SECTION 7 SOLID KEEL FOR SAILING YACHTS

1 General

1.1 Application

1.1.1 The present Section defines structural requirements for the scantling of keels and local bottom hull reinforcement of sailing yachts. Where existing, attachments of bulbs to fin keels are also in scope of the review.

1.1.2 Moveable keels (lifting and canting) and centreboards are reviewed on a case-by-case basis.

1.2 Materials

1.2.1 Keels made of steel

All structural parts of keels are to be made of rolled steel, steel forging or steel casting according to applicable requirements of the Rule Note NR216 Materials and Welding.

Keels fabrication by welding is to be carried out in compliance with the applicable Society Rules and in particular in compliance with Chapter 5, Section 1 of the Rule Note NR216 Materials and Welding.

1.2.2 Keels made of aluminium

Aluminium material used for structural parts of keels are to comply with requirements of the Rule Note NR216 Materials and Welding.

In case of welding of two different aluminium alloys, the material factor k to be taken for the scantling is to be the greater material factor of the aluminium alloys of the assembly

The loss of mechanical properties of some aluminium alloys (6000 series) induced by welding operation is to be taken into account for scantling.

Where aluminium alloys of 6000 series are used, protection from sea water by permanent coating is to be provided. Details of coating are to be submitted for information.

1.2.3 Keels made of composite

All composite parts of keels are to comply with Part B, Chapter 12.

The Society can request that mechanical tests e carried out as defined in Ch 12, Sec 5.

1.2.4 Bolts materials

Bolts and washers are to be of stainless steel or equivalent sea water corrosion resistant materials.

2 Design Loads

2.1 Application

2.1.1 As a general Rule, design loading cases to apply on keels and supporting structures are those where sailing yacht is at a heel angle of 30° with respect to vertical and a trim angle of 10° with respect to horizontal.

2.1.2 Design loading cases defined in [2.1.1] are also applicable on movable keel's arrangements.

2.1.3 In addition to forces and bending moments generated by loading cases defined in [2.1.1], torsional moments can be caused where the centre of gravity of bulb, at lower end of keel, is significantly apart from the torsional axis of the keel.

2.2 Loads induced by heel

2.2.1 The design load due to roll motion of yacht, in KN, are to be taken equal to:

$$F_{hheel} = P \cdot (1 + a_H) \cdot \sin 30$$

$$F_{vheel} = P \cdot (1 + a_H) \cdot \cos 30$$

where:

F_{hheel} : Horizontal component of the keel weight, in KN

F_{vheel} : Vertical component of the keel weight, in KN

P : Total weight of keel, in KN

a_H : Heave vertical acceleration, in g, as defined in Ch 5, Sec 1, [2.2.2].

2.2.2 The bending moment M_{heel} , in KNm, induced by keel due to roll motion of yacht at hull bottom is to be taken equal to:

$$M_{heel} = F_{hheel} \cdot Z_{keel}$$

where:

F_{hheel} : Design load due to roll motion, in KN, as defined in [2.2.1]

Z_{keel} : Distance, in m, between the external side of hull's bottom and the center of gravity of the keel.

2.3 Loads induced by pitch

2.3.1 The design load F_{pitch} due to pitch motion of yacht, in KN, is to be taken equal to:

$$F_{pitch} = P(1 + a_H) \sin 10 (L_{WL} - X_K)(1 + a_{PFP}) / Z_{keel}$$

where:

P : Total weight of keel, in KN

a_H : Heave vertical acceleration, in g, as defined in Ch 5, Sec 1, [2.2.2]

a_{PFP} : Pitch vertical acceleration, in g, as defined in Ch 5, Sec 1, [2.2.3]

L_{WL} : Yacht waterline length, in m, as defined in Ch 1, Sec 2, [2.1.1]

X_K : Longitudinal distance, in m, between the aft perpendicular as define in Ch 1, Sec 2, [3.4.2] and the center of gravity of the keel

Z_{keel} : Distance, in m, between the external side of hull's bottom and the center of gravity of the keel.

2.3.2 The bending moment M_{pitch} , in KNm, induced by keel due to pitch motion of yacht at hull bottom is to be taken equal to:

$$M_{pitch} = F_{pitch} \cdot Z_{keel}$$

with F_{pitch} and Z_{keel} as defined in [2.3.1].

3 Allowable stresses

3.1 Steel and aluminium

3.1.1 Requirements relevant to the determination of scantling contained in this section are based on allowable stresses as defined in Ch 4, Sec 3.

3.2 Composite materials

3.2.1 Requirements relevant to the determination of scantling contained in this section are based on theoretical individual breaking strength criteria as defined in Ch 12, Sec 3, [5] and safety coefficients as defined in Ch 4, Sec 3, [5.4].

4 Keel's arrangements

4.1 General

4.1.1 The type of keel dealt in this section are the keel bolted to the hull bottom structure or the keel completely integrated to the hull structure.

4.1.2 Keel's arrangement is to be designed in such a way that it simultaneously sustains forces and moments defined in [2], within allowable stresses' level as defined in [3].

4.1.3 Bottom structural arrangements of stiffeners and plating are to be designed in such a way that distributions of forces and moments, defined in [2], induce stresses within allowable stresses level, as defined in [3].

4.1.4 For moveable keels, attachments of keel's operating system to side and/or deck are to be designed in such a way that distributions of forces and moments, defined in [2], induce stresses within allowable stresses level, as defined in [3].

4.2 Bolting system

4.2.1 General

All bolting systems have to comply with the following requirements:

a) Bolts are to be of stainless steel or equivalent sea-corrosion resistant material. The back plate, washers, nuts... are to be made of the same materials or of a compatible material of the keel bolts

b) As a rule, a large back plate extending from one bolt to the symmetrical bolt is to be provided. The thickness of this back plate is not to be less than 0,25 times the bolt diameter

c) Washers are to be provided under the nut head of each keel bolt. The diameter of the washer is not to be less than 4 times the bolt diameter, and its thickness is not to be less than 0,25 times the bolt diameter

d) Bolting system is to be in such a way that taking off can be handled for inspection

e) Nuts of bolting system are to be so arranged as to allow inspection

f) Where applicable, bolts may be pre-stressed in compliance with appropriate standards. In such a case, the grade of bolts is to be selected accordingly and details of pre-stressing process are to be submitted.

4.2.2 Bolts

The bolts are to be designed to sustain tensile and shear forces, induced by loads defined in [2].

For each bolt i, the total tensile stress σ_i, in MPa, can be estimated by the following formula (see Fig 1):

$$\sigma_i = \frac{M_{heel} X_i 10^2}{I_{X'X'}} + \frac{M_{pitch} Y_i 10^2}{I_{Y'Y'}} + \frac{F_{vheel} 10^3}{A_{SH}}$$

where:

M_{heel} : As defined in [2.2.2]

M_{pitch} : As defined in [2.3.2]

F_{vheel} : As defined in [2.2.1]

$I_{X'X'}$: Total inertia of all bolts, in cm^4, with respect to global axis XX' as defined in Fig 1

$I_{Y'Y'}$: Total inertia of all bolts, in cm^4, with respect to global axis YY' as defined in Fig 1

X_i : Distance, in mm, of the considered bolt i to the global axis XX'

Y_i : Distance, in mm, of the considered bolt i to the global axis YY'

A_{SH} : Total cross section, in mm^2, of all bolts

Note 1: X'X' axis is defined in Fig 1 where X', in m, is equal to $b_{i\,max}/2$, with $b_{i\,max}$ equal to the greater value of the distances between bolts b_i.

Y'Y' axis is defined as the neutral fibre of the global cross section of all the bolts (see Fig 1).

For each bolt i, the shear stress τ_i, in MPa, can be estimated by the following formula:

$$\tau_i = \frac{F_{hheel} 10^3}{A_{SH}}$$

where:

F_{hheel} : As define in [2.2.1]

A_{SH} : Total cross section, in mm², of all bolts.

For each bolt, the Von Mises combined stress is to be less than 0,5 time R_{eH}, where R_{eH} is the minimum guaranteed yield strength of bolts, in MPa.

5 Keel grounding

5.1 General

5.1.1 Keel grounding is considered by the Society only where controlled.

5.1.2 Uncontrolled keel grounding is not covered by the Class Society.

5.2 Controlled keel grounding

5.2.1 Application

Controlled keel grounding is:

- considered by the Society only where yacht's structural design allows this type of operation
- reviewed on a case by case basis.

Specific hull design is to be submitted.

Figure 1 : Keel bolting arrangement