Section 2

Mast and Rig

A. General

1. Examination

1.1 According to the development of computation methods GL examines mast and rig dimensioning through geometric non-linear finite element analysis (FEA).

1.2 Load levels of standing rigging and factors of safety (FoS) respectively against breaking loads will be determined as well as compression levels in the mast allowing assessment of global and local stiffness.

1.3 Setup of the finite element model (FEM), computation prerequisites and load cases are described in the following.

1.4 Calculations following the same outline may be submitted. GL reserve the right to verify such results.

B. Basis for Calculation

1. Finite element model setup and prerequisites

1.1 The FE model must correctly reflect the geometry of the rig as specified in the sailplan.

1.2 The mast is generated from beam elements with assigned properties according to the mast section, i.e. moments of inertia and modulus of elasticity.

1.3 Spreaders and jumpers are setup analogously.

1.4 Standing rigging will be assembled from truss elements according to material and diameter of shrouds and stays, for example 1×19 steel wire, dyform or rod.

1.5 There will be no prestressing of the rig in the FE-model. Consequently, the calculated axial loads in standing rigging do not include the contribution of prestressing. This fact is covered by the required FoS against breaking loads.

2. Load cases and determination of loads

2.1 Normally, four sailing conditions upwind and one spinnaker case are considered, all at 30° heeling angle of the yacht according to the following specifications.

Upwind condition 1:	Full main sail plus max. genoa
Upwind condition 2:	First reef plus 100 % genoa
Upwind condition 3:	Second reef plus 100 % genoa
Upwind condition 4:	Third reef in main without headsail

Spinnaker case: Here it is assumed that only the spinnaker is set by an apparent wind angle of 90°.

2.2 Transverse rig loads according to all five sailing conditions are determined based on the yacht's righting moment at 30° heeling angle.

2.3 Under the simplifying assumption that 3/7 of the sail force act at the head and 2/7 each at tack and clew these forces can be determined if it is additionally assumed that the ratio between main sail force and genoa force is the same as between their sail areas.

2.4 The products of each transverse force multiplied by its distance from the centre of effort of the underwater body are summed up to obtain the heeling moment. The result must equal the righting moment.

2.5 According to this distribution the FE-model is to be loaded with the relevant forces at mainsail and genoa head and at the gooseneck.

2.6 In the spinnaker case the procedure for transverse force determination is analogous except for the percentages which are here 4/10 at the head and 3/10 each at the clews. The FE-model is to be loaded with the spinnaker head force only.

C. Assessment Criteria

1. Requirements for shrouds

1.1 Among others results of the FE-calculation are axial loads in transverse standing rigging for each load case.

For each shroud the highest calculated load of all five load cases must have a minimum FoS of 3,3 against breaking load.

2. Requirements for longitudinal stays

2.1 Headstay dimensioning

The headstay's axial load F_{hs} can be calculated analytically by the formula

$$F_{hs} = \frac{F_g}{8 \cdot s}$$

from the genoa sail force F_g and a given relative sag

$$s = \frac{\text{sag}}{\text{headstay length}}$$

F_g is to be determined from the righting moment at 30° heel as outlined in B.

The relative sag s is not to exceed 1,5 %

The headstay load calculated with this input must not exceed half of its breaking load.

2.2 The backstay (or runner) must be capable to oppose the headstay while meeting the same FoS requirement.

3. Stiffness requirements

3.1 FE-calculation also enables assessment of mast stiffness by determining the compression levels of the mast for each load case.

3.2 Loads in longitudinal stays and halyards also contribute to mast compression. As a general approach this contribution to mast compression will be brought into account by 85 % of the maximum load at the mast step of the four upwind cases and is to be added accordingly to give the maximum total load.

3.3 Buckling load will be calculated observing the contribution described under 3.2. As a requirement for sufficient stiffness buckling load must be at least a factor 2,6 above the maximum total load.

D. Construction Notes and Chainplates

1. Notes regarding construction of the rig

1.1 Forces from shrouds and stays shall be applied to the mast profile free from any moments. This necessitates the use of suitable fittings.

1.2 Rigging screws shall be freely movable longitudinally and transversely in the chainplates.

1.3 Bolts and other detachable parts shall be durably secured.

1.4 Where fittings are of different materials, electrolytic corrosion shall be prevented by suitable insulation.

1.5 Wire ropes plus associated terminals, thimbles, shackles, and rigging screws shall be of sea water resistant material and of a proven type.

1.6 Halyard sheaves are to be fitted into their housings with such small tolerances, and to be made in such a way, that the ropes of the running rigging cannot jam between sheave and housing.

2. Chainplate scantlings

2.1 Generally, for all metal parts of the chainplate construction dimensioning load is the breaking load of the attached shroud or stay.

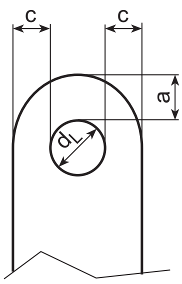
2.2 Permissible stress is the applicable yield stress with the exception of bearing stress for which the arithmetic mean of yield and ultimate stress is the allowable limit.

2.3 Generally, for FRP substructure and interfaces with metal parts of the chainplate construction dimensioning load is 1,6 times breaking load of the attached shroud or stay.

2.4 Permissible stress is the applicable FRP’s ultimate stress.

2.5 If two shrouds are attached to one chainplate fitting then the breaking load of the stronger shroud and half of the breaking load of the lighter shroud are to be added for dimensioning purpose.

2.6 In case of chainplate fittings according to the following sketch having a thickness t and pin hole diameter d_l minimum edge distances a and c as given by the formulae below must be provided for:



$$a_{min} = \frac{F}{2 \cdot t \cdot \sigma_{all}} + \frac{2}{3} \cdot d_L \quad \text{and}$$

$$c_{min} = \frac{F}{2 \cdot t \cdot \sigma_{all}} + \frac{1}{3} \cdot d_L$$

Fig. 2.1

Therein F is the breaking load of the attached shroud or stay and σ_{all} the yield stress of the fitting material.

Pin hole bearing stress is not to exceed the arithmetic mean of yield and ultimate strength.

3. Attachment of chainplates to FRP structure

3.1 If fittings are bolted to FRP-reinforced bulkheads or webs FRP bearing stress in way of bolts is to be calculated on the basis of 1,6 times breaking load of the attached shroud or stay and must not exceed the GRP's ultimate compressive strength.

3.2 Bolt holes shall have a minimum distance of 3 times hole diameter from one another, measured from edge to edge.

3.3 For shear loading in bulkheads and webs due to chainplate attachment and secondary bonding respectively an analogous approach applies, i.e. relevant ultimate GRP mechanical properties are not to be exceeded if 1,6 times breaking load of attached shroud or stay is applied.

Note

If provision is made for a composite chainplate attachment or other solutions special consideration is required.

3.4 Chainplate arrangements may be load tested to prove sufficient strength.