Foundation and mounting of machinery
FOREWORD

DNV GL class guidelines contain methods, technical requirements, principles and acceptance criteria related to classed objects as referred to from the rules.
This is a new document.
SECTION 1 GENERAL

1 Objective
The objective of this guideline is to provide guidance and best practices for foundation and mounting of machinery components.

2 Scope
The guideline provides acceptance criteria, calculation procedures and illustrations of acceptable arrangements for foundation and mounting of machinery components.

3 Application
The guideline may be applied for all types of machinery and equipment.
The guideline is mandatory for machinery as stated in RU SHIP Pt.4 Ch.2 Sec.1 [6].

4 Documentation

4.1 General
Documentation shall be submitted as required in the rules (see RU SHIP Pt.4 Ch.2 Sec.1 [6.2]) and shall contain details as described below with additional documentation as described in [4.2] and [4.3] if applicable:

— dimensioned assembly drawing including parts list and details concerning:
  — arrangement, number and size of chocks
  — arrangement, number and size of stoppers (front and side stoppers)
  — arrangement, number and dimensions of foundation bolts (through bolts and fitted bolts), nuts, extension sleeves, fitted sleeves, clamping sleeves, pins, washers, and disc springs
  — materials for chocks, stoppers, foundation bolts, nuts, extension sleeves, fitted sleeves, clamping sleeves, pins, washers, and disc springs.
— dimensioned section drawings in the vicinity of various foundation bolts
— dimensioned individual part drawings of various foundation bolts
— calculations for the requisite pre-loading forces and bolt elongations with details of the procedure for bolt tightening.

4.2 Seating on cast resin
For seating on cast resin the following procedure for submitting the documentation shall be applied:

— the name of manufacturer and the designation of the cast resin shall be submitted
— the name of the application company of the cast resin shall be submitted
— the documentation, which has been established by the shipyard for an actual mounting, shall be checked, confirmed and as far as necessary made up by the cast resin manufacturer or the application company
— the documents created in this way shall be submitted to the Society for approval by the cast resin manufacturer, an authorized representative or the shipyard
4.3 Resilient mounting

In the case of a resilient mounting the following additional documents shall be submitted:

— description of the complete spring-mass system
— arrangement, number and securing measures for the resilient mounting components, vibration amplitude limiters, and, where appropriate, locking devices
— specification data for the resilient mounting components:
  — manufacturer
  — designation, type, dimensions, shore hardness
  — spring stiffness for the horizontal and vertical loading directions (static and dynamic)
  — damping coefficients
  — characteristic curves for the horizontal and vertical load direction with details concerning permissible continuous load
  — data concerning the time settling behavior at ambient conditions (see RU SHIP Pt.4 Ch.1 Sec.3 Table 3).
— specification data for the torsionally flexible coupling as well as for the essential flexible pipe connections
— calculation of the natural frequencies of the total vibrational system for 6 degrees of freedom
— calculation of the static displacements in the x, y, and z directions at the flexible system components, on the basis of all loadings effective at rated power, resulting from the engine's dead weight, the engine's rated torque, or shaft torque where there is a close-coupled gearbox, the ship's angles of inclination (athwartship/for-and-aft), and, if applicable, propeller thrust
— comparison of the calculated displacements with the permissible values for the flexible system components
— calculation for the forced, damped vibrations.

This calculation is only to be submitted when requested by the Society. It is required if the natural frequency calculation predicts important resonances within the operating speed range.

For operation with misfiring, evidence for the acceptance of the loadings shall be proved by calculation. The results from the calculation shall be commented upon appropriately. Barred speed ranges shall be defined, and a comparison shall be carried out of the amplitudes calculated with the values permissible for the flexible system components.
SECTION 2 PRINCIPLES FOR THE WORKMANSHIP OF SEATINGS

1 General requirements

1.1 For the design and construction of ships’ structural foundations and their sub-structures RU SHIP Pt.3 Ch.10 Sec.6 [5].

1.2 It shall be arranged for easy access to the assembly and inspection openings provided in the propulsion plant for maintenance activities.

1.3 Each seating shall only be carried out after completion of the process of alignment. Where alignment shall be carried out taking into account thermal expansion under operational conditions and the dynamic behavior of the plant components (coupling, gearbox, etc.). Care shall be taken that the alignment of the individual plant components with respect to each other is not altered during the seating activities. Before seating, all welding procedures in the seating area shall be finished.

1.4 In the course of the seating of the individual plant components the installation instructions of the manufacturers shall be observed.

2 Rigid mounting

A rigid mounting is a direct connection of the plant components to the ship’s structural foundations using rigid chocks. The chocks shall be of the same material throughout. Any deviations require the agreement of the Society. The use of shims is not permissible. All innovative types of rigid mountings shall be approved by the Society in advance. The kind of approval and the scope of examination will be defined by the Society in individual cases.

2.1 Metal chocks

2.1.1 Metal chocks are preferably to be manufactured from steel, including cast steel; the use of grey iron is permissible. To enable satisfactory adjusting of the chocks, the top plates of the foundations shall be machined in the vicinity of the chocks. Multi-layer chocks should be avoided. Cut-outs in chocks should not amount to more than 20% of the total surface area. Chocks shall be finished and trued up on both surfaces. The load-bearing area of the chock shall amount to at least 75%. Tack welds are not permissible on chocks.
2.1.2 Metal chocks with adjustable height shall be approved by the Society for every application.

2.2 Cast resin chocks

2.2.1 The casting compounds shall be type approved according to DNVGL CP 0432 *Pourable compounds for foundation chocking*.

The chocks should only be poured by companies authorized by the cast resin manufacturer. Boundary conditions for the resin and the process shall be complied with.

Documentation of qualification and training of the personnel performing the casting shall be presented to the surveyor on request.

2.2.2 Two foundation bolts should as far as possible be located in each cast resin chock.

The height of a cast resin chock should be between 20 mm and 50 mm. Lower or greater chock heights may be acceptable dependent on the cast resin approval conditions. Under no circumstances shall the height of the chock exceed the width or length of the chock.

Cast resin chocks shall only be placed under load if the casting compound has achieved the requisite minimum hardness. This shall be verified by means of a hardness test.

2.2.3 Plant components mounted on cast resin shall be fitted with a reference plate that contains the following details:

— name of the company carrying out the work
— designation of the casting compound
— tightening values of the foundation bolts
— date of pouring.

The reference plate shall be manufactured in metal or plastic and permanently secured.

3 Resilient mounting

3.1

A resilient mounting is a connection of the plant components to the ship's structural foundations using elastic mounting components.

3.2

The resilient mounting of high speed and medium speed diesel engines is primarily used in order to reduce the transmission of vibrations and structure-borne sound into the ship's hull. The desired insulation effect can, however, only be achieved if the natural frequencies of the resilient mounting are sufficiently separated from the excitation frequencies. For plants operating at constant speed a safety margin of at least 10% between the rated speed and the resonance speed shall be maintained.

3.3

In the design of a resilient mounting account shall be taken of the ageing and natural wear of the mounting components. The settling rates over defined time intervals shall be checked and recorded in accordance with the manufacturer's specifications. When the maximum permissible amount of settling is reached the resilient mounting shall be renewed.
3.4
Pipe connections to resiliently mounted plant components require flexible connectors, which shall be held as short as possible, type approved by the Society and, insofar as prescribed by the Society, shall be designed to be flame-resistant. Flexible hoses are preferably to be installed in the length-wise direction of the plant with a small amount of slack.

3.5 Mounting components
The properties (quality, elasticity and loading direction) of the resilient mounting components shall be matched to vibrational conditions and component weights.
The mounting components shall be arranged so that a uniform loading is ensured.
Mounting components shall be protected effectively and permanently against the effects of oil and fuel.
To limit the vibrational amplitudes a sufficient number of buffer stops shall be installed.

4 Fixing to the foundation

4.1 Instructions for installation
In order to ensure the fixing of the propulsion plant under all operating conditions, the individual plant components shall be effectively and permanently secured to the foundations in accordance with the manufacturer’s instructions for installation.

4.2 Choice of fixing
The fixing can, according to choice, be carried out by means of:
— fitted bolts or fitted sleeves located at the drive end in conjunction with side stoppers, see App.A Figure 4
— front stoppers located at the drive end with bolted connection to the engine in conjunction with side stoppers, see App.A Figure 7
— front stoppers in conjunction with fitted bolts (in the case of gear boxes with an integrated thrust bearing), see App.A Figure 8 and App.A Figure 9
— fitted pins and clamping sleeves (only permissible for smaller plants)
— special configurations (in accordance with the instructions of the component manufacturers), see App.A Figure 5 and App.A Figure 6

4.3 Chocks
Chocks for front and side stoppers shall be made from metallic materials. There shall be metal-to-metal contact on both sides and they shall be secured against displacement.
For propulsion plants the stopper chocks shall be manufactured to a wedge or double wedge design. Positioning of the wedge-shaped chocks without clearance shall be executed with the plant at its operating thermal condition. The subsequent fixing is preferably to be ensured by welding up the wedges over the entire wedge length, see App.A Figure 10, App.A Figure 11 and App.A Figure 12.

4.4 Stoppers
For the seating of high speed and medium speed engines with more than 6 cylinders in one line and a cylinder diameter ≥ 250 mm, a further pair of side stoppers shall be provided near the midpoint of the engine length, in the vicinity of a bearing stool, in addition to the side stopper pair at the opposite end to the coupling.
The transmission of the propeller thrust to the ship's structure can be achieved via front stoppers or fitted bolts.
In case fitted bolts are transmitting the propeller thrust the conditions of [5.3.2] shall be observed.
Front stoppers shall be structurally designed so that they can withstand the maximum ahead and astern occurring propeller thrust, without taking into account the foundation bolt pre-loading.
Examples of stopper arrangements for engines and steering gears can be found in App.A.

5 Securing to the foundation

5.1 General
Only bolted joints are permitted for securing the propulsion plants to the ship's structural foundations, see App.A Figure 13 to App.A Figure 17.

5.1.1 Foundation bolts (through bolts and fitted bolts) are, if at all possible, to be designed as headed bolts, and shall be installed so that a check of the bolt preloading can be executed at any time.
The requisite preloading of the foundation bolts shall be specified in co-ordination with the engine manufacturer or the manufacturer of the individual plant component.

5.1.2 When using necked-down bolts (bolts with a reduced shank diameter) the shank diameter shall be less than the thread root diameter but shall not be less than 80% of the thread root diameter. Otherwise subsequent heat treatment and/or material testing of the finished bolts shall be carried out.

5.1.3 Tack welds are not permitted on foundation bolts and nuts.

5.1.4 The mating surfaces for bolt heads, nuts and extension sleeves on the bed plates and top plates shall be machined plane parallel.

5.1.5 In order to hold amounts of settling as small as possible, the number of parting lines in the bolted joints shall be limited to a minimum.
If washers are necessary, they shall be provided to a machined and rigid design. Collared washers shall be located as required, see App.A Figure 17.

5.1.6 For the layout of the foundation bolts a sufficient high utilization of the bolt material shall be considered. It is recommended to provide in the range of the minimum bolt cross section an utilization of at least 70% of the material's yield strength.

5.2 Foundation bolts - Mounting on metal chocks

5.2.1 Bolted joints shall be dimensioned so that, according to calculation, a bolt elongation of at least 0.25 mm is achieved under the requisite pre-loading, see calculation example in Sec.3 [6].

5.2.2 Fitted bolts shall be specified for fixing and securing the plant components. With appropriate dimensioning, fitted bolts can be taken into account for the transmission of propeller thrust.

5.2.3 The nuts for the foundation bolts shall be secured with locking nuts. Self-locking nuts are permitted. Securing of the nut can be dispensed with if the bolted joint is based on a bolt pre-stress, of at least 250 N/ mm², calculated on the thread root cross-sectional area.
5.3 Foundation bolts - Mounting on cast resin chocks

5.3.1 Foundation bolts should be designed as necked-down bolts. The requisite preloading for the foundation bolts shall be established by the companies involved in the seating, taking account of the surface pressure approved by the Society for the cast resin that shall be used. Here care shall be taken that the bolt preloading defined by the permissible surface pressure for the cast resin is greater than the load acting on the bolted joint under maximum operational loading conditions.

5.3.2 Fitted bolts shall be provided on principle for fixing and securing the plant components; they shall not be taken into account in the transmission of propeller thrust. For directly coupled 2-stroke combustion engines, fitted bolts can be accepted for the transmission of propeller thrust under the following conditions:
   — agreement of the engine manufacturer or licensee is provided
   — agreement of the cast resin producer is provided
   — fitting bolts have been structurally designed so, that they can withstand the maximum occurring ahead and astern propeller thrust without taking into account the preloading of the foundation bolts
   — on request a commented calculation of the loads in the fitted bolts is provided.

5.3.3 Bolted joints shall be dimensioned so that under the requisite pre-loading, a calculated minimum bolt elongation is achieved as a function of the cast resin surface pressure that is present, see calculation example in Sec.3 [6].

5.3.4 The nuts of the foundation bolts shall be secured with locking nuts. Self-locking nuts are permitted. Securing of the nut can be dispensed with if the bolted joint is based on a bolt pre-stress, calculated on the thread root cross-sectional area, of at least 150 N/mm² for high speed and medium speed engines, or 100 N/mm² for low speed engines respectively, see calculation example in Sec.3 [8].

5.4 Materials

5.4.1 Quality standards
Material for foundation bolts shall be documented by the Society’s material certificate. Standardized, manufactured nuts and bolts with threads up to M 39, which are made from alloyed or unalloyed steel of the strength category according to ISO 898 (EN 20898-1 and -2), and which are subject to a continuous quality control, may be accepted with manufacturer’s inspection certificates according to RU SHIP Pt.2 Ch.1 Sec.2 [4.2], with details concerning the chemical and mechanical characteristics of the material.
SECTION 3 BASIC CALCULATIONS

1 General

1.1 Introduction
The following basic calculations are mainly valid for cast resin chocks, but they may basically be transferred also to other types of mountings, as e.g., metal chocks.

1.2 Definitions, symbols and units

\( A_e \) = Effective total mating surface of cast resin chocks \([\text{mm}^2]\)

\( A_m \) = Required minimum mating surface of cast resin chocks \([\text{mm}^2]\)

\( A_p \) = Effective piston area of hydraulic tension device \([\text{mm}^2]\)

\( D_m \) = Minimum shank diameter of foundation bolt \([\text{mm}]\)

\( D_o \) = Outer diameter of thread of foundation \([\text{mm}]\)

\( D_r \) = Thread root diameter of foundation bolt \([\text{mm}]\)

\( D_s \) = Shank diameter of foundation bolt \([\text{mm}]\)

\( D_{s1} \ldots D_{si} \) = Individual shank diameters of foundation bolt corresponding to \( L_1 \ldots L_i \) \([\text{mm}]\)

\( F_o \) = Axial bolt force exerted on each bolt under operational loading conditions \([\text{N}]\)

\( F_p \) = Preloading force exerted on each bolt by tightening \([\text{N}]\)

\( k \) = Hydraulic coefficient for setting and resilience behaviour \([-]\)

\( \Delta L \) = Theoretical elongation of foundation bolt \([\text{mm}]\)

\( \Delta L_m \) = Required minimum theoretical elongation of foundation bolt \([\text{mm}]\)

\( L_1 \ldots L_i \) = Individual part shank lengths of foundation bolt corresponding to \( D_{s1} \ldots D_{si} \) \([\text{mm}]\)

\( n \) = Number of foundation bolts \([-]\)

\( p_a \) = approved surface pressure \([\text{N/mm}^2]\)

\( p_h \) = Hydraulic pressure for hydraulic tension device \([\text{bar}]\)

\( p_t \) = Total surface pressure exerted on the chocks caused by weight of plant component and bolt preloading force \([\text{N/mm}^2]\)

\( p_{tw} \) = Total surface pressure exerted on the chocks caused by weight of plant component \([\text{N/mm}^2]\)

\( P \) = Pitch of bolt thread \([\text{mm}]\)

\( R_{yH} \) = Minimum yield strength of bolt material \([\text{N/mm}^2]\)

\( T \) = Tightening torque of foundation bolt \([\text{Nm}]\)

\( W \) = Weight of serviceable plant component \([\text{N}]\)

\( s_e \) = Equivalent stress (tensile stress combined with torsional stress) \([\text{N/mm}^2]\)

\( s_t \) = Tensile stress \([\text{N/mm}^2]\)
2 Calculation of the required minimum mating surface of cast resin chocks

\[ A_m - (W/p_w) \quad [N/mm^2] \]

Boundary conditions:

\[ p_w \leq 0.7 \quad [N/mm^2] \]
\[ A_m \leq A_e \quad [mm^2] \]

3 Calculation of preloading force exerted on one foundation bolt by tightening

\[ F_p = \{(p_t - p_w) \cdot A_c\}/n \quad [N] \]

Boundary conditions:

\[ p_t \leq p_a \quad [N/mm^2] \]
\[ F_p > F_o \quad [N] \]

4 Calculation of tightening torque of foundation bolt if using a torque wrench

\[ T = (F_p \cdot D_o)/5000 \quad [Nm] \]

Boundary conditions:

— the calculation is valid for steel foundation bolts with usual standard thread and oil-lubricated thread courses and nut mating surfaces without slide additives, such as molybden sulfid (Mo S\(_2\)), being used.
— If such additives are used, the pre-loading forces actually applied shall be proved by measurements.

5 Calculation of hydraulic pressure if using hydraulic tension device

\[ p_h = 10 \cdot \frac{F_p}{A_p \cdot k} \quad [bar] \]

Boundary conditions:

— \( k = 0.85 \)
— if hydraulic coefficients \( k \) shall be used which deviate from the given one the preloading forces actually applied shall be proved to the Society by measurements.

6 Calculation of bolt elongation on basis of pre-loading force

\[ \Delta L = F_p \left( \frac{L_1}{D_{s1}^2} + \frac{L_2}{D_{s2}^2} + \ldots + \frac{L_n}{D_{sn}^2} \right) 618 \cdot 10^{-8} \quad [mm] \]

Boundary conditions:

\[ \Delta L \geq \Delta L_m \]
— cast resin chocks

\[ \Delta L_m = 0.0343 \cdot p_t \quad [mm] \quad \text{for} \quad p_t \geq 3.5 \quad [N/mm^2] \]
\[ \Delta L_m = 0.12 \quad [mm] \quad \text{for} \quad p_t < 3.5 \quad [N/mm^2] \]
— metal chocks

\[ \Delta L_m = 0.25 \text{ [mm]} \]

### 7 Calculation of equivalent and/or tensile stress related to the minimum shank diameter of foundation bolt on basis of preloading force

#### 7.1 Tightening of bolts by torque wrench

**7.1.1 Bolt with non-reduced shank diameter \((D_m = D_r)\)**

\[ \sigma_e = 1.5 \frac{F_p}{d_r^2} \text{ [N/mm}^2\text{]} \]

Boundary condition:

\[ \sigma_e \leq 0.9 R_{eh} \text{ [N/mm}^2\text{]} \]

**7.1.2 Necked-down bolt with reduced shank \((0.8 D_r \leq D_m < 1.0 D_r)\)**

\[ \sigma_e = 1.72 \frac{F_p}{D_m^2} \sqrt{0.6 + \frac{D_t}{D_m^2} (P + 0.2 D_r)} \text{ [N/mm}^2\text{]} \]

Boundary condition:

\[ \sigma_e \leq 0.9 R_{eh} \text{ [N/mm}^2\text{]} \]

#### 7.2 Tightening of bolts by hydraulic tension device

\[ \sigma_t = 1.274 \frac{F_p}{d_m^2} \text{ [N/mm}^2\text{]} \]

Boundary condition:

\[ \sigma_t \leq 0.8 R_{eh} \text{ [N/mm}^2\text{]} \text{ for } k = 0.85 \]

### 8 Calculation of tensile stress related to thread root diameter of foundation bolt on basis of preloading force

\[ \sigma_t = 1.274 \frac{F_p}{d_r^2} \text{ [N/mm}^2\text{]} \]

#### 8.1 Criterion for locking of nuts

Locking of nuts is required under the following condition:

\[ \sigma_t < 150 \text{ [N/mm}^2\text{]} \]

For low-speed engines:

\[ \sigma_t < 100 \text{ [N/mm}^2\text{]} \]
APPENDIX A EXAMPLES FOR FOUNDATIONS

Figure 1 Effective mating surface of cast resin chocks for a diesel engine
Figure 2 Foundation bolts
Figure 3 Fitted foundation bolts
Figure 4 Illustration of method of locating engine on seating using fitted bolts and side stoppers
Figure 5 Illustration of method of locating engine on seating using side stoppers and fitted bolts located at one engine side
Figure 6 Illustration of method of locating engine on seating using side stoppers and fitted bolts located at one side and in the middle of the engine
Figure 7 Illustration of method of locating engine on seating using front and side stoppers
Figure 8 Illustration of method of locating propulsion plant with main engine and separate gear box
Figure 9 Illustration of method of locating propulsion plant with main engine and close-coupled gear box
Figure 10 Illustration of a side stopper when mounting on metal chocks
Figure 11 Illustration of a side stopper when mounting on cast resin chocks
Figure 12 Illustration of a front stopper with bolted connection and metal chock
Figure 13 Principal arrangement for the fixing of a rudder drive with double acting cylinders

= Stoppers to be provided
Figure 14 Principal arrangement for the fixing of a rudder drive with single acting cylinders
Figure 15 Principal arrangement for the fixing of a rudder drive with rotating piston
Figure 16 Illustration of a through bolt connection when mounting on metal chocks
Figure 17 Illustration of a fitted bolt connection when mounting on metal chocks
Figure 18 Illustration of a necked-down bolt connection when mounting on cast resin chocks
Figure 19 Illustration of a fitted necked-down bolt connection when mounting on cast resin chocks
Figure 20 Illustration of a necked-down bolt connection with fitted sleeve when mounting on cast resin chocks
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