# Section 1

# Design and Construction of Large Modern Yacht Rigs

## A. General

### 1. Scope

**1.1** These Guidelines generally apply to sailing yachts of **L** > 24 m, under the condition, that the yacht is handled correctly in terms of good seamanship.

**1.2** These Guidelines are generally applicable for bermudian rigs with spars made of carbon fibre reinforced plastics or aluminium alloy.

**1.3** The principles presented in the following are to 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.

**1.4** Scope of these Guidelines are the structural integrity of one- or multiple-masted, bermudian rigged monohull or multihull sailing yachts including the dimensioning of standing rigging, mast and boom sections as well as local construction in way of fittings structurally attached to the spars.

**1.5** Upon request, the performance on construction can be supervised by 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.

### 2. Documents to be submitted

Relate to Annex A for the scope of documents and information required for Certification listed for each of the different Certification modules.

## B. Design and Construction Principles

### 1. General

**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 SWA.

**1.2** The "Safe Working Angle (SWA)", which will be referred to in the following, generally represents a heeling angle of 30°. However, other angles may be defined as SWA in agreement with GL. 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** 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.

### 2. Load cases

### 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 |

### 2.2 Extreme conditions

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

## 3. Determination of rig loads

### 3.1 Pretensioning of rig

The pretensioning of the rigging is to 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".

### 3.2 Transverse sail forces

#### 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 Fig. 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:

$$F_{tm} = \frac{RM_{design}}{\overline{CoE_m\,CLR} + \frac{A_F \cdot SFC_f}{A_m \cdot SFC_m} \cdot \overline{CoE_f\,CLR}} \quad [N]$$

Transverse force from foresail:

$$F_{tf} = \frac{A_f \cdot SCF_f}{A_m \cdot SCF_m} \cdot F_{tm} \quad [N]$$

Transverse force from spinnaker when "broaching".

$$F_{ts} = \frac{RM_{Design}}{\overline{CoE_s CLR}} \quad [N]$$

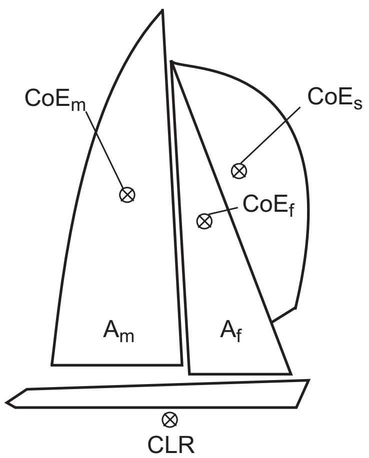



**Fig. 1.1 Centres of effort**

$RM_{Design}$ = righting moment as defined in B.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]

Am = mainsail area, projected laterally [$m^2$]

$A_f$ = foresail area, projected laterally [$m^2$]

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

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

$$v_a = \sqrt{\frac{F_{t(m/f)}}{SFC_{f/m} \cdot A_{m/f} \cdot 0{,}5 \cdot \rho}} \quad [m/s]$$

ρ = density of air [$kg/m^3$]

#### 3.2.2 Multiple-mast rig

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

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

The sail area moment is defined as:

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

A = projected sail area

The sail area moment for each mast is defined as:

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

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 $RM_{design}$ for each mast is to be taken the lower of:

– $RM_{design} = 1,0 \cdot (RM \text{ at SWA})$

– $RM_{design} = 1,56 \cdot f \cdot (RM \text{ at SWA})$

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 3.2.3

### 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.

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

TWS = True Wind Speed

TWA = True Wind Angle

BS = Boat Speed

This operational wind speed $AWS_0$ 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:

$$F = \rho / 2 + AWS_D^2 \cdot A \cdot c_S$$

$\rho$ = 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.

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

A set of point loads is to be calculated from $F_{tm}$ acting on the mast as shown in Fig. 1.2. The point load distribution shall be appropriate for the specified sail configuration and has to 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 [1] | (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

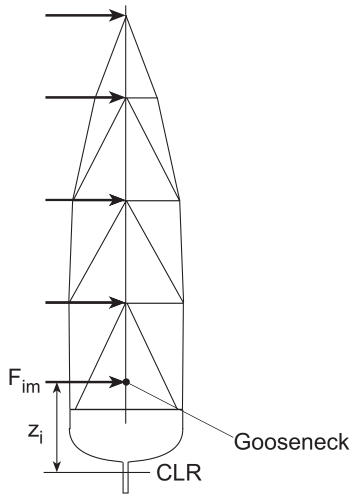



**Fig. 1.2 Mainsail load distribution**

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

$$\frac{\overline{CoE_m\ CLR}}{\sum\limits_{i=1}^{n}\left(c_{im}\cdot z_i\right)} \overset{!}{=} 1$$

$F_{tm}$ = transverse force mainsail according to 3.2

$c_{im}$ = distribution factor with:

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

$z_i$ according to Fig. 1.2

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

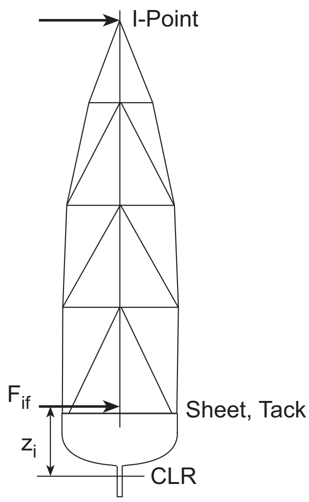



**Fig. 1.3 Foresail point loads**

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

$$\frac{\overline{CoE_f\ CLR}}{\sum\limits_{i=1}^{3}\left(c_{if}\cdot z_i\right)} \overset{!}{=} 1$$

$F_{tf}$ = transverse force foresail according to 3.2

$c_{if}$ = distribution factor with:

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

$z_i$ according to Fig. 1.3

Table 1.3 shows an example of the foresail load distribution.

**Table 1.3 Approach for foresail load distribution**

| | $c_{if}$ |
|---|---|
| tack [1] | (0,3) |
| clew [1] | (0,3) |
| head | 0,4 |
| [1] not applied on rig explicitly | |

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

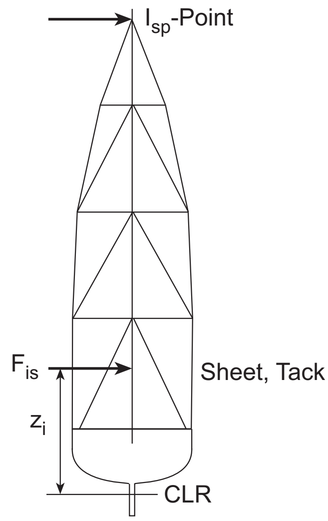



**Fig. 1.4 Spinnaker point loads**

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

$$\frac{\overline{CoE_s\ CLR}}{\sum\limits_{i=1}^{3}\left(c_{is}\cdot z_i\right)} \overset{!}{=} 1$$

$F_{ts}$ = transverse force spinnaker according to 3.2

$c_{is}$ = distribution factor with:

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

$z_i$ according to Fig. 1.4

Table 1.4 shows an example of spinnaker load distribution.

**Table 1.4 Approach for spinnaker load distribution**

| | $c_{is}$ |
|---|---|
| tack [1] | (0,3) |
| clew [1] | (0,3) |
| head | 0,4 |

[1] not applied on rig explicitly

### 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.

### 3.4 Extreme loads

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

## 4. Determination of working loads of running and standing rigging

### 4.1 Running rigging

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

#### 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 is to 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]

##### 4.1.1.1 Mainsail and/or mizzensail halyards:

$F_{mhy} = 1{,}08 \cdot F_{ml}$ [N]

$F_{ml}$ = mainsail leech load

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

$f_r$ = roach factor

$= \dfrac{A_m}{0{,}5 \cdot P \cdot E}$

$F_{tm}$ = according to 3.2

s = sag fraction

= 0,065 [–], (6,5 % of leech length) for all categories

##### 4.1.1.2 Foresails (genoa, jib, staysail, etc.) halyards

$F_{fhy} = 1{,}02 \cdot \dfrac{F_{tf}}{8 \cdot s}$ [N]

$F_{tf}$ = according to 3.2

s = sag fraction

= 0,045 [–], (4,5 % of leech length)

#### 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.

$$F_{oh} = \cos\left(\arctan\left(\frac{P}{E}\right)\right) \cdot F_{ml} + F_{tm} \cdot \frac{E}{P \cdot 8 \cdot 0{,}05} \quad [N]$$

$F_{ml}$ = according to 4.1.1.1

$F_{tm}$ = transverse force from mainsail according to 3.2

For P and E see 3.2.1.

#### 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 formula:

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

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

$F_{ml}$ = according to 4.1.1.1

#### 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 formula for the vang load Fv results from force equilibrium according to Fig. 1.5.

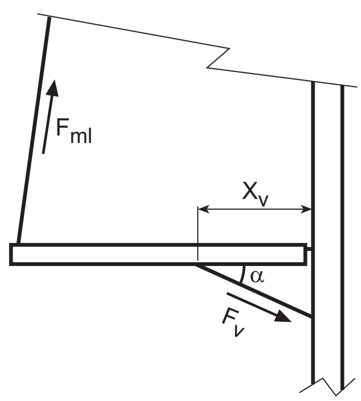



**Fig. 1.5 Vang load determination**

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

$F_{ml}$ = according to 4.1.1.1

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

$\alpha$ = angle between vang and boom

s = sag fraction

= 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

#### 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 Fig. 1.6.

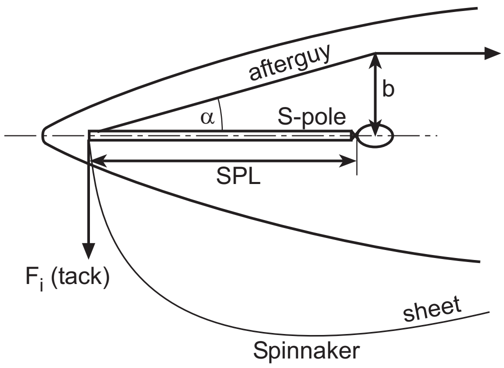



**Fig. 1.6 Spinnaker pole force**

Maximum working compression of spinnaker pole:

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

$F_i$ (tack) = relevant $F_{is}$ according to 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 is to be considered whether a supplement has to be made due to sheet loads (for rather flat spinnakers or gennakers).

### 4.2 Standing rigging

GL examines standing rigging sizes by calculating tensile forces and correlate them with the reserve factors according to 5.1. Calculation method is geometric nonlinear finite element analysis. The tensile forces determined this way are also called maximum working loads (MWL) under the conditions of these Guidelines.

***Note***

*Working loads of longitudinal stays can be determined analytically (see 4.2.2).*

#### 4.2.1 Shrouds

Calculation of shroud working loads is to be based on the input specified in 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 3.2.1, see Fig. 1.7.

Headstay working load $F_{hs}$:

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

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

$l_0$ = stay length [m]

s = the magnitude of sag "s" as a fraction of the stay length is not to be taken more than according to Table 1.5:

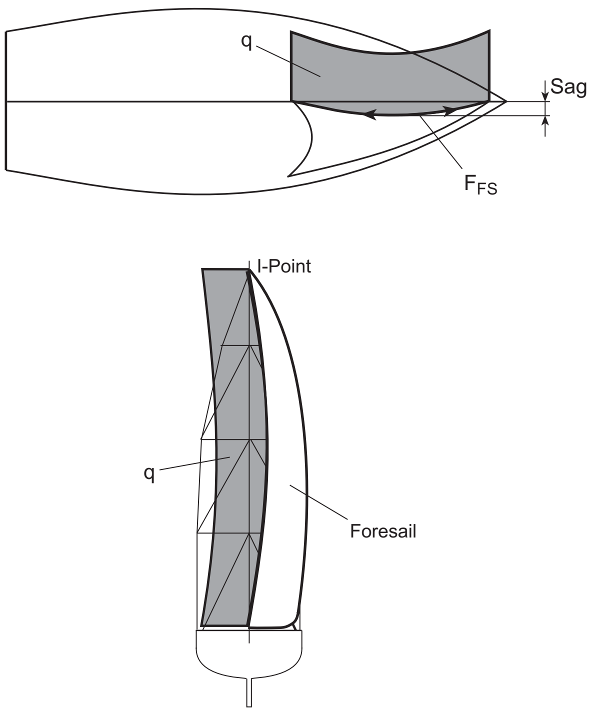



**Fig. 1.7 Headstay load**

**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 5.2.

### 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.

### 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 5.2.

## 5. Global analysis

### 5.1 Standing rigging

#### 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 have to 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.

#### 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.

##### 5.1.2.1 Transverse rigging and jumper

RF ≥ 2,5 on working loads determined according to 4.2

##### 5.1.2.2 Fore and aft rigging, others

RF ≥ 2,0 on design load according to 4.2

RF ≥ 2,5 on design load according to 4.2 for soft aramid rigging and generally for Category I yachts

#### 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 these guidelines so far may not exceed the cable's maximum working load specified by the cable supplier. This maximum cable working load may be a GL-certified value and thus/or be determined by the approach offered in Chapter 3 – Guidelines 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:

##### 5.1.3.1 Transverse rigging and jumper

RF ≥ 4,5 on working loads determined according to 4.2 including the self-weight effect

##### 5.1.3.2 Fore and aft rigging, others

RF ≥ 3,6 on design load according to 4.2

RF ≥ 4,5 on design load according to 4.2 for Category I yachts

### 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.

#### 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 ≥ 3,1 on each set of mast panel compressions (resulting from all relevant working loads according to 4.)

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

#### 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 ≥ 2,6 on each set of mast panel compressions resulting from all relevant working loads according to 4.

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

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

Also refer to C.1.3 for minimum elastic properties of tubes.

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

#### 5.2.4 Thin wall buckling of the tube

Tube wall buckling has to be considered.

RF ≥ 3,0 on ultimate buckling stress or strain according to max. working compression in each wall panel resulting from load cases acc. to 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 are to be considered particularly in way of:

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

### 5.3 Spreader construction

Spreaders are subjected to axial, bending and shear loads. Each of the following scenarios described in 5.3.1 to 5.3.4 is to be considered. Proof of sufficient safety is based on "first principles" of engineering. In Figures 1.8 and 1.9 relevant arrangements and coordinates are shown. Relevant allowable strains and stresses are defined in 9.1.2, 9.1.3 and 9.1.4. The design loads are to be determined as follows:

#### 5.3.1 Loading on windward side

$F_x$ = load in x-direction, resulting from relevant components of 2,5 times the calculated shroud working loads [N]

$M_{bv}$ = 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 × diam. $V_{n+1}$
- for Navtec 534/834: 0,5 × diam $V_{n+1}$
- for others: to be specified

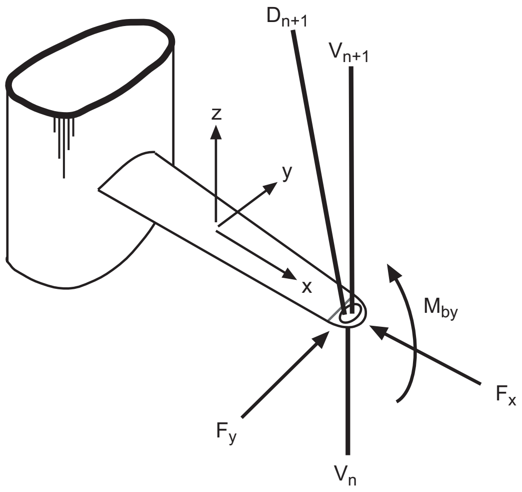



**Fig. 1.8 Forces on a spreader**

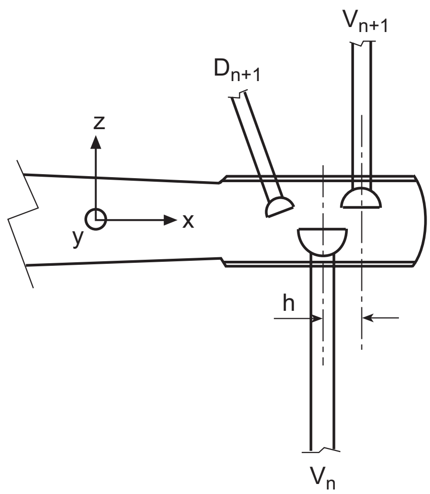



**Fig. 1.9 Spreader end detail**

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):

$$= V1 \cdot 0{,}0055 \cdot k_1 \cdot k_2 \quad [N]$$

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

or

$F_{yb}$ = 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-spreader-rig | 4-spreader-rig | 5-spreader-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 |

### 5.3.2 Loading on leeward side

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

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

$$l_p = \frac{P}{n+1} \quad [m]$$

n = number of spreaders

P = mainsail hoist, see 3.2.1

ρ = density of air [kg/m³]

$v_{aws}$ = apparent wind speed for design purpose = 19 m/s

$c_1$ = sail girth factor, refer to Table 1.7

$c_2$ = distribution factor, refer to Table 1.8

$c_3$ = overload factor = 2,0

E = foot of mainsail, see 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 |

### 5.3.3 Spreader buckling

RF ≥ 1,1 for Euler-Buckling of spreader versus relevant design loads specified in 5.3.1

### 5.3.4 Spreader wall buckling

RF ≥ 1,1 for thin wall buckling of spreader versus relevant design loads specified in 5.3.1

## 6. Booms

Booms are subjected to compression, bending, shear and torsion primarily through the loads from sheet, leech, outhaul and vang, see Fig. 1.10.

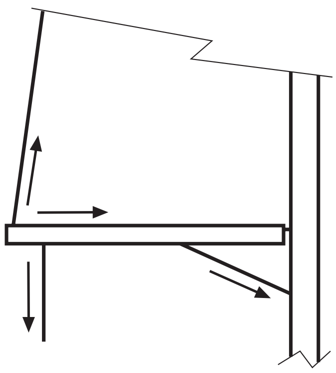


**Fig. 1.10 Forces on boom**

**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 Fig. 1.12

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

$F_{sh}$ = horizontal component of mainsheet load [N], see Fig. 1.11

$F_{sail}$ = component of mainsail load acting at mainsail clew [N], see Fig. 1.11

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

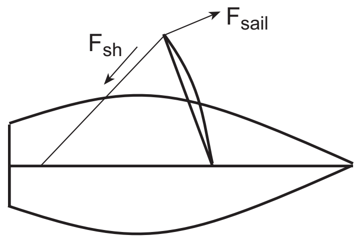



**Fig. 1.11 Mainsail clew**

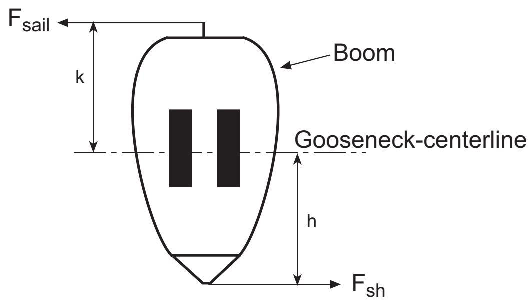



**Fig. 1.12 Boom section**

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

A = mainsail area [m$^2$]

ρ = density of air [kg/m$^3$]

An appropriate combination of the above loads is to 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 has to be replaced by:

1,0 × breaking load of vang [N]

The requirements for allowable strains and stresses as defined in 9.1.2, 9.1.3 and 9.1.4 shall be met when applying the design loads. Also wall buckling of the boom shall be considered.

## 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.

## 8. Mast-panel between maststep and uppermost 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 have to be taken into account additionally when designing Panel 0. The resultant loads due to the following design loads are to be considered then:

Vang: resultant loads due to 1,5 × max. vang working-load according to 4.1.4 (for hydraulic device: vang load = release load at max. eased mainsheet)

Poles: 2 × resultant loads due to pole compression according to 4.1.5

Gooseneck: resultant loads due to 1,5 × max. vang load (for hydraulic device: vang load = release load at max. eased mainsheet plus other relevant contributions (outhaul, mainsheet etc.))

## 9. Local analysis

### 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 these Guidelines 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 have to be defined separately.

**Pin seating:**

– bearing stress/strain [MPa]:

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

– shear-out stress [1] (for CRP) [MPa]:

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

– tensile (hoop) stress [MPa]:

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

where

F = design load according to 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]

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) have to 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

---

1 Shear-out stress has to be considered for bolt-fastenings with an edge distance lower than 2d. In any case, when plate material is not quasi-isotropic.

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 C.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)

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

1,0 × release load of halyard tensioners / winches 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 has to be chosen.

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

$\varepsilon_{b\,all}$ = 0,25 % allowable bearing strain of carbon laminate with circular holes

$\varepsilon_{bc\,all}$ = 0,35 % allowable bearing strain of clamped carbon laminate with circular holes

$\varepsilon_{ct\,all}$ = 0,25 % allowable compression and tensile strain

$\varepsilon_{is\,all}$ = 0,45 % allowable in-plane shear strain

#### 9.1.3 Applicable reduction factors for carbon fibre laminate strength under design loads on the basis of appropriate and approved material test data, refer to C.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

#### 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 have to be taken into account.

### 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 9.1.1

### 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 is to 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

## C. Materials and Fabrication

### 1. Materials

### 1.1 CRP 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$^2$ respectively. Generally, grouping of 90° plies is to 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 B.9.1).

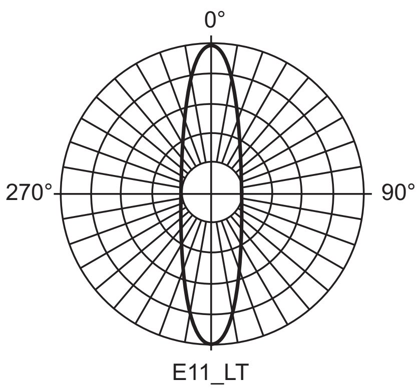
In any case the transverse Young's modulus in compression shall exceed a minimum of 20 % of the value in longitudinal direction. The polar graph of the in-plane Young's modulus shall not have major concave areas see Fig. 1.13.

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 are to be avoided.

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

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



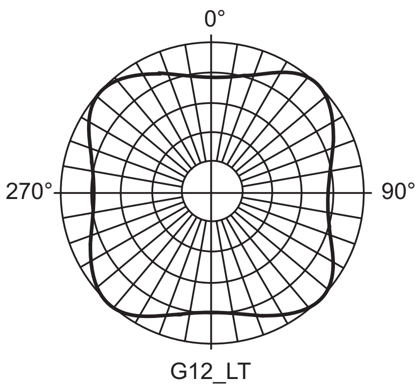




**Fig. 1.13 Polar diagrams**

### 1.2 CRP samples

CRP samples of the fabricated tube have to be submitted to 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 are to 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.

### 1.3 Material tests (CRP)

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 have to 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 Design values

For each mechanical property of a laminate a min. number of tests is to 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) is to be applied here. The relevant formula for the characteristic value $R_k$ is:

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

$u_{\alpha/P}$ = α %/P % fractile (percentile value) of a normal distribution for defining a minimum value

= 1,654 for the above condition (α = 5 %, P = 95 %)

x = arithmetic mean value from test results

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

s = standard deviation

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

$x_i$ = 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 C.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° plies contained therein. This allows to obtain the ultimate strain values from a 100 % 0° 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 ± 45°.

To obtain allowable values, the design values for strength and strain properties have to be combined with the reduction factors (refer to B.9.1.3). Fig. 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.

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

### 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 GL. Otherwise, GL will base the calculations on general minimum properties for the aluminium alloy in question.

### 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.

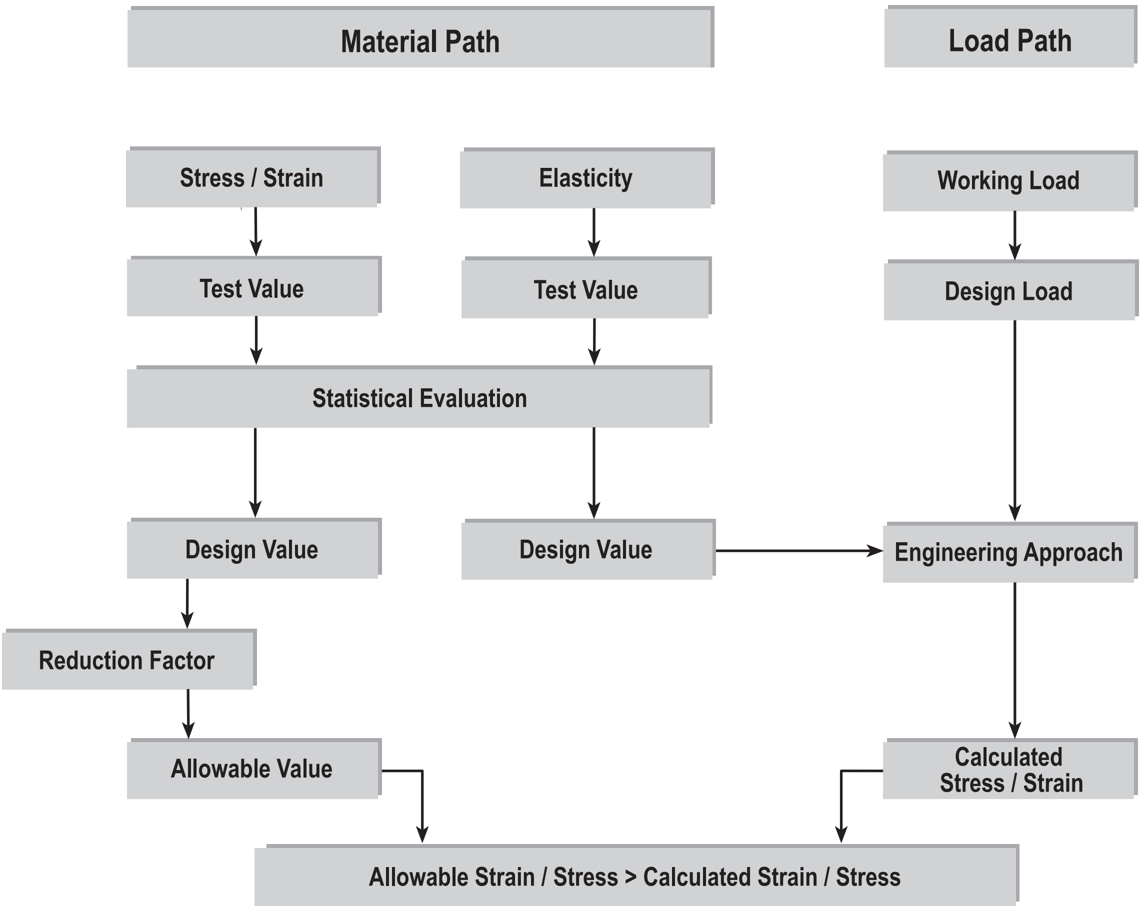



**Fig. 1.14 Engineering flow chart**

**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. |
| Interlaminate shear strength | ASTM D2344, 5 samples |

### 2. Fabrication

The fabrication of polymer matrix composites shall in general be in compliance with the material suppliers recommendations and/or requirements and the GL Rules II – Materials and Welding, Part 2 – Non-metallic Materials.

## D. Miscellaneous

### 1. Fittings, equipment

Rigging parts like terminals, turnbuckles, toggles, shackles, eyes, jaws, tip cups are not within the scope of these Guidelines 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, are to 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

### 2. Rigging

### 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.

### 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 refer to 3.

### 2.3 PBO, carbon rigging

It is generally recommended to provide a GL type approval for cables made of PBO or carbon fibres. This will be carried out in accordance with Chapter 3 – Guidelines for the Type Approval of Carbon Strand and PBO Cable Rigging for Sailing Yachts.

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 refer to 3.1.3.

### 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 have to be considered.

### 3.1 Rigging and attached fittings

**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.

#### 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.

#### 3.1.3 PBO and carbon rigging

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

## 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.

## 5. Corrosion protection

Metallic parts have to 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 have to be insulated from aluminium alloy components.

## 6. General recommendations for lightning protection

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

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

**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 by determined graphically. All components inside the protection zone shall be lightning grounded to earth.

**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$^2$ 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.

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

**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 6.3.

**6.7** The lightning spike should have a metallic diameter of not less than 8 mm.

Also refer to ISO 10134 and/or GL Rules Part 3 – Special Craft, Chapter 3 – Yachts and Boats up to 24 m, Annex F.

## 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 A.1.5, an inclining test has to be carried out. The test will be witnessed by a GL surveyor. The interpretation of the measured data to gain hydrostatic stability values, i.e. the righting moments, will be checked by GL.

## 8. Stepping and rigging of masts

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

## 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 have to 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.

## E. 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 GL. The repair of structural components is to be agreed with GL for maintaining the validity of the Certificate.