rigging components).

If more than one of the following design loads is relevant, the highest resulting value shall be chosen.

1.0 × release load of halyard tensioners/winchers and sheet winches etc.

0.8 × breaking load of running rigging

2.0 × max. working load of running rigging

1.5 × max. vang load (hydraulic device: release load).

Others to be specified in detail.

If more than one design load is relevant, the highest resulting value shall be chosen.

#### 1.3.9.1.2 Allowable strains for carbon fibre laminates under design loads

$\epsilon_{b\ all}$  = 0.25% allowable bearing strain of carbon laminate with circular holes

$\epsilon_{bc\ all}$  = 0.35% allowable bearing strain of clamped carbon laminate with circular holes

$\epsilon_{ct\ all}$  = 0.25% allowable compression and tensile strain

$\epsilon_{is\ all}$  = 0.45% allowable in-plane shear strain.

#### 1.3.9.1.3 Applicable reduction factors for carbon fibre laminate strength under design loads on the basis of appropriate and approved material test data, see [1.4.1.3]

$\gamma_b$  = 2.0 on ultimate bearing strength (compressive test)

$\gamma_{bc}$  = 1.5 on ultimate bearing strength of clamped laminates (compressive test)

$\gamma_{ct}$  = 2.0 on ultimate compression and tensile strength

$\gamma_s$  = 2.0 on ultimate in-plane shear strength.

#### 1.3.9.1.4 Applicable reduction factors for aluminium alloys under design loads

- $\gamma_b$  = 1.1 on ultimate bearing strength  
 $\gamma_{ct}$  = 1.1 on ultimate compression and tensile strength  
 $\gamma_s$  = 1.1 on ultimate shear strength.

For welded components the modified material properties in the heat affected zone shall be taken into account.

#### 1.3.9.2 Local strength of metallic pins and other attachments made of stainless steel or aluminium alloy

- $\gamma_y$  = 1.1 on yield strength under design-loads according to [1.3.9.1.1].

#### 1.3.9.3 Bonded joints

Bonded joints are normally in-plane shear loaded.

- $\gamma_{gjb}$  = 2.0 on ultimate shear strength of adhesive in connection with bolts/rivets  
 $\gamma_{gj}$  = 2.5 on ultimate shear strength of adhesive without bolts/rivets
- cleavage shall be avoided
  - joints of mast-, boom- or spreader shells shall be located in one of the neutral axes
  - structural threads are not allowed in laminates.

## 1.4 Materials and fabrication

### 1.4.1 Materials

#### 1.4.1.1 Carbon fibre reinforced plastic in general

A solid laminate lay-up shall have well-balanced mechanical properties, i.e. off-axis fibres evenly distributed, unless special configurations are required in well-founded exceptional cases.

In a laminate a batch of plies with fibres aligned solely in one direction may not exceed a thickness of 1.5 mm or a fibre weight of 1500 g/m<sup>2</sup> respectively. Generally, grouping of 90° plies shall be avoided.

For polymer matrix composites the reinforcement fibre will be the primary load carrying element, because it is stronger and stiffer than the matrix. The mechanism for transferring load throughout the reinforcement is the shearing stress developed in the matrix. Thus, a fibre dominated laminate characteristic is desired wherever possible. A (0°/±45°/90°)-lay-up is recommended, a minimum of 10% of the fibres should be aligned in each of those directions (see also [1.3.9.1]).

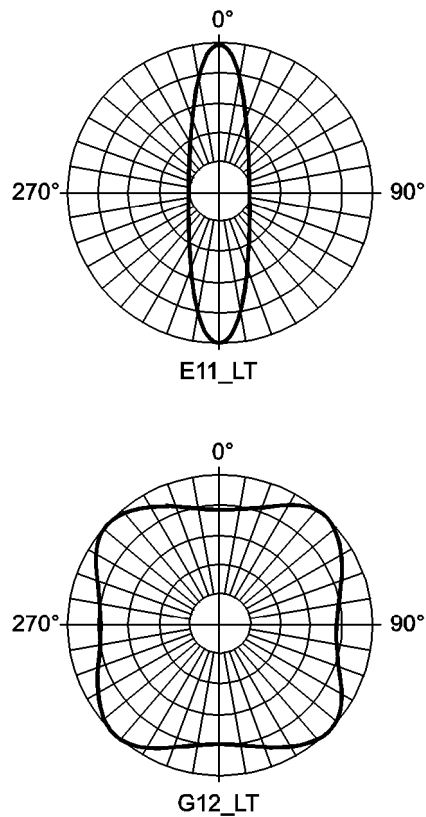
In any case the transverse Young's modulus in compression shall exceed a minimum of 20% of the value in longitudinal direction. The polar graph of the inplane Young's modulus shall not have major concave areas see Figure 1-13.

The minimum shear modulus in shell plane shall be not less than 11% of the Young's modulus in compression.

Conditions, where peel stresses occur due to abrupt steps or bonded structures with significantly different stiffnesses shall be avoided.

The taper of a laminate, for example reduction of section thickness or a reinforcement patch, shall be carried out according to a proper taper ratio.

When drilling holes in CRP, measures shall be taken to prevent fibres from breaking out of the back face.



**Figure 1-13 Polar diagrams**

#### 1.4.1.2 Carbon fibre reinforced plastic samples

CRP samples of the fabricated tube shall be submitted to DNV GL. Samples can be:

- spar shell ends close behind cut-offs
- pieces from cut-outs, e.g. from:
  - spreaders, tang fittings
  - halyard slots
  - others, if available, with designation of their location.

Pieces will be stored.

Some of the CRP samples shall be representative of the 0° (longitudinal) direction of the tube with a minimum size of  $100 \times 10 \times t$  [mm] for a possible compression test.

#### 1.4.1.3 Material tests (Carbon fibre reinforced plastic)

Analysis of local details may be performed in a more exact and less conservative way, when reliable test data of the relevant laminate properties are available. However, before applying test data values it shall always be considered, whether the test data in question are (really) significant for the particular design problem. Tests shall be carried out according to appropriate standards at an independent, accredited institute. The specimen shall be supplied by the mast-builder and be fabricated under realistic conditions corresponding to the component-construction.

#### 1.4.1.4 Design values

For each mechanical property of a laminate a min. number of tests shall be carried out. A statistical average is then to be taken as outlined in the following, to obtain the characteristic value, which will be taken as design value.

A normal distribution is assumed for the test values of the mechanical properties. A 5% fractile for a probability of  $P = 95\%$  (confidence interval) shall be applied here. The relevant equation for the characteristic value  $R_k$  is:

$$R_k(\alpha, P, s, n) = x - s \cdot \left( u_\alpha + \frac{u_P}{\sqrt{n}} \right)$$

where:

$u_{\alpha/P}$  =  $\alpha\%/P\%$  fractile (percentile value) of a normal distribution for defining a minimum value  
= 1.645 for the above condition ( $\alpha = 5\%$ ,  $P = 95\%$ )

$x$  = arithmetic mean value from test results

$$= \frac{\sum_{i=1}^n x_i}{n}$$

$s$  = standard deviation

$$= \sqrt{\frac{1}{n-1} \cdot \sum_{i=1}^n (x_i - x)^2}$$

$x_i$  = individual test value  $i$  of set of  $n$  tests

$n$  = number of tests for one mechanical property.

Elastic properties for a laminate with off-axis content can be calculated if the properties for the pure unidirectional laminate are known according to the classic laminate theory. An analogous conclusion for strength properties is unfortunately not possible.

A simplified approach to derive strength properties of multiaxial laminates from properties of unidirectional laminates is given here with the "strain to failure" consideration:

It is assumed that the strength properties of a laminate are fibredominated (see also provisions in [1.4.1.1]). The strain to failure values are similar for multiaxials and unidirectionals. This is because for a multiaxial laminate the ultimate strain in compression or tension is governed by the ultimate strain of the  $0^\circ$  plies contained therein. This allows to obtain the ultimate strain values from a 100%  $0^\circ$  laminate as to represent design values when statistically assured. Further, it will be assumed that the in-plane shear strain is governed by tensile/compression properties of fibres running under  $\pm 45^\circ$ .

To obtain allowable values, the design values for strength and strain properties shall be combined with the reduction factors (see [1.3.9.1.3]). Figure 1-14 illustrates the path and links between load application and load absorption accordingly.

The tests according to Table 1-9 are considered appropriate for the investigation of material properties for CRP.

DNV GL reserves the right to interpret the test data due to different test methods.

### 1.4.1.5 Material certificates for aluminium alloys

Valid material properties of specific aluminium alloy verified by a "3.1.B. material certificate" according to DIN EN 10204 or similar can be submitted to DNV GL. Otherwise, DNV GL will base the calculations on general minimum properties for the aluminium alloy in question.

### 1.4.1.6 Quality assurance

An internal quality assurance of the production facility shall be guaranteed, e.g. be in compliance with the ISO 9000 series or be suitable for the facilities and comprise inspection of incoming goods, storage of material, responsibilities and the process of fabrication.

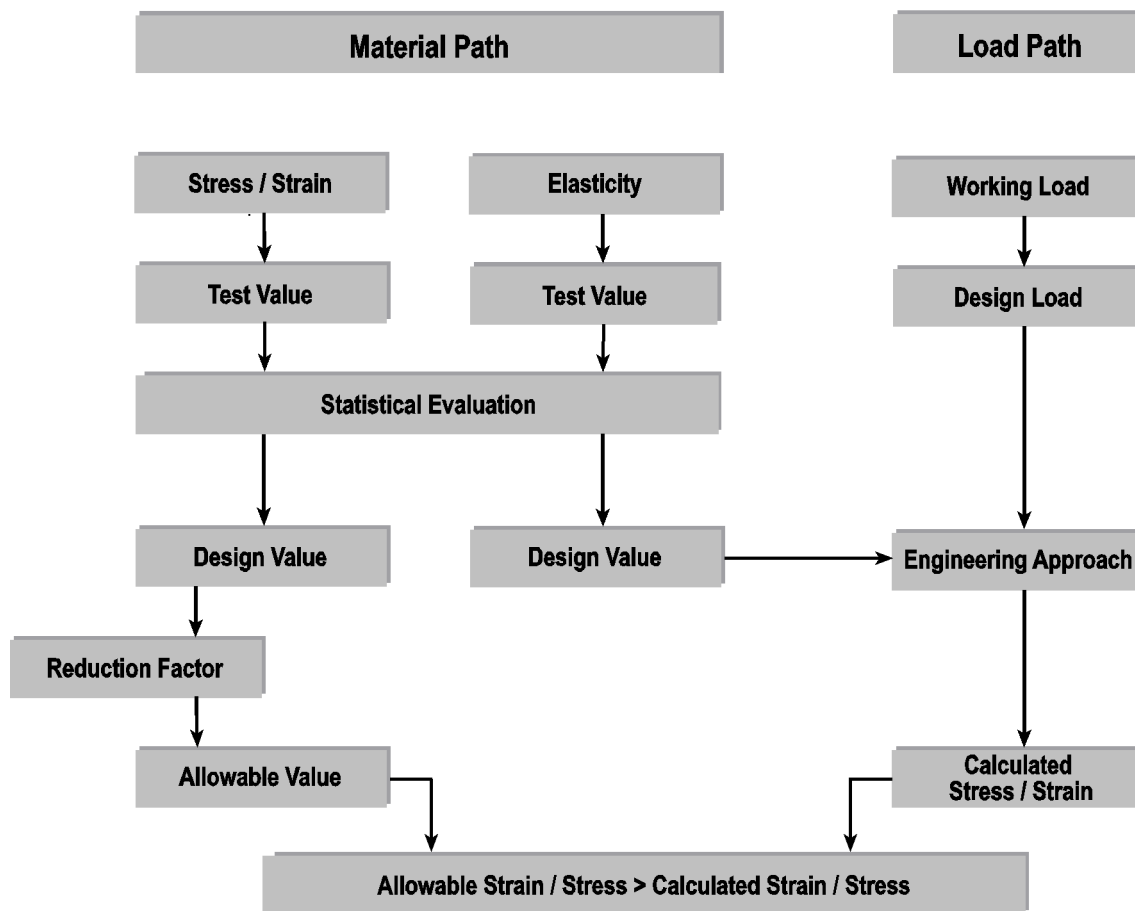


Figure 1-14 Engineering flow chart

Table 1-9 Material tests

(Tensile strength), tensile modulus, elongation at break	ASTM D3039, SACMA SRM4 or DIN EN ISO 527-4, test specimen III, 5 samples
(Compressive strength), compressive modulus, elongation at break	ASTM D3410, SACMA SRM1 or Draft DIN EN 2850, specimen A1 with free edge of 8 mm, 5 samples
Flexural strength, flexural modulus (if applicable)	ASTM D790, EN 63-ISO 178, 5 samples
Interlaminar shear strength	ASTM D2344, 5 samples

## 1.4.2 Fabrication

The fabrication of polymer matrix composites shall in general be in compliance with the material suppliers recommendations and/or requirements and the DNV GL rules [DNVGL-RU-SHIP Pt.2 Ch.3](#).

## 1.5 Miscellaneous

### 1.5.1 Fittings, equipment

Rigging parts like terminals, turnbuckles, toggles, shackles, eyes, jaws, tip cups are not within the scope of this Standard but shall nevertheless be state of the art equipment and of good common marine quality.

Relief valve settings and/or max. pull or max. holding power of non-manual driven devices, that act on standing rigging, shall be adjusted to

- 66% of the breaking load of the respective stay for rod and wire
- 50% of the breaking load of the respective stay for aramid rigging.

### 1.5.2 Rigging

#### 1.5.2.1 Solid rod rigging

Rod rigging shall be made of an established metallurgical high strength steel alloy of sufficient toughness (e.g. "Nitronic 50" cold drawn wire with appropriate cold reduction treatment). It shall be self-aligning under changing lead to avoid bending. The best common fitting for alignment under load is the marine eye combined with a toggle. For transverse rigging, ball-type fittings are also acceptable (stemball fittings), but not so for head stays due to the magnitude of lead change under load.

#### 1.5.2.2 Soft (flexible) aramid rigging

Soft aramid rigging is generally acceptable for aft longitudinal rigging (backstays, running backstays, checkstays), but not recommended for category I yachts.

Spliced terminals are not allowed due to the possibility of chafe.

Soft aramid rigging shall be proof tested to at least 25% of the rated strength of the stay prior to installation.

Terminals shall have a sufficient bend and strain relief and transition towards the cable and shall provide a good isolation from salt water, humidity and UV-radiation.

For maintenance recommendations/requirements see [\[1.5.3\]](#).

#### 1.5.2.3 PBO, carbon rigging

It is generally recommended to provide a DNV GL's type approval for cables made of PBO or carbon fibres. This will be carried out in accordance with [DNVGL-CP-0413](#).

Apart from the required proof and testing defined therein, the following shall be considered in general:

- if cables are intended for components other than for diagonal shrouds, aft stays and "secondary" headstays, particular considerations shall be given to special features such as additional chafe protection, special arrangements for the case a cable is being central part of a furling headsail, etc.
- terminals shall be free of bending moment introduction
- terminals shall have a sufficient strain and bend relief
- fibres shall be totally protected from ingress of humidity and UV radiation
- cables shall be proof-tested prior to installation.

For general maintenance recommendations/requirements see [\[1.5.3.1.3\]](#).

## 1.5.3 Maintenance

Rigging and other highly loaded components of the rig shall be inspected in appropriate intervals, depending on the proportion of usage with non-destructive testing methods, especially at terminals, fittings and ball-heads. Suppliers recommendations shall be considered.

### 1.5.3.1 Rigging and attached fittings

1.5.3.1.1 Rod rigging should be replaced, when:

- any kind of crack appears (typically at "cold heads")
- in case of a permanent bent caused by mishandling.

A first disassembly and inspection of the rigging should be carried out latest after 2 years (1 year for category III and IV rigs) or 40 000 miles (10 000 miles for category III and IV rigs) or according to suppliers schedules.

#### 1.5.3.1.2 Soft aramid rigging

Soft aramid cable shall be replaced when the cover is damaged such that the break penetrates to the fibre core.

Rigging should be inspected at least every year (every 1/2 year for category III or IV rigs) or after 10 000 miles (5 000 miles for category III or IV rigs), whichever comes first or according to suppliers schedules.

The terminals should be inspected according to suppliers recommendations.

#### 1.5.3.1.3 PBO and carbon rigging

In general, maintenance and replacement schedule of the cable supplier shall be followed.

## 1.5.4 Coating

All carbon parts that are subjected to direct sunlight shall be protected by a non-transparent, light colour. The thickness shall be sufficient to protect from UV-radiation.

## 1.5.5 Corrosion protection

Metallic parts shall be insulated from carbon fibres by using an adhesive layer or a thin glass fibre ply, which shall ensure sufficient protection against conductive connection. The reason is that carbon fibres do not only conduct electrical current, but are also sensitive to cathodic corrosion.

It is generally recommended to wrap carbon-spars in a resin-rich layer of glass woven roving laminate to prevent splintering of carbon fibres in case of damage and to provide a certain protection against local impact.

For spars made of aluminium-alloy, austenitic metals shall be insulated from aluminium alloy components.

## 1.5.6 General recommendations for lightning protection

**1.5.6.1** An aluminium mast itself is a good conductor with enough cross sectional area to conduct a lightning strike.

**1.5.6.2** Carbon fibres are not to be used as a conductor.

**1.5.6.3** For mast heights over 15 m above water line, the protection zone is based on the striking distance of the lightning stroke. Since the lightning stroke may strike any grounded object within the striking distance of the point from which final breakdown to ground occurs, the zone is defined by a circular arc. The radius



of the arc is the striking distance (30 m). The arc passes through the top of the mast and is tangent to the water. If more than one mast is used, the zone of protection is defined by arcs to all masts.

The protection zone formed by any configuration of masts or other elevated, conductive and grounded objects can readily be determined graphically. All components inside the protection zone shall be lightning grounded to earth.

**1.5.6.4** The entire circuit from the top of the mast to the ground shall have a mechanical strength and conductivity not less than that of a 25 mm<sup>2</sup> copper conductor. The path to ground followed by the conductor shall be essentially straight and on the shortest way possible. Corners or sharp edges shall be avoided in conductors.

**1.5.6.5** For carbon masts it is recommended to protect other cables against (strong) magnetic fields occurring, when passing the conductor through the mast.

**1.5.6.6** The top of the lightning spike should at least be 300 mm above anything that is susceptible in this context (structure, antenna, instruments), see also definition of protection zone in [\[1.5.6.3\]](#).

**1.5.6.7** The lightning spike should have a metallic diameter of not less than 8 mm. See also ISO 10134, IEC 62305, IEC 61892 and/or [DNVGL-ST-0491 App.F](#).

## 1.5.7 Inclining test

It is strongly recommended to carry out an inclining test about the initial stability of the completed vessel. If a construction survey is carried out according to [\[1.1.1.4\]](#), an inclining test shall be carried out. The test will be witnessed by a DNV GL surveyor. The interpretation of the measured data to gain hydrostatic stability values, i.e. the righting moments, will be checked by DNV GL.

## 1.5.8 Stepping and rigging of masts

The stepping and rigging of a mast shall be performed by experts according to the designers/manufacturers specifications.

## 1.5.9 Visual pre-delivery inspection

It is strongly recommended to carry out a shake-down cruise of at least 7 days offshore. Wind speeds of at least 25 - 30 knots shall be experienced over a period of at least 24 hours.

A visual inspection of the rig will in any case be carried out prior to delivery.

## 1.6 Certificate

A certificate will be issued, once the design has successfully passed the approval and a visual inspection has shown satisfactory results. Though the approval will render invalid, when the construction does not comply with the drawings and/or when modifications in design or construction are being made, without informing DNV GL. The repair of structural components shall be agreed with DNV GL for maintaining the validity of the certificate.

## APPENDIX A DOCUMENTS TO BE SUBMITTED FOR RIG ANALYSIS

### A.1 Global rig basic analysis, global rig motoring analysis, global rig natural frequencies analysis

- DNV GL rig spec sheet or comparable
- Rig layout.

Further documents depending on service.

### A.2 Global mast tube stress/strain analysis


- Mast section drawing
- Mast top taper
- Mast laminate.

### A.3 Global boom analysis

- Boom layout
- Shell laminate and frames
- Roller and ring frame
- Typical gooseneck detail
- Vang detail
- Gooseneck knuckle
- Boom lines or typical sections.

### A.4 Local mast tube analysis

- Cut out plan
- Patching plan
- Section joint
- Masthead layout
- Masthead laminate
- Yankee sheave box
- Cap-tang attachment
- Forestay pins toggles
- Headstay attachment
- Genoa sheave box
- Yankee lock box
- Genoa lock box
- Runner attachment
- Inner forestay attachment
- Staysail box
- Staysail lock box
- D-tangs
- Lower mast layout
- Gooseneck arrangement
- Vang
- Vang toggle and pin
- Mast step layout

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- Mast foot
  - Mast step plate
  - Mast step chocks
  - Heel plug
  - Spreader X attachment
  - Spreader X laminate.

## CHANGES – HISTORIC

There are currently no historical changes for this document.

**DNV GL**

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