RULES FOR BUILDING AND CLASSING
LIGHT WARSHIPS, PATROL AND HIGH-SPEED NAVAL VESSELS
JANUARY 2023

PART 3
HULL CONSTRUCTION AND EQUIPMENT

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# PART 3

## CHAPTER 1

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1 **Application**

The following definitions of terms apply throughout the requirements in these Rules.

3 **Length (2018)**

$L$ is the distance, in meters (feet), on the full load design waterline in the displacement mode, from the fore side of the stem to the centerline of the rudder stock. For use with these Rules, $L$ is not to be less than 96% and need not be greater than 97% of the extreme length on the full load design waterline in the displacement mode. The forward end of $L$ is to coincide with the fore side of the stem on the waterline on which $L$ is measured.

5 **Breadth**

$B$ is the greatest molded breadth, in meters (feet).

Breadth used in 3-2-1/1.1.1 for vessels which have flare or tumblehome, is the mean breadth of the waterline breadth and the maximum breadth between the waterline and main deck at the longitudinal center of flotation (LCF).

7 **Depth**

$D$ is the molded depth, in meters (feet), measured at the middle of the length $L$, from the molded keel line to the top of the freeboard deck beams at the side of the vessel. On vessels with rabbeted keel construction, $D$ is to be measured from the rabbet line. In cases where watertight bulkheads extend to a deck above the freeboard deck and are to be recorded in the Record as effective to that deck, $D$ is to be measured to the bulkhead deck.

9 **Draft for Scantlings**

$d$ is the draft, in meters (feet), measured at the middle of the length $L$ from the molded keel or the rabbet line at its lowest point to the estimated summer load waterline or the design load waterline in the displacement mode.
11 Decks

11.1 Freeboard Deck (2018)
The freeboard deck is normally the uppermost complete deck exposed to weather and sea, which has permanent means of closing all openings in the weather portions, and below which all openings in the vessel side are equipped with permanent means for watertight closing.

11.3 Bulkhead Deck
The bulkhead deck is the highest deck to which watertight bulkheads extend and are made effective.

11.5 Strength Deck
The strength deck is the deck which forms the top of the effective hull girder at any part of its length. See Section 3-2-1.

11.7 Superstructure Deck
A superstructure deck is a deck above the freeboard deck to which the side shell plating extends or of which the sides are fitted inboard of the hull side not more than 4% of the breadth, \( B \). Except where otherwise specified, the term superstructure deck where used in these Rules refers to the first such deck above the freeboard deck.

13 Superstructure
A superstructure is an enclosed structure above the freeboard deck having side plating as an extension of the shell plating, or not fitted inboard of the hull side more than 4% of the breadth \( B \).

15 Deckhouses
A deckhouse is an enclosed structure above the freeboard deck, having side plating set inboard of the hull side-shell plating more than 4% of the breadth \( B \) of the vessel.

17 Displacement and Block Coefficient

17.1 Displacement
The displacement \( \Delta \), is the mass displacement of the vessel in the design condition in metric tons (long tons), unless otherwise specifically noted.

17.3 Block Coefficient \( (C_b) \)
\( C_b \) is the block coefficient obtained from the following equation:

\[
C_b = \frac{\Delta}{L B_{wl} d} \quad \text{(SI & MKS units)}
\]

\[
C_b = \frac{35\Delta}{L B_{wl} d} \quad \text{(US units)}
\]

where

\( \Delta \) = molded displacement, as defined in 3-1-1/17.1
\( L \) = scantling length, as defined in 3-1-1/3
\( d \) = draft, as defined in 3-1-1/9
\( B_{wl} \) = greatest molded breadth at the design load line
18 **Deadweight (DWT)**

For the purpose of these Rules, deadweight (DWT), is the difference, in metric tons (long tons), between the displacement of the vessel at its summer load line or the vessel with all tanks filled, maximum cargo loaded, maximum stores, and naval personnel or passengers and their effects on board, in water having a specific gravity of 1.025, and the unloaded weight of the vessel. For the purpose of these Rules, the unloaded weight is the displacement of the vessel, in metric tons (long tons), with no cargo, fuel, lubricating oil, ballast water, fresh water nor feed water in tanks, no consumable stores, and no naval personnel or passengers nor their effects.

19 **Significant Wave Height**

Significant wave height is the average height of the one-third highest observed wave heights over a given period.

21 **Rabbet Line (Fiber Reinforced Plastic)**

The rabbet line is the line intersection between the outside of a vessel’s bottom and a vessel’s keel. Where there is no keel, the rabbet line is the bottom of the vessel.

23 **Naval Administration**

The department, directorate, bureau or command to whom the National Government has delegated authority over the acquisition, acceptance, maintenance and technical requirements of naval vessels, and who acts on the Government’s behalf in all matters relating to the procurement and support of the vessels. In the case where these authorities are invested in separate departments within the naval organization, the term “Naval Administration” means the ensemble of departments having those authorities, or the command that overarches these departments. The Naval Administration may exist as part of the Navy, or within a separate arm of the government, such as a material procurement directorate.

25 **Military Personnel**

All people that are riding the vessel, including the crew, that either have a function in the operation of the vessel or are trained personnel that are taking part in the overall mission of the vessel.

27 **Passenger**

Any personnel on the vessel other than military personnel as defined above in 3-1-1/29.

29 **Safe Harbor**

A friendly natural or artificial sheltered area which may be used as a shelter by a vessel under conditions likely to endanger its safety.

31 **Fiber-Reinforced Plastic (FRP)**

FRP consists of two basic components: a glass-filament or other material fiber reinforcement and a plastic, or resin, in which the reinforcing material is imbedded.

31.1 **Reinforcement**

Reinforcement is a strong, inert material bonded into the plastic to improve its strength, stiffness and impact resistance. Reinforcements are usually fibers of glass (a lime-alumina-silicate composition having a low alkali content) or other approved material such as aramid or carbon fiber, in a woven or non-woven form, with a strong adhesive bond to the resin.

31.1.1 **Strand**

A bundle of continuous filaments combined in a single, compact unit.
31.1.2 **Roving**
A band or ribbon of parallel strands grouped together.

31.1.3 **Yarn**
A twisted strand or strands suitable for weaving into a fabric.

31.1.4 **Binder**
The agent applied in small quantities to bond the fibers in mat form.

31.1.5 **Coupling Agent**
An active water soluble chemical that allows resin to adhere to glass.

31.1.6 **Chopped-strand Mat**
A blanket of randomly oriented chopped-glass strands held together with binder.

31.1.7 **Woven Roving**
A coarse roving woven from rovings.

31.1.8 **Cloth**
A fabric woven from yarn

31.1.9 **Peel-Ply**
An “E” glass fabric that does not have any coupling agent applied, used as a protective covering on a laminate being prepared for a secondary bond to keep foreign particles from adhering to the surface.

31.1.10 **Uni-directional**
A woven or non-woven reinforcement with substantially more fibers in one principal axis of the reinforcing ply.

31.1.11 **Double Biased**
A woven or non-woven reinforcement with fibers primarily at +45° to the principal axes of the reinforcing ply.

31.1.12 **Knitted or Stitched Fabrics**
Two or more layers of unidirectional fabrics that are stitched together.

31.1.13 **Bi-axial Fabric**
A stitched or knitted reinforcement with fibers primarily in the two principal axes of the reinforcing ply.

31.1.14 **Tri-axial Fabric**
A stitched or knitted reinforcement with fibers running in one principal axis of the ply and in addition, with fibers running at + and -45° to the warp.

31.1.15 **Ply Principal Axes**
The two principal axes of a reinforcing ply are the axis that is parallel to the warp and the axis that is parallel to the fill.

31.1.16 **Warp**
The roving or yarn running lengthwise in woven fabric (in the “roll direction”).
31.1.17 **Fill, Weft or Woof**
The roving or yarn running at right angles to the warp in a woven fabric.

31.1.18 **“E” glass**
A family of glass reinforcement material of aluminoborosilicate composition and having high electrical resistivity.

31.1.19 **“S” glass**
A family of glass reinforcement material of magnesium aluminosilicate composition that contains a higher silicon content and provides higher strength and stiffness properties than “E” glass.

31.1.20 **Kevlar**
An aramid fiber reinforcement.

31.1.21 **Carbon Fiber**
A reinforcement material made of mostly carbon produced by the pyrolysis of organic precursor fibers in an inert environment.

31.3 **Resin**
Resin is a highly reactive synthetic that in its initial stage is a liquid, but upon activation is transformed into a solid.

31.3.1 **Accelerator**
A material that, when mixed with a catalyst or resin, speeds the cure time.

31.3.2 **Additive**
A substance added to another substance, usually to improve properties, such as plasticizers, initiators, light stabilizers and flame retardants.

31.3.3 **Catalyst or Initiator**
A material that is used to activate resin, causing it to harden.

31.3.4 **Crazing**
Hairline cracks, either within or on the surface of resin, caused by mechanical or thermal stresses.

31.3.5 **Cure**
To change resin from a liquid to a solid.

31.3.6 **Cure time**
The time required for resin to change from a liquid to a solid after a catalyst has been added.

31.3.7 **Exothermic Heat**
The heat given off as the result of the action of a catalyst on resin.

31.3.8 **Filler**
A material added to resin to modify its working properties or other qualities, or to lower densities.

31.3.9 **Gel**
A partially cured resin in a semi-solid state similar to gelatin in consistency.

31.3.10 **Gel Time**
The time required to change a flowable, liquid resin into a nonflowing gel.
31.3.11 Inhibitor
A material that retards activation or initiation of resin, thus extending shelf life or influencing exothermic heat or gel time.

31.3.12 Polymerization
The reaction that takes place when resin is activated or initiated.

31.3.13 Pot Life
The length of time that a catalyzed resin remains workable.

31.3.14 Shelf Life
The length of time that an uncatalyzed resin maintains its working properties while stored in a tightly sealed, opaque container.

31.3.15 Tack
The degree of stickiness of the resin.

31.3.16 Thixotropy
The property or phenomenon, exhibited by some resins, of becoming jelly-like at rest but becoming fluid again when stirred or agitated. This facilitates the application of the resin to inclined or vertical surfaces.

31.3.17 Polyester Resin
A thermosetting resin that is formed by combining saturated and unsaturated organic acids. Such as orthophthalic and isophthalic acids.

31.3.18 Vinylester Resin
A thermosetting resin that consists of a polymer chain and an acrylate or methacrylate termination.

31.3.19 Epoxy
A resin that contains one or more of the epoxide groups.

31.5 Laminate
A laminate is a material composed of successive bonded layers, or plies, of resin and fiber or other reinforcing substances.

31.5.1 Bi-directional Laminate
A laminate having essentially the same strength and elastic properties in the two in plane principal axes. Bi-directional laminates may be constructed of bi-axial, double bias, tri-axial, mat or unidirectional reinforcing layers, or a combination of any of these.

31.5.2 Uni-directional Laminate
A laminate with substantially more of the fibers in the plane of the laminate oriented in one of the two principal axis of the laminate plane so that the mechanical properties along that axis are appreciably higher than along the other natural axis.

31.5.3 Sandwich Laminate
A laminate consisting of two fiber reinforced plastic skins attached to a non-structural or structural core (see 3-1-1/31.7 “Encapsulation”).

31.5.4 Barcol Hardness
A measurement of the hardness of a laminate and thereby the degree of completion of the cure.
31.5.5 Delamination
The separation of the layers of material in a laminate.

31.5.6 Gel Coat
The first resin applied to mold when fabricating a laminate to provide a smooth protective surface for the laminate.

31.5.7 Layup
The process of applying to a mold the layers of resin and reinforcing materials that make up a laminate. These materials are then compressed or densified with a roller or squeegee to eliminate entrapped air and to spread resin evenly. Also a description of the component materials and geometry of a laminate.

31.5.8 Verified Minimum Mechanical Property
The mechanical properties, in Part 2, Chapter 6, of laminates differing from the basic, verified by the appropriate test(s) listed in 2-6-1/5.5 TABLE 1.

31.5.9 Laminate Principal Axes
The two principal axes of a square or rectangular plate panel are for the application of these Rules those perpendicular and parallel to the plate panel edges.

31.5.10 Vacuum Bagging
A method used to apply a uniform pressure over an area by applying a vacuum to that area.

31.5.11 Resin Impregnation
A process of construction for large layers of fabric that consists of running a roll of fabric through a resin bath to completely saturate the fabric.

31.5.12 Resin Transfer Molding
A closed mold method that mechanically pumps resin through dry fabric previously placed in the mold.

31.5.13 Resin Infusion
A method of FRP construction that uses a vacuum to pull catalyzed resin through dry fabric.

31.5.14 Primary Bond
The bond that is formed between two laminated surfaces when the resin on both surfaces has not yet cured.

31.5.15 Secondary Bond
The bond that is formed between two laminated surfaces when the resin on one of the two surfaces has cured.

31.5.16 Post Cure
The act of placing a laminate in an autoclave and raising the temperature to assist in the cure cycle of the resin.

31.5.17 Autoclave
A large oven used in post curing large laminated parts.

31.7 Encapsulation
The containment of a core material, such as softwoods, balsa, PVC (cross linked) or linear polymer, within FRP laminates. The cores may be structurally effective or ineffective.
31.7.1 Bedding Putty
Material used to adhere the core material to the FRP skins.

31.7.2 Scores
Slits cut into the core material to aid in forming the core to complex shapes.

32 Ride Control System (RCS) (1 July 2022)
Ride Control System (RCS) is a system designed to reduce the wave-induced ship motions with the purpose of increasing the range of the vessel's operability. RCS can include canards, stabilizers, T-foils, stern flaps, interceptors, and lifting foils.

33 Units
These Rules are written in three systems of units: SI units, MKS units and US customary units. Each system is to be used independently of any other system.

Unless indicated otherwise, the format of presentation in these Rules of the three systems of units is as follows:

SI units (MKS units, US customary units)
CHAPTER 1
General

SECTION 2
General Requirements

1 Materials

These Rules are intended for welded vessels constructed of steel, welded vessels constructed of aluminum, and fiber reinforced plastic (FRP) vessels; complying with the requirements of Part 2, Chapters 1, 2, 5 and 6 respectively, including the Naval vessel supplementary requirements indicated in Part 2, Chapter 11. The use of materials other than those specified in Part 2, Chapters 1, 2, 5, 6, 11 and the corresponding scantlings will be specially considered.

1.1 Selection of Material Grade (2023)

For vessels 61 m (200 ft) and over in length, steel materials are not to be lower grades than those required by 3-1-2/1.1 TABLE 1 for the material class given in 3-1-2/1.1 TABLE 2 for the particular location.

<table>
<thead>
<tr>
<th>Plate Thickness (t) mm (in.)</th>
<th>Material Class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
</tr>
<tr>
<td>t ≤ 15 (t ≤ 0.60)</td>
<td>A(1), AH</td>
</tr>
<tr>
<td>15 &lt; t ≤ 20 (0.60 &lt; t ≤ 0.79)</td>
<td>A, AH</td>
</tr>
<tr>
<td>20 &lt; t ≤ 25 (0.79 &lt; t ≤ 0.98)</td>
<td>A, AH</td>
</tr>
<tr>
<td>25 &lt; t ≤ 30 (0.98 &lt; t ≤ 1.18)</td>
<td>A, AH</td>
</tr>
<tr>
<td>30 &lt; t ≤ 35 (1.18 &lt; t ≤ 1.38)</td>
<td>B, AH</td>
</tr>
<tr>
<td>35 &lt; t ≤ 40 (1.38 &lt; t ≤ 1.57)</td>
<td>B, AH</td>
</tr>
<tr>
<td>40 &lt; t ≤ 100 (1.57 &lt; t ≤ 4.0)</td>
<td>D, AH</td>
</tr>
</tbody>
</table>

Note:
1 (2017) ASTM A36 steel otherwise manufactured by an ABS approved steel mill, tested and certified to the satisfaction of ABS may be used in lieu of Grade A for a thickness up to and including 12.5 mm (0.5 in.) for plate and 19 mm (0.75 in.) for sections.
### TABLE 2  
Material Class of Structural Members (2017)

<table>
<thead>
<tr>
<th>Structural Members</th>
<th>Material Class Within 0.4L Amidships</th>
<th>Material Class Outside 0.4L Amidships</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shell</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom plating including keel plate (2)</td>
<td>II</td>
<td>A(3)/AH</td>
</tr>
<tr>
<td>Bilge strake (1)</td>
<td>II</td>
<td>A(3)/AH</td>
</tr>
<tr>
<td>Side Plating</td>
<td>I</td>
<td>A(3)/AH</td>
</tr>
<tr>
<td>Sheer Strake at strength deck (1)</td>
<td>II</td>
<td>A(3)/AH</td>
</tr>
<tr>
<td><strong>Decks</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength deck plating (2)</td>
<td>II</td>
<td>A(3)/AH</td>
</tr>
<tr>
<td>Stringer plate in strength deck (1)</td>
<td>II</td>
<td>A(3)/AH</td>
</tr>
<tr>
<td>Strength deck strake on tankers at longitudinal bulkhead</td>
<td>II</td>
<td>A(3)/AH</td>
</tr>
<tr>
<td>Strength deck plating within line of hatches and exposed to weather, in general</td>
<td>I</td>
<td>A(3)/AH</td>
</tr>
<tr>
<td><strong>Longitudinal Bulkheads</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lowest strake in single bottom vessels</td>
<td>I</td>
<td>A(3)/AH</td>
</tr>
<tr>
<td>Uppermost strake including that of the top wing tank</td>
<td>II</td>
<td>A(3)/AH</td>
</tr>
<tr>
<td><strong>Other Structures in General</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External continuous longitudinal members and bilge keels</td>
<td>II</td>
<td>A(3)/AH</td>
</tr>
<tr>
<td>(1 July 2015) Plating materials for stern frames supporting rudder and propeller boss, rudders, rudder horns, steering equipment (3), propeller nozzles, and shaft brackets</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>Strength members not referred to in above categories and above local structures</td>
<td>A(3)/AH</td>
<td>A(3)/AH</td>
</tr>
</tbody>
</table>

**Note:**

1. A radius gunwale plate may be considered to meet the requirements for both the stringer plate and the sheer strake, provided it extends suitable distances inboard and vertically. For formed material see 2-4-1.3.13.

2. Plating at the corners of large hatch openings are to be specially considered.

3. (2017) ASTM A36 steel otherwise manufactured by an ABS approved steel mill, t tested and certified to the satisfaction of ABS may be used in lieu of Grade A for thickness up to and including 12.5 mm (0.5 in.) for a plate and 19 mm (0.75 in.) for sections.

4. (1 July 2015) Steering equipment components other than rudders, as described in Section 3-2-8.

When tensile stresses through the thickness (Z direction) exceed approximately 50% of the minimum specified yield stress (as defined in the applicable ABS Rules), consideration is to be given to applying Z grade steel (refer to 2-1-1/17 of the ABS Rules for Materials and Welding (Part 2)). Alternatives to applying Z grade may be proposed provided it is demonstrated by ultrasonic testing before and after welding that no through thickness tearing has occurred, and/or the welding preparation, weld size and bead sequence is such that damaging through thickness loads induced by weld shrinkage are avoided.
1.3 **Note for the Users**

The attention of users is drawn to the fact that when fatigue loading is present, the effective strength of higher-strength steel in a welded construction may not be greater than that of ordinary-strength steel. Precautions against corrosion fatigue to higher strength steel and aluminum alloy materials may also be necessary.

1.5 **6000 Series Aluminum Alloys (1 January 2004)**

The use of 6000 series aluminum alloys is only permitted in structural applications in the extrusion form above the freeboard deck. The welded yield strength, $\sigma_{yw}$, for these alloys is based on the fully annealed condition, and is to be taken as 55 N/mm$^2$ (5.5 kgf/mm$^2$, 8000 psi). The use of 6000 series aluminum alloys in other locations is permitted only when approved in writing by the Naval Administration, and the following requirements are complied with:

i) The welding procedure is to be submitted for review and approval. This procedure is needed for process control in all welds and not allow for pre/post heating of the alloy. It will need to establish methods for certifying welders to this process and methods for inspection of the completed welds.

ii) Since pre/post heating is not permitted on 6000 series alloys, areas that can accumulate large “pre-stresses” such as the forward bow structure and water jet duct structure are to be examined. This examination is to include a determination of the actual pre-stress in the members and the reactions in the member when loaded with the required hydrostatic and slamming pressures.

iii) The procedure for the repair of the 6000 series alloys is to be submitted for review and approval. This procedure will need to demonstrate that the repair will not lower the heat affected zone below the level used for design.

The use of a welded yield strength, $\sigma_{yw}$, greater than the fully annealed condition may be considered when low heat welding techniques are used or with specialty extrusions that minimize the amount of weld. As part of this consideration, a test program will need to be established to validate the proposed welded yield strength. This test program is to include tensile, hardness, and fatigue “coupon” type testing of the alloy in the heat affected zone. Testing of samples that have been effectively repaired to determine the effects of multiple weld passes and the possible annealing of the alloy are also to be performed. In all cases, the Naval Administration is to confirm the use of the greater welded yield strength in writing.

1.7 **Vessels Exposed to Low Air Temperatures (1 July 2019)**

For vessels intended to operate in areas with low air temperatures [below and including $-10^\circ$C ($14^\circ$F)], the materials in exposed structures are to be selected based on the design temperature $t_D$, to be taken as defined in 3-1-2/1.9.

Materials in the various strength members above the lowest ballast water line (BWL) exposed to air (including the structural members covered by Note 5 of below TABLE 3) are not to be of lower grades than those corresponding to Classes I, II and III, as given in 3-1-2/1.7 TABLE 3, depending on the categories of structural members (secondary, primary and special). For non-exposed structures (except as indicated in Note 5 of 3-1-2/1.7.5) and structures below the lowest ballast water line, 3-1-2/1.1 applies.
TABLE 3
Application of Material Classes and Grades – Structures Exposed at Low Temperatures (2017)

<table>
<thead>
<tr>
<th>Structural Member Category</th>
<th>Material Class</th>
<th>Within 0.4L Amidships</th>
<th>Outside 0.4L Amidships</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary</td>
<td></td>
<td>I</td>
<td>I</td>
</tr>
<tr>
<td>Deck plating exposed to weather, in general</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side plating above BWL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transverse bulkheads above BWL (^{(5)})</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary</td>
<td></td>
<td>II</td>
<td>I</td>
</tr>
<tr>
<td>Strength deck plating (^{(1)})</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous longitudinal members above strength deck, excluding longitudinal hatch coamings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longitudinal bulkhead above BWL (^{(5)})</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top wing tank bulkhead above BWL (^{(5)})</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Special</td>
<td></td>
<td>III</td>
<td>II</td>
</tr>
<tr>
<td>Sheer strake at strength deck (^{(2)})</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stringer plate in strength deck (^{(2)})</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deck strake at longitudinal bulkhead (^{(3)})</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous longitudinal hatch coamings (^{(4)})</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:

1. Plating at corners of large hatch openings to be specially considered. Class III or Grade E/EH to be applied in positions where high local stresses may occur.
2. Not to be less than Grade E/EH within 0.4L amidships in vessels with length exceeding 250 meters (820 feet).
3. In vessels with breadth exceeding 70 meters (230 feet) at least three deck strakes to be Class III.
4. Not to be less than Grade D/DH.
5. \((2017)\) Applicable to plating attached to hull envelope plating exposed to low air temperature. At least one strake is to be considered in the same way as exposed plating and the strake width is to be at least 600 mm (24 in.).

The material grade requirements for hull members of each class depending on thickness and design temperature are defined in 3-1-2/1 TABLE 4. For design temperatures \(t_D < -55^\circ C\) (\(-67^\circ F\)), materials are to be specially considered.

TABLE 4
Material Grade Requirements for Classes I, II and III at Low Temperatures
\((1\ Text\ 2019)\)

Class I
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>t ≤ 10 (t ≤ 0.39)</td>
<td>A, AH</td>
<td>A, AH</td>
<td>B, AH</td>
<td>D, DH</td>
<td>D, DH</td>
</tr>
<tr>
<td>10 &lt; t ≤ 15 (0.39 &lt; t ≤ 0.60)</td>
<td>A, AH</td>
<td>B, AH</td>
<td>D, DH</td>
<td>D, DH</td>
<td>D, DH</td>
</tr>
<tr>
<td>15 &lt; t ≤ 20 (0.60 &lt; t ≤ 0.79)</td>
<td>A, AH</td>
<td>B, AH</td>
<td>D, DH</td>
<td>D, DH</td>
<td>E, EH</td>
</tr>
<tr>
<td>20 &lt; t ≤ 25 (0.79 &lt; t ≤ 0.98)</td>
<td>B, AH</td>
<td>D, DH</td>
<td>D, DH</td>
<td>D, DH</td>
<td>E, EH</td>
</tr>
<tr>
<td>25 &lt; t ≤ 30 (0.98 &lt; t ≤ 1.18)</td>
<td>B, AH</td>
<td>D, DH</td>
<td>D, DH</td>
<td>E, EH</td>
<td>E, EH</td>
</tr>
<tr>
<td>30 &lt; t ≤ 35 (1.18 &lt; t ≤ 1.38)</td>
<td>D, DH</td>
<td>D, DH</td>
<td>E, EH</td>
<td>E, EH</td>
<td>E, EH, -</td>
</tr>
<tr>
<td>35 &lt; t ≤ 45 (1.38 &lt; t ≤ 1.80)</td>
<td>D, DH</td>
<td>E, EH</td>
<td>E, EH</td>
<td>E, EH</td>
<td>E, EH, -</td>
</tr>
<tr>
<td>45 &lt; t ≤ 50 (1.80 &lt; t ≤ 1.97)</td>
<td>D, DH</td>
<td>E, EH</td>
<td>E, EH</td>
<td>E, EH, -</td>
<td>E, EH, -</td>
</tr>
</tbody>
</table>

**Class III**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>t ≤ 10 (t ≤ 0.39)</td>
<td>B, AH</td>
<td>D, DH</td>
<td>D, DH</td>
<td>E, EH</td>
<td>E, EH</td>
</tr>
<tr>
<td>10 &lt; t ≤ 20 (0.39 &lt; t ≤ 0.79)</td>
<td>B, AH</td>
<td>D, DH</td>
<td>D, DH</td>
<td>E, EH</td>
<td>-,-</td>
</tr>
<tr>
<td>20 &lt; t ≤ 25 (0.79 &lt; t ≤ 0.98)</td>
<td>D, DH</td>
<td>E, EH</td>
<td>E, EH</td>
<td>E, EH</td>
<td>-,-</td>
</tr>
<tr>
<td>25 &lt; t ≤ 30 (0.98 &lt; t ≤ 1.18)</td>
<td>D, DH</td>
<td>E, EH</td>
<td>E, EH</td>
<td>-,-</td>
<td>-,-</td>
</tr>
<tr>
<td>30 &lt; t ≤ 35 (1.18 &lt; t ≤ 1.38)</td>
<td>E, EH</td>
<td>E, EH</td>
<td>-,-</td>
<td>-,-</td>
<td>-,-</td>
</tr>
<tr>
<td>35 &lt; t ≤ 40 (1.38 &lt; t ≤ 1.57)</td>
<td>E, EH</td>
<td>-,-</td>
<td>-,-</td>
<td>-,-</td>
<td>-,-</td>
</tr>
<tr>
<td>40 &lt; t ≤ 50 (1.57 &lt; t ≤ 1.97)</td>
<td>E, EH</td>
<td>-,-</td>
<td>-,-</td>
<td>-,-</td>
<td>-,-</td>
</tr>
</tbody>
</table>

Single strakes required to be of Class III or of Grade E/EH or FH are to have breadths not less than 800 + 5L mm, maximum 1800 mm.

Plating materials for sternframes, rudder horns, rudders and shaft brackets are not to be of lower grades than those corresponding to the material classes given in 3-1-2/1.1.

### 1.9 Design Temperature \( t_D(2017) \)

The design temperature \( t_D \) is to be taken as the lowest mean daily average air temperature in the area of operation.

---

**ABS RULES FOR BUILDING AND CLASSING LIGHT WARSHIPS, PATROL AND HIGH-SPEED NAVAL VESSELS • 2023**
Mean: Statistical mean over observation period (at least 20 years)

Average: Average during one day and night

Lowest: Lowest during year

For seasonally restricted service the lowest value within the period of operation applies.

For the purpose of issuing a Polar Ship Certificate in accordance with the Polar Code, the design temperature \( t_D \) shall be no more than 13°C (23.6°F) higher than the Polar Service Temperature (PST) of the vessel.

In the Polar Regions, the statistical mean over observation period is to be determined for a period of at least 10 years.

3-1-2/1.9 FIGURE 1 illustrates the temperature definition.

**FIGURE 1**
Commonly Used Definitions of Temperatures (2017)

MDHT = Mean Daily High (or maximum) Temperature

MDAT = Mean Daily Average Temperature

MDLT = Mean Daily Low (or minimum) Temperature

3 Workmanship

All workmanship is to be of commercial marine quality and acceptable to the Surveyor. Welding is to be in accordance with the requirements of Part 2, Chapter 4, Appendix 2-5-A1, Part 2, Chapter 14, and Section 3-2-13.
5 Design

5.1 Continuity

Care is to be taken to provide structural continuity. Changes in scantlings are to be gradual, such that the maximum angle from horizontal is 45°, see 3-1-2/5.1 FIGURE 2. Strength members are not to change direction abruptly, such that the maximum change in direction is 45°, see 3-1-2/5.1 FIGURE 3. Where primary structural members terminate at another structural member, tapering of the primary member or tapering brackets may be required beyond the other structural member, as indicated in 3-1-2/5.1 FIGURE 4, and as required in 3-2-5/1. Stanchions and bulkheads are to be aligned to provide support and to minimize eccentric loading. Major appendages outside the hull and strength bulkheads in superstructures are to be aligned with major structural members within the hull.

FIGURE 2

FIGURE 3

FIGURE 4

5.3 Openings

The structural arrangements and details are to be in accordance with Section 3-2-6. In general, major openings such as doors, hatches, and large vent ducts are to be avoided in the hull in close proximity to the gunwale. Corners of openings in strength structures are to have generous radii. Compensation may be required for openings.

5.5 Brackets

5.5.1 Steel Brackets

Where brackets are fitted having thicknesses as required by 3-1-2/5.5.2 TABLE 5A and faces at approximately 45 degrees with the bulkhead deck or shell, and the bracket is supported by a bulkhead, deck or shell structural member, the length of each member, \( \ell \), may be measured at a point 25% of the extent of the bracket beyond the toe of the bracket as shown in 3-1-2/5.5.2 FIGURE 5. The minimum overlap of the bracket arm along the stiffener is not to be less than obtained from the following equation:

\[
x = 1.4y + 30 \text{ mm}
\]

\[
x = 1.4y + 2 \text{ in.}
\]
where

\[ x = \text{length of overlap along stiffener, in mm (in.)} \]
\[ y = \text{depth of stiffener, in mm (in.)} \]

Where a bracket laps a member, the amount of overlap generally is to be 25.5 mm (1 in.).

### 5.5.2 Aluminum Brackets

Aluminum brackets are to comply with 3-1-2/5.5.1 except that the thicknesses given in 3-1-2/5.5.2 TABLE 5B are to be multiplied by 1.45 for the same length of face.

**TABLE 5A**  
Brackets (Steel)

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Length of Face, ( f ), mm</th>
<th>Millimeters</th>
<th>Width of Flange, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain</td>
<td>Not exceeding 305</td>
<td>5.0</td>
<td>—</td>
</tr>
<tr>
<td>Flanged</td>
<td></td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Over 305 to 455</td>
<td>6.5</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>Over 455 to 660</td>
<td>8.0</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>Over 660 to 915</td>
<td>11.0</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td>Over 915 to 1370</td>
<td>14.0</td>
<td>9.5</td>
</tr>
</tbody>
</table>

**FIGURE 5**  
Bracket
### Thickness

<table>
<thead>
<tr>
<th>Length of Face, f, mm</th>
<th>Inches</th>
<th>Width of Flange, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Plain</td>
</tr>
<tr>
<td>Not exceeding 12</td>
<td>$\frac{3}{16}$</td>
<td>—</td>
</tr>
<tr>
<td>Over 12 to 18</td>
<td>$\frac{1}{4}$</td>
<td>$\frac{3}{16}$</td>
</tr>
<tr>
<td>Over 18 to 26</td>
<td>$\frac{5}{16}$</td>
<td>$\frac{1}{4}$</td>
</tr>
<tr>
<td>Over 26 to 36</td>
<td>$\frac{7}{16}$</td>
<td>$\frac{5}{16}$</td>
</tr>
<tr>
<td>Over 36 to 54</td>
<td>$\frac{9}{16}$</td>
<td>$\frac{3}{8}$</td>
</tr>
</tbody>
</table>

#### TABLE 5B
Brackets (Aluminum)

<table>
<thead>
<tr>
<th>Length of Face, f, mm</th>
<th>Millimeters</th>
<th>Width of Flange, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plain</td>
<td>Flanged</td>
</tr>
<tr>
<td>Not exceeding 305</td>
<td>7.0</td>
<td>—</td>
</tr>
<tr>
<td>Over 305 to 455</td>
<td>9.5</td>
<td>7.0</td>
</tr>
<tr>
<td>Over 455 to 660</td>
<td>11.5</td>
<td>9.5</td>
</tr>
<tr>
<td>Over 660 to 915</td>
<td>16.0</td>
<td>11.5</td>
</tr>
<tr>
<td>Over 915 to 1370</td>
<td>20.0</td>
<td>13.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Length of Face, f, mm</th>
<th>Inches</th>
<th>Width of Flange, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Plain</td>
</tr>
<tr>
<td>Not exceeding 12</td>
<td>$\frac{1}{4}$</td>
<td>—</td>
</tr>
<tr>
<td>Over 12 to 18</td>
<td>$\frac{3}{8}$</td>
<td>$\frac{1}{4}$</td>
</tr>
<tr>
<td>Over 18 to 26</td>
<td>$\frac{7}{16}$</td>
<td>$\frac{3}{8}$</td>
</tr>
<tr>
<td>Over 26 to 36</td>
<td>$\frac{5}{8}$</td>
<td>$\frac{7}{16}$</td>
</tr>
<tr>
<td>Over 36 to 54</td>
<td>$1\frac{3}{8}$</td>
<td>$\frac{9}{16}$</td>
</tr>
</tbody>
</table>

#### 5.7 Structural Design Details

The designer is to give consideration to the following:

5.7.1

The thickness of internals in locations susceptible to rapid corrosion.

5.7.2

The proportions of built-up members to comply with established standards for buckling strength.
5.7.3 (1 July 2021)
The design of structural details such as noted below, against the harmful effects of stress concentrations and notches:

i) Details of the ends, the intersections of members and associated brackets

ii) Shape and location of air, drainage or lightening holes

iii) Shape and reinforcement of slots or cutouts for internals

iv) Elimination or closing of weld scallops in way of butts, “softening” of bracket toes, reducing abrupt changes of section or structural discontinuities

v) Details of welding sequence for local members to minimize heat input, residual stress, and distortion

vi) Details of hull fabrication sequence

vii) Weld details are to minimize excessive weld reinforcement (excess weld metal introduces a stress concentration point). Maximum Weld Reinforcement is \( R_{\text{max}} = 2.5 \text{ mm (0.01 in.)} \) for material thickness \( (t) \leq 10 \text{ mm (0.4 in.).} \)

5.7.4
Proportions and thickness of structural members to reduce fatigue response due to engine, propeller or wave-induced cyclic stresses, particularly for higher-strength steels.

Standard construction details based on the above considerations are to be indicated on the plans or in a booklet submitted for review and comment.

5.9 Termination of Structural Members
Unless permitted elsewhere in these Rules, structural members are to be effectively connected to the adjacent structures in such a manner to avoid hard spots, notches and other harmful stress concentrations. Where members are lightly loaded and not required to be attached at their ends, special attention is to be given to the end taper, by using soft-toed concave brackets or by a sniped end of not more than 30°. Bracket toes or sniped ends are to be kept within 25 mm (1.0 in.) of the adjacent member and the depth at the toe or snipe end is generally not to exceed 15 mm (0.60 in.). Where a strength deck or shell longitudinal terminates without end attachment, it is to extend into the adjacent transversely framed structure or stop at a local transverse member fitted at about one transverse frame space beyond the last floor or web that supports the longitudinal.

7 Effective Width of Plating
The section modulus and moment of inertia of stiffening members are provided by the member and a portion of the plating to which it is attached. The effective width is as given in the following paragraphs. The section modulus and moment of inertia of a shape, bar, fabricated section, or laid-up member not attached to plating is that of the member only.

7.1 FRP Laminates
Where the plating is an FRP single-skin laminate, the maximum effective width of plating for floors, frames, beams and bulkhead stiffeners is not to exceed either the stiffening member spacing or the width obtained from the following equation, whichever is less. See 3-1-2/7.1 FIGURE 6.

\[ w = 18t + b \]

where:
\[ w = \text{effective width of plating, in mm (in.)} \]
\[ t = \text{thickness of single skin plating, in mm (in.)} \]
\[ b = \text{net width of stiffening member, in mm (in.), but not more than } 18t \]

Where the plating is an FRP sandwich laminate with a flexurally and compressively ineffective (balsa, cross linked PVC, or linear polymer) core, \( t \) in the above equation is the thickness of a single skin laminate having the same moment of inertia per unit width as the two skins of the sandwich about the neutral axis of the sandwich, excluding the core.

For a stiffening member along an opening, the maximum effective width of plating is equal to either one-half the stiffening member spacing or the width obtained from the following equation, whichever is less.

\[ w = 9t + b \]

where \( w, t \) and \( b \) are as defined above.

**FIGURE 6**

Effective Width of FRP Plating

7.3 Steel and Aluminum Plating

7.3.1 Primary Structural Members

The effective width of plating for deep supporting members is to equal to the lesser of either one half the sum of spacing on each side of the member, 0.33 time the unsupported span, \( \ell \), or 750 mm (30 in.). For girders and webs along hatch openings, the effective width of plating is to be half of that obtained from the above. Due account is to be taken in regards to plate buckling, see 3-2-3/1.1.

7.3.2 All Other Structural Members

The maximum effective width of plating is equal to either one-half the sum of spacing on each side of the member or the width obtained from the following equation, whichever is less.

Steel Members \[ w = 80t \]
Aluminum Members \[ w = 60t \]

where

\[ w = \text{effective width of plating, in mm (in.)} \]
\[ t = \text{thickness of single skin plating, in mm (in.)} \]
For a stiffening member along an opening, the maximum effective width of plating is one-half of the effective width given above.

9 Hull Construction Monitoring Plan (1 July 2022)

The structural strength criteria specified in the ABS Rules are used by designers to establish acceptable scantlings, in order that a vessel constructed to such standards and properly maintained will have adequate durability and capability to resist the failure modes of yielding, buckling, and fatigue.

The application of this Section and other review techniques to assess a design also gives the designer and ABS the ability to identify areas that are considered critical to satisfactory in-service performance.

Knowing that the actual structural performance is also a function of construction methods and standards, it is prudent to identify "critical" areas, particularly those approaching design limits, and use appropriate specified construction quality standards and associated construction monitoring and reporting methods, to limit the risk of unsatisfactory in-service performance.

9.1 Applicability

The Construction Monitoring Plan (CMP) is applicable to vessels that require direct analysis as per Section 1-1-4 of the ABS Rules for Conditions of Classification – Light and High-Speed Craft (Part I).

9.3 Critical Areas

The term "critical area" is defined as an area within the structure that may have a higher probability of failure during the life of the vessel compared to the surrounding areas, even though it may have been modified in the interest of reducing such probability. The higher probability of failure can be a result of stress concentrations, high stress levels, and high stress ranges due to loading patterns, structural discontinuities, corrosion prone environment, or a combination of these factors.

In order to provide an even greater probability of satisfactory in-service performance, the areas that are approaching the acceptance criteria can be identified so that additional attention may be paid during fabrication.

The objective of heightened scrutiny of building tolerance and monitoring in way of the critical areas is to minimize the effect of stress increases incurred as a result of the construction process. Improper alignment and fabrication tolerances may be potentially influential in creating construction-related stress.

9.5 Determination of Critical Areas

Critical areas are to be determined by the following procedures.

9.5.1 Rule- and Experienced-based Critical Areas

The critical areas are to be identified based on the Rules and previous service experiences:

i) Input from ABS, owners, designers, and/or shipyards based on previous in-service experience from similar vessels, such as locations sensitive to cracking, buckling, or corrosion that could impair the structural integrity of the vessel.

ii) Details where fabrication is difficult, such as blind alignment, complexity of structural details and shape, limited access, etc.

9.5.2 Design-specific Critical Areas

While a Rule or experience-based critical area may be identified to a generic location, the design critical area is to be identified to a very specific location based on the engineering analysis. This information will be used to provide an enhanced degree of granularity with respect to the survey and inspection of the specific design and also to help guide the Surveyor towards the areas where additional attention is warranted.
A critical area is determined through the structural analysis based on the following criteria:

1) The calculated von-Mises stress greater than 0.9 of the allowable stress (i.e., UC ≥ 0.9) based on fine mesh analysis in terms of the yielding strength criteria as specified in 3-1-3/11.3.

2) The calculated fatigue life (FL) less than 1.25 times the target fatigue life (TFL) (i.e., FL ≤ 1.25 x TFL) based on the local fine mesh fatigue analysis.

Special attention is to be paid to locations where weld improvements with means of toe grinding and weld profiling, etc., are to be made to meet the fine-mesh fatigue design criteria. This special location is to be identified with a special mark on the structural critical area plan.

9.7 Hull Construction Monitoring Plan

A Hull Construction Monitoring Plan for critical areas is to be prepared by the shipyard and submitted for approval prior to the start of fabrication. The plan is to include:

1) Structural drawings indicating the location of critical areas as identified by the ABS review
2) Construction standards and control procedures to be applied
3) Verification and recording procedures at each stage of construction
4) Procedures for defect correction
5) Additional requirements specified in 3-6-3/1.1 of these Rules

An approved copy of the Construction Monitoring Plan is to be placed on board the vessel.

11 Fatigue Strength Assessment (1 July 2022)

Fatigue analyses are required for the applicable vessels indicated in 1-1-4/5 Table 2 of the ABS Rules for Conditions of Classification – Light and High-Speed Craft (Part 1) to demonstrate the adequacy of the structural design. The simplified approach provided in Appendix 3-2-A4 of these Rules or the spectral fatigue analysis (SFA) provided in the ABS Guide for Spectral-Based Fatigue Analysis for Vessels is to be used to comply with fatigue strength assessment.
1 **General (1 July 2021)**

This section applies for both high speed and non-high-speed vessels.

This Section states requirements for a variety of direct analysis methods that can be used in lieu of or in conjunction with the specific requirements given in Sections 3-2-1, 3-2-2, 3-2-3, and 3-2-4 or to meet the requirements in 1-1-4/5. If the structure of the vessel complies with 3-1-3/3.5, 3-1-3/5.3, 3-1-3/7.1.2, 3-1-3/7.3, 3-1-3/9.1, 3-1-3/9.3.3, and 3-1-3/11.3 of this section and the requirements in Sections 3-2-1, 3-2-2, 3-2-3, and 3-2-4 it will be eligible to receive the SH-DLA Class Notation. For guidance on the SH-DLA class notation not given in this Section, see the ABS Guidance Notes on Structural Direct Analysis for High-Speed Craft.

3 **Loading Conditions**

3.1 **General**

The loading conditions considered are to include all intended operational conditions of the vessel as specified by the Naval Administration. These operating conditions are to be defined by significant wave height, wave period, and maximum operating speed. 3-1-3/3.1 Sea States is to be used when the significant wave height is given in terms of Sea States. When the wave period is not given, the most probable modal period is to be used in the analysis.

### Sea States

<table>
<thead>
<tr>
<th>Sea State</th>
<th>Significant Wave Height m (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>0.10 (0.3)</td>
</tr>
<tr>
<td>2</td>
<td>0.50 (1.6)</td>
</tr>
<tr>
<td>3</td>
<td>1.25 (4.1)</td>
</tr>
<tr>
<td>4</td>
<td>2.5 (8.2)</td>
</tr>
<tr>
<td>5</td>
<td>4 (13.1)</td>
</tr>
<tr>
<td>6</td>
<td>6 (19.7)</td>
</tr>
<tr>
<td>7</td>
<td>9 (29.5)</td>
</tr>
</tbody>
</table>
3.3  Environmental and Service Conditions

3.3.1  General

The environmental condition is anticipated to be described by appropriate sets of wave data. The sources and reliability of this data are to be submitted. The wave parameters used in the analysis are to be selected and documented based on the conditions given in the vessel specification. If these parameters are to be used in conjunction with the requirements in 3-1-3/3.5, 3-1-3/5.3, 3-1-3/7.1.2, 3-1-3/7.3, 3-1-3/9.1, 3-1-3/9.3.3, and 3-1-3/11.3, then they are to be compatible with the stochastic response and extreme value prediction methods.

3.3.2  Types of Wave Spectra

3.3.2(a) Deep-water Ocean Waves.

Two-parameter spectra, such as the Bretschneider or PM wave spectral formulations, are to be used. If the swell and wave components are known to interact, a bi-modal Ochi-Hubble spectrum is to be used. Directional spreading appropriate to coastal conditions is also to be applied.

3.3.2(b) Shallow-water Waves.

Wave conditions that include the effects of bathymetry, wind field, coastal contours of the region are to be used. For fetch-limited sea conditions, JONSWAP spectrum or a modified version of the spectrum is to be used.

3.5  Loading Conditions for Direct Analysis

3.5.1  Dominant Load Parameters

A list of Dominant Load Parameters (DLP) is to be developed. This will include select motion and load effect parameters. Other loads, such as those due to wave impacts on the bow and stern, flare and bottom slamming, wet-deck slamming (multi-hulls) and vibration effects on local structural strength, have to be treated separately. Considerations for slamming analysis are given in 3-1-3/3.5.7.

3.5.2  Load Cases

Load cases are defined by a combination of vessel loading conditions, a set of global motion and load effect parameters set forth in terms of each of the DLPs, other load components accompanying the DLPs and an equivalent wave system for the specified DLP. Justification for load cases selected for use in the structural analysis is to be submitted to ABS for review.

3.5.3  Analyses of Ship Motions, Wave Loads, and Extreme Values

Calculations are to be made using the spectral analysis-based approach, which by definition relies on the use of Response Amplitude Operators (RAOs). Each RAO is to be calculated for regular waves of unit amplitude for a range of wave frequencies and wave headings that will be given below.

3.5.4  Essential Features of Spectral Analysis of Motions and Loads

3.5.4(a) General Modeling Considerations. (1 July 2022)

The model of the hull is to include the masses of all equipment, vehicles and supporting structure. There is also to be sufficient compatibility between the hydrodynamic and structural models so that the application of fluid pressures onto the finite element mesh of the structural model can be done appropriately. If ride control systems exist to reduce a DLP(s), it is required to include the
systems in the motion and load analysis, as fixed at their neutral positions. The active controls of the RCS, to further improve the motions or loads, will be given special consideration by ABS.

For the load component types and structural responses of primary interest, software formulations derived from linear idealizations are deemed to be sufficient. The capabilities and limitations of the software are to be known, and in cases where the software is not known to ABS, it may be necessary to demonstrate the adequacy of the software.

3.5.4(b) Diffraction-Radiation Methods.
Computations of the wave-induced motions and loads are to be carried out through the application of seakeeping analysis codes utilizing three-dimensional potential flow based diffraction-radiation theory. Computation of the hydrodynamic pressures is to take account of, as a minimum, all six degree-of-freedom rigid-body motions of the hull. These codes may be based either on linear (small) wave and motion amplitude assumptions or nonlinear (large) amplitude motion and wave formulations.

3.5.4(c) Panel Model Development.
The Rankine source panel method is recommended for solving the hydrodynamic boundary value problem.

3.5.4(d) Motion and Load-Effect Response Amplitude Operators. (1 July 2022)
For each loading condition, RAOs of all the selected DLPs are to be calculated. The RAOs are to represent the pertinent range of wave headings ($\beta$), in increments not exceeding 15 degrees. A range of wave frequencies is to be considered based on the route-specific wave conditions (see 3-1-3/3.3). The nominal range is 0.2 rad/s to 1.8 rad/s in increments of 0.05 rad/s for monohulls. For multi-hull vessels, 0.05 rad/s to 2.0 rad/s in increments of 0.05 rad/s is recommended.

The worst frequency-heading ($\omega$, $\beta$) combination is to be determined from an examination of the RAOs for each DLP. Only the heading $\beta_{max}$ and the wave frequency $\omega_e$ at which the RAO of the DLP is a maximum, need to be used in DLA or direct analysis.

3.5.5 Extreme Values Analysis
Extreme value analysis is to be performed for each DLP to determine the maximum values. An extreme value method that follows the so-called long-term approach is to be used. The use of a validated short-term extreme value approach, which is appropriate to the vessel type and route-specific environmental data, will also be considered. The supplementary use of such a short-term approach to confirm or test the sensitivity of the long-term based design values is recommended.

The relevant value to be obtained from the long-term response analysis is the most probable extreme value (MPEV) having a probability of level of $10^{-8}$ in terms of wave encounters.

3.5.6 Equivalent Wave
For each load case, an equivalent wave is to be determined which simulates the magnitude and location of the extreme value of the dominant load component of the load case.

The amplitude of the equivalent wave is to be determined using the extreme values of the DLP (see 3-1-3/3.5.4) and the RAO of that DLP occurring at the wave frequency and wave heading corresponding to the maximum amplitude (peak) of the RAO. The amplitude of the equivalent wave is given by:

$$a_{wj} = \frac{MPEV_j}{MaxRAO_j}$$

where
aa_{wj} \quad = \quad \text{wave amplitude}

MPEV_{j} \quad = \quad \text{Most Probable Extreme Value of the } j^{th} \text{ DLP at a probability level equivalent to the design criterion}

MaxRAO_{j} \quad = \quad \text{maximum amplitude of the } j^{th} \text{ DLP's RAO}

3.5.7 Slamming Loads

Loads due to slamming and wave impact on vessel hulls are categorized into global slamming effects and local slam-induced structural response.

3.5.7(a) Global Slamming Effects.

The simplified formulae given in Section 3-2-1 may be used to account for global slamming effects in the preliminary design stage. For detailed analysis, a direct time-domain simulation involving short-term predictions are to be used for the global strength assessment of monohulls. In most cases involving high speeds, the absolute motions or relative motions will be of such large amplitude that nonlinear calculations will be required. In catamarans, wet deck slam-induced global whipping effects of the hull is to be assessed using methods that account for coupling of the symmetric and anti-symmetric modes of responses. These calculations will require time-domain analysis methods.

3.5.7(b) Local Impact Loads.

Panel structures with horizontal flat or nearly flat surfaces such as a wet deck of a multi-hull craft will need to be hydroelastically modeled, where in the dynamics of the fluid and the elastic response of the plate and stiffeners are simultaneously modeled.

5 Motion Predictions

5.1 Model Testing

Vessel hull motions and accelerations obtained from scale model tests may be used to validate motions predicted by computer programs. Model testing is required to be performed and reported to ABS when loads are being submitted in lieu of the loads determined in Section 3-2-2 or other loads determined by ABS. This paragraph is to be complied with when model testing is required by the Naval Administration. The model is to accurately represent the structure that is to be built in both principal particulars and hull geometry.

5.1.1 Testing Program

The model is to be tested over a range of speeds, headings, and wave characteristics (height, length, and period), as indicated by the Naval Administration. When this is not specified, the testing program is to include the following:

5.1.1(a) Speeds.

The model is to be tested at the minimum speed required by the Naval Administration and the maximum achievable speed of the vessel for a particular wave profile and heading.

5.1.1(b) Headings.

The model is to be tested in head, beam, quartering, and following seas.

5.1.1(c) Wave Parameters.

The model is to be tested in both deep water and shallow water wave conditions. These are defined in 3-1-3/3.3.2. For vessels that are limited to operation in coastal regions (Coastal Naval Craft and Riverine Naval Craft), deep water wave profile testing is not required.
5.1.2 Model Measurements and Reporting

The parameters listed below are to be measured and reported based on the model test program. Some of the parameters listed may be derived through statistical analysis of measured data obtained from testing. When statistical analysis is used, the methods of analysis employed are to be indicated in the report.

5.1.2(a) Vertical or Heave Acceleration.

The significant, $1/10$th highest, or $1/100$th highest vertical acceleration at the longitudinal center of gravity, bow, and stern are to be reported. The accelerometer is to be adjusted such that the acceleration due to gravity is not measured. The $1/100$th highest vertical acceleration at the longitudinal center of gravity may be used in place of $n_{cg}$ in 3-2-2/1 and 3-2-2/3.

5.1.2(b) Roll Acceleration.

The significant roll acceleration about a longitudinal axis through the center of gravity and the maximum roll angle are to be reported.

5.1.2(c) Pitch Angle and Acceleration.

The significant coupled pitch-and-heave acceleration at the bow and the stern and the maximum pitch angle are to be reported.

5.3 Accelerations from Direct Analysis

5.3.1 General

The wave-induced vessel motions may be determined by direct analysis. When this analysis is not performed by ABS, it is to be verified by model testing as indicated in 3-1-3/5.3.

5.3.2 Global Accelerations

Global accelerations are to be determined using the loading conditions indicated in 3-1-3/3.5 above. The $1/100$th highest vertical (heave) acceleration at the longitudinal center of gravity may be used in place of $n_{cg}$ in Sections 3-2-1 and 3-2-2.

5.3.3 Local Accelerations

Local accelerations at points where the lightship weight of the structure, (non-liquid cargo), are located, including deck-mounted equipment, are to be calculated to determine the inertia loads. For vehicle decks, wheel loading is to be applied. An evenly distributed load equivalent to the weight of the vehicles may be used. The acceleration RAO at a location of interest is to be calculated to account for all translational and rotational components of motions.

The components of the gravitational acceleration in the vessel’s coordinate system are to be included.

7 Load Predictions

7.1 Global Loads

As a minimum, the still-water hogging and sagging moments and shear forces, the wave-induced hogging and sagging moments and shear forces and the slam-induced moments and shear force, are to be determined for monohull vessels. Multi-hulled craft are to have the transverse bending moment, the torsional (or pitch connecting) moment and the transverse shear force determined in addition to the moments and shear forces determined for monohull vessels. These loads are to be reported so that they can be used in conjunction with the requirements in 3-1-3/9 or Section 3-2-1.

7.1.1 Computation of Global Load Effects

7.1.1(a) Still-water Bending Moment and Shear Force
The still-water bending moments and shear forces are to be calculated in the light load, half load, and full load conditions. The light load condition consists of all components of the vessel (structure, machinery, piping equipment, outfitting, wiring, interiors, paint, etc.) plus 10% of tank and cargo capacity. The half load condition is to include all components of the vessel plus 50% of the tank and cargo capacity. The full load condition consists of all components of the vessel plus 100% of the tank and cargo capacity. The distribution of the load is to capture all major weight discontinuities, and no single weight distribution segment is to be greater than 0.20L.

7.1.1(b) Wave-Induced Longitudinal Bending Moment and Shear Force
The wave-induced bending moments and shear forces can be determined by using the environmental conditions outlined in 3-1-3/3.3.

7.1.1(c) Transverse Bending Moment and Shear Force – Multi-hulled Craft
The transverse bending moment and shear force may be determined by distributing the weights and loads athwartships across the craft and using the environmental conditions outlined in 3-1-3/3.3.

7.1.1(d) Torsion Bending Moment
The torsional bending moment may be determined by distributing the weights and loads on segments of the hull sliced at a 45° angle from centerline and using the environmental conditions outlined in 3-1-3/3.3.

7.1.1(e) Slamming Induced Bending Moment and Shear Force
The slam induced bending moment and shear force may be calculated by applying the acceleration determined in 3-1-3/5 or in 3-2-2/1 to the lumped masses developed for 3-1-3/7.1.1(a).

7.1.2 Global Loads from Computations
Global loads from computer software programs are to be developed by loading the structure as outlined in 3-1-3/3.5. The computer program is to be capable of determining the moments and shear forces in 3-1-3/7.1 or developing loads that can be used in conjunction with finite element methods as outlined in 3-1-3/9.1.

7.3 Local Loads
Loads that differ from the pressure loads developed in Section 3-2-2 may be used to determine the required scantlings in conjunction with the requirements in 3-1-3/9.3 or Sections 3-2-3 and 3-2-4. These loads are to be developed under the loading conditions in 3-1-3/3 and the following subparagraphs.

7.3.1 External Hydrodynamic Pressure
The hydrodynamic pressures at selected points on the external contours of the hull sections, are to be calculated in regular waves.

7.3.1(a) External Pressure Components.
The total hydrodynamic pressure is to include the pressure components due to waves and the components due to vessel motion. Components of the hydrodynamic pressure are to be calculated from the panel model analysis of 3-1-3/3.5.3.

7.3.1(b) Pressures Accompanying the Dominant Load Parameter and Their Distribution.
The external pressure is to be calculated either as a complex number or in terms of the amplitude and phase. Then, ‘simultaneously’ acting pressures over the wetted surface can be represented in the form:

\[ P = (A)(a_{\omega})\sin(\omega_{\epsilon} t + \epsilon_t) \]

where
\[ P = \text{simultaneous pressure} \]
\[ A = \text{amplitude of the pressure RAO} \]
\[ a_w = \text{equivalent wave amplitude} \]
\[ \omega_e = \text{frequency of the equivalent wave when the RAO of the dominant load component of the load case reaches its maximum} \]
\[ t = \text{time under consideration.} \]
\[ \varepsilon_l = \text{phase angle of the (other) load component’s RAO} \]

7.3.1(c) Pressure Loading for Finite Element Models.
The hydrodynamic pressure can be linearly interpolated to obtain the nodal pressures for the finite element models required for structural analysis.

7.3.1(d) Pressure Loading for Rule Requirements.
For pressures that are to be used in conjunction with the requirements in Sections 3-2-3 and 3-2-4 for determining the local scantlings, the hydrodynamic pressures are to be resolved into kN/m² (tf/m², psi).

7.3.2 Internal Tank Pressure
Liquid pressures in the cargo tanks are to be calculated and applied to the structural model used in finite element analysis. Both static and dynamic pressures are to be included in the analysis, assuming that there is no relative motion between the tank and the contained fluid.

7.3.2(a) Pressure Components.
The internal tank pressure is to account for both the quasi-static and motion-induced (dynamic) pressure components. The quasi-static component results from gravity and is to include vessel roll and pitch rotations. The dynamic component is to be developed from the accelerations in the liquid at the tank boundary caused by the hull’s motions in six degrees of freedom. These are to be obtained from motion analysis as specified in 3-1-3/3.

The total instantaneous internal tank pressure for each of the tank boundary points is to be calculated by combining the inertial and quasi-static components as follows:

\[ p = p_o + \rho h_t \left[ (g_x + a_x)^2 + (g_y + a_y)^2 + (g_z + a_z)^2 \right]^{1/2} \]

where

\[ P = \text{total instantaneous internal tank pressure at a tank boundary point} \]
\[ p_o = \text{vapor pressure or the relief valve pressure setting} \]
\[ \rho = \text{fluid density, cargo or ballast} \]
\[ h_t = \text{total pressure head defined by the height of the projected fluid column in the direction of the total instantaneous acceleration vector} \]
\[ a_{x,y,z} = \text{longitudinal, lateral, and vertical wave-induced accelerations relative to the vessel’s axis system at a point on a tank’s boundary} \]
\[ g_{x,y,z} = \text{longitudinal, lateral, and vertical components of gravitational accelerations relative to the vessel’s axis system at a tank boundary point} \]

7.3.2(b) Roll and Pitch Motions.
The influence of ship motions on tank pressures is to be taken into account using the maximum pitch and roll angles. As reflected in the previous formulations, the inclination of the tank due to
vessel roll and pitch is to be considered in the calculation of the hydrostatic pressure. The
direction of gravitational forces in the ship-fixed coordinate system varies with roll and pitch,
resulting in a change in pressure head and a corresponding change in the static pressure.

7.3.2(c) Simultaneously Acting Tank Pressure.
At each wave condition, for each load case described in 3-1-3/3.5, simultaneously acting tank
pressures (quasi-static and dynamic) are to be calculated. Each wave condition is defined by wave
amplitude, frequency, heading angle and wave crest position, as explained in 3-1-3/3.5. Using the
wave amplitude and phase angle determined based on the RAO of a DLP, the simultaneously
acting tank pressure is to be calculated for the instant when the maximum value of the DLP
occurs. These internal tank pressures are to be used in the structural finite element model.

7.3.3 Inertia Force of Lumped Structural Mass
The inertia force, or point load, of a structural mass, such as deck equipment or cargo, can be
determined by the following equation:

\[ F = m(A_t) \]

where

\[ F \] = inertial load of the item

\[ m \] = mass of the lumped weight of the structural member

\[ A_t \] = amplitude of the acceleration RAO

For finite element models, the inertia forces in three (global) directions are to be calculated and
applied. For a first-principles analysis, the inertia force in the vertical direction is to be calculated
and applied.

7.3.4 Loads on Ride Control Systems (RCS) (1 July 2022)
The RCS (control fins) will experience a hydrodynamic force when moving in the water, which
will affect the motions and loads of the craft. These loads consist of two components - lift and
drag. The lift, \( F_L \), in kN (tf), is perpendicular to the flow direction and can be determined by the
following equation:

\[ F_L = \frac{1}{2} \rho C_L A U^2 \]

where

\[ \rho \] = density of sea water, in t/m\(^3\) (Lt/ft\(^3\))

\[ C_L \] = lift coefficient of the fin

\[ A \] = total projected area of the fin, in m\(^2\) (ft\(^2\))

\[ U \] = flow velocity, in m/s (ft/s)

The drag, \( F_D \), in kN (tf), is parallel to the flow direction and can be determined by the following
equation:

\[ F_D = \frac{1}{2} \rho C_D A U^2 \]

where
ρ = density of sea water, in t/m³ (Lt/ft³)

C_D = drag coefficient of the fin

A = total projected area of the fin, in m² (ft²)

U = flow velocity, in m/s (ft/s)

The details of the fin characteristics, including the lift and drag coefficients, are to be provided by the vendor.

9 Structural Response

9.1 Global Response

The global bending moments developed in 3-1-3/7.1 can either be applied to the requirements in 3-2-1/1.1.2(e), 3-2-1/1.5, 3-2-1/1.9.4, and 3-2-1/3.5 or to a global finite element model as outlined in this paragraph.

9.1.1 General

The load cases of 3-1-3/3.5 are to be applied to the global structural analysis model described in 3-1-3/9.1.4. Each load case is to include the hydrostatic and still-water load components that have not otherwise been directly included in the load component determination performed in accordance with 3-1-3/7.3.1 and 3-1-3/7.3.3. These hydrostatic or still-water components are to be included in the hydrostatics analysis.

9.1.2 Equilibrium Check

The model of the hull girder structure is to be close to equilibrium when all the loads (static and dynamic) are applied.

The unbalanced forces in the model’s global axis system for each load case need to be determined and resolved. The magnitudes of the unbalanced forces, and the procedure used to balance the structural model in equilibrium is to be fully documented.

9.1.3 General Modeling Considerations

To the maximum extent practicable, the overall model of the hull structure is to comprise the entire hull. There is also to be sufficient compatibility between the hydrodynamic and structural models so that the application of fluid pressures onto the finite element mesh of the structural model can be done appropriately.

For the load component types and structural responses of primary interest, analysis software formulations derived from linear idealizations are sufficient. Enhanced bases of analysis may be required so that non-linear loads, such as hull slamming, may be required. The adequacy of the selected software is to be demonstrated to the satisfaction of ABS.

The results of overall (global) model analysis are to be directly employed in the creation and analysis of the required finer mesh, local structural models. Appropriate boundary conditions determined in the larger scale model are to be imposed onto the local models for appropriate structural continuity and load transfer between the various levels of models.

9.1.4 Analysis of the Global Hull Structure

The global structural and load model is to be as detailed and complete as possible. The stress results of the global model are used only to assess the hull girder plating of the deck (and wet deck for multi-hulled craft), side shell, bottom, inner bottom, longitudinal bulkheads, transverse bulkheads and stools or deck box girders. The main supporting members of the hull girder may be
evaluated using 2-D fine-mesh local models. In developing the 3-D global finite element model, the following requirements apply:

\( i \) The finite element model is to include all primary load-carrying members. Secondary structural members which may affect the overall load distribution are also to be included.

\( ii \) Structural idealization is to be based on the stiffness and anticipated response of the structure, not wholly on the geometry of the structure itself.

\( iii \) The relative stiffness between associated structural members and their anticipated response under the specified loading is to be considered.

\( iv \) A judicious selection of nodes, elements, and degrees of freedom is to be made to represent the stiffness and mass properties of the hull, while keeping the size of the model and required data generation within manageable limits. Lumping of plating stiffeners, use of equivalent plate thickness, and other techniques may be used for this purpose.

\( v \) The finite elements, whose geometry, configuration, and stiffness closely approximate the actual structure, can typically be of three types:

- Truss or bar elements with axial stiffness only
- Beam elements with axial, shear, and bending stiffness
- Membrane plate elements, either triangular or quadrilateral.

\( vi \) When possible, the finite element structure is to be based on the use of gross or as-built scantlings.

### 9.3 Local Response

The local loads developed in 3-1-3/7.3 may be used in conjunction with the scantling requirements in Sections 3-2-3 and 3-2-4. For local structure that forms a grillage, or that is arranged in a manner not indicative of the principles given in the other Sections of these Rules, or structure that is being examined in conjunction with a finite element analysis may be reviewed using the following:

#### 9.3.1 Non-Prismatic Beam Analysis

Beams that do not have uniform cross-sections may be analyzed using a non-prismatic beam program. The adequacy of the selected software is to be demonstrated to the satisfaction of ABS. In developing the non-prismatic beam model, the following requirements apply:

\( i \) The program is to be capable of calculating the shear and bending moment at all locations along the length of the beam.

\( ii \) Section properties of the beam are to be inputted into the program to resemble the actual construction of the beam and are to have a maximum segment length of 300 mm (1 foot).

\( iii \) The loads for the beam may be derived from Section 3-2-2 or 3-1-3/7.

\( iv \) The boundary conditions of the beam are to reflect the structural arrangement.

#### 9.3.2 Grillage or Plane Frame Analysis

Structure that forms a grillage, or an area of structure that is arranged in a manner that is different from the principles of these Rules, may be analyzed using a grillage or plane frame analysis program. The adequacy of the selected software is to be demonstrated to the satisfaction of ABS. In developing the grillage or plane frame model, the following requirements apply:

\( i \) The beam elements in the model are to be arranged to reflect all of the structure in the area under consideration.

\( ii \) The program is to be capable of applying off-axis loads to the elements and nodes.
iii) The program is to be capable of calculating and reporting the bending moments and shear forces at each node.

iv) The loads for the model may be derived from Section 3-2-2 or 3-1-3/7.

v) The boundary conditions of the model are to reflect the structural arrangement. Boundary conditions that model symmetry will be specially considered.

### 9.3.3 Local Fine Mesh Model from Global 3-D Model

Detailed local stresses are to be determined by fine mesh FEM analysis of local structures, based on the results of the global 3-D analysis.

The requirements for developing the 3-D coarse mesh global model in 3-1-3/9.3.4 are also applicable to the development of the 2-D fine-mesh models. In developing the 2-D fine mesh model, the following requirements apply:

i) The mesh size of the 2-D finite element model are to be determined by adequately modeling the stiffness of the individual structural members forming the local structure.

ii) In modeling a local transverse structure, the web plating is modeled by membrane plates, using both quadrilateral and triangular elements. Stiffeners on the web plating, such as panel breakers, tripping brackets, flat bar stiffeners, etc., and the face plates of the webs are modeled by rod elements of equivalent cross sectional areas. Where face plates on brackets are tapered at the ends, the area of the rod elements is to be reduced accordingly. The out-of-plane hull girder plating (i.e., deck, side shell, bottom shell, girders, etc.) is also to be modeled by rod elements, using an appropriate effective width.

iii) The mesh size used is to be adequate to represent the overall stiffness of the considered local structure as a whole, such that smooth stress distributions in the structure can be obtained.

iv) Finer meshes are to be used in the probable high stressed areas in order to obtain more accurate stress distributions for these areas. The use of a uniform mesh with smooth transition and with avoidance to abrupt changes in mesh sizes is recommended.

v) In laying out the mesh, the shapes of membrane elements created are to be as regular as possible. The aspect ratios of plate elements are to be kept within 2:1. Elements with an aspect ratio higher than 5:1 may be used for convenience of modeling in way of low stress areas, or areas of low interest.

vi) The grid line spacing and element sizes for the transverse section can be determined by the spacing of the longitudinals on the bottom shell, inner bottom, and topside tank. The grid lines can either be in line with the longitudinals, or for a finer mesh, an additional one division can be added between the longitudinal spacing.

vii) Cutout openings for longitudinals and access holes need not be considered in the 2-D models. This is also applies to all lightening holes or other small openings in the webs.

viii) The stiffeners, panel breakers, and ribs that prevent local buckling that are parallel to the principal direction of stress are to be included in the model.

Boundary displacements obtained from the 3-D global analysis are to be used as boundary conditions in the fine mesh analysis. As applicable, the fine mesh models are to include at least the following local structures:

- A number of transverse web frames
- Centerline longitudinal girder
- Side longitudinal girder
- Horizontal stringers of watertight transverse bulkhead
- Other areas of high stress indicated from the 3-D global analysis.
Where the 3-D global analysis is not comprehensive enough to determine adequately the total stress in the longitudinal plating (e.g., deck and shell) and transverse bulkhead plating of the vessel, additional analyses may be required. Such analyses may not require the performance of fine mesh FEM analysis, where the needed results can be provided by another acceptable method.

**9.3.4 Local Fine Mesh Model without Global 3-D Model**

Structure that forms a grillage or an area of structure that is arranged in a manner different from the principles of these Rules may be analyzed using a local finite element model. The adequacy of the selected software is to be demonstrated to the satisfaction of ABS. In developing the local finite element model, the following requirements apply:

1. The requirements in 3-1-3/9.3.4 are to be applied as applicable.
2. The loads for the model may be derived from Section 3-2-2 or 3-1-3/7.
3. The boundary conditions of the model are to reflect the structural arrangement. Boundary conditions that model symmetry will be specially considered.

**11 Structural Acceptability**

**11.1 Beam, Grillage, or Plane Frame Analysis**

The allowable bending stress for elements in beam, grillage or plane frame models is given in 3-2-4/1.3.1 TABLE 1 or 3-2-4/7 TABLE 2. The allowable shear stress for aluminum and steel elements is \(0.5\tau_y\) (0.75 \(\tau_y\) for bottom primary structures) for bottom primary structures) where \(\tau_y\) is the minimum shear yield strength of the material. For aluminum structure, \(\tau_y\) is to be in the welded condition. The allowable shear stress for composite members is \(0.4\tau_u\), where \(\tau_u\) is the lesser of the ultimate shear strength in either the warp or fill of the web laminate.

**11.3 Finite Element Analysis**

**11.3.1 General**

The adequacy of the finite element analysis results is to be assessed for the failure modes of material yielding and buckling. The requirements in this section are for steel, aluminum and FRP vessels. The acceptance criteria for vessels constructed of other materials will be specially considered.

**11.3.2 Yielding (1 July 2022)**

For a plate element subjected to biaxial stress, a specific combination of stress components, rather than a single maximum normal stress component constitutes the limiting condition. In this regard, the total equivalent stress is to be based on the Hencky von-Mises criterion as the following equation:

\[
\sigma_e = \left[\sigma_x^2 + \sigma_y^2 - \sigma_x\sigma_y + 3\tau_{xy}^2\right]^{1/2}
\]

where

- \(\sigma_x\) = normal stress in the \(x\) coordinate direction of the element
- \(\sigma_y\) = normal stress in the \(y\) coordinate direction of the element
- \(\tau_{xy}\) = in-plane shearing stress

The total equivalent stress (Hencky von-Mises stress) is to be less than or equal to the following design stress for global coarse mesh model:
Steel: \(0.95\sigma_{\text{yield}}\)

Aluminum: \(0.85\sigma_{\text{yield}}\)

FRP: \(0.37\sigma_{\text{yield}}\)

where \(\sigma_{\text{yield}}\) is the yield strength for steel structures or the welded yield strength for aluminum structure, and \(\sigma_u\) is the ultimate tensile or compressive strength of the laminate, whichever is less.

Component stresses \((\sigma_x, \sigma_y, \tau_{\text{max}})\) are to be less than or equal to allowable local structure design stress.

For a solid element, a specific combination of stress components, instead of a single maximum normal stress component constitutes the limiting condition. In this regard, the total equivalent stress is to be based on Hencky von-Mises criterion as the following equation:

\[
\sigma_e = \sqrt{\frac{1}{2} \left[ (\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 \right] + 6 (\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2)}
\]

where

\(\sigma_x = \) normal stress in the \(x\) coordinate direction of the element

\(\sigma_y = \) normal stress in the \(y\) coordinate direction of the element

\(\sigma_z = \) normal stress in the \(z\) coordinate direction of the element

\(\tau_{xy} = \) shear in \(x - y\) plane

\(\tau_{yz} = \) shear in \(y - z\) plane

\(\tau_{zx} = \) shear in \(z - x\) plane

The total equivalent stress (Hencky von-Mises) is to be less than or equal to the following design stress:

Steel: \(0.95\sigma_{\text{yield}}\)

Aluminum: \(0.85\sigma_{\text{yield}}\)

FRP: \(0.37\sigma_{\text{yield}}\)

where \(\sigma_{\text{yield}}\) is the yield strength for steel structures or the welded yield strength for aluminum structure, and \(\sigma_u\) is the ultimate tensile or compressive strength of the laminate, whichever is less.

Component stresses \((\sigma_x, \sigma_y, \sigma_z, \text{and} \tau_{\text{max}})\) are to be less than or equal to allowable local structure design stress.

\(\tau_{\text{max}}\) is the Maximum Shear through the solid element. The Maximum Shear occurs along the principle angle through the element and is not to be confused with the three in-plane shears.

For local fine mesh models and in way of structural discontinuities, the limits specified in 3-1-3/11.3.2 Table 1 are applicable for the specific mesh sizes.
### TABLE 1
Variance of Allowable Hencky von Mises Stresses vs. Mesh Size
*(1 July 2022)*

<table>
<thead>
<tr>
<th>Mesh Size</th>
<th>Stress Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 x Longitudinal Stiffener Spacing (LSS)</td>
<td>$0.95 , S_m \sigma_y$</td>
</tr>
<tr>
<td>1/2 x LSS</td>
<td>$1.00 , S_m \sigma_y$</td>
</tr>
<tr>
<td>1/3 x LSS</td>
<td>$1.05 , S_m \sigma_y$</td>
</tr>
<tr>
<td>1/4 x LSS</td>
<td>$1.10 , S_m \sigma_y$</td>
</tr>
<tr>
<td>1/5 x LSS - 1/10 x LSS</td>
<td>$1.16 , S_m \sigma_y$</td>
</tr>
<tr>
<td>Plate Thickness</td>
<td>$1.25 , S_m \sigma_y$</td>
</tr>
</tbody>
</table>

Where

\[
S_m = \begin{cases} 
1.00 & \text{for mild steel} \\
0.95 & \text{for HT 32} \\
0.908 & \text{for HT 36} \\
0.90 & \text{for HT 40} \\
0.90 & \text{for aluminum} \\
0.37 & \text{for composite} 
\end{cases}
\]

\(\sigma_y\) is yield strength for steel structures or the welded yield strength for aluminum structure, and \(\sigma_u\) is ultimate tensile or compressive strength of laminate, whichever is less.

\(\sigma_u\) for aluminum, \(\tau_y\) is to be calculated in the welded condition. For composite materials, the shear stress allowable is 0.4\(\tau_y\), where \(\tau_y\) is the lesser of the ultimate shear strength in either the warp or fill of the web laminate.

For local models outside of 0.4\(L\) and extreme fibers, if the global load cases are not available for application to the local FEM, the allowable stresses are to be decreased by 20% for both the von-Mises and normal stress checks. For the component stresses, Stress Limits specified in 3-1-3/Table 1 may be used instead of \(\sigma_y\) to calculate \(\sigma_a\).

### 11.3.3 Design Global Hull Girder Stresses *(2007)*

The design stresses are as follows:

- Global Longitudinal Strength of All Hull Types
Design Longitudinal Bending Stress:

\[ \sigma_a = \frac{f_p}{CQ} \text{ N/mm}^2 / (\text{kgf/mm}^2, \text{psi}) \]

Design Shear Stress:

\[ \tau_a = \frac{110}{Q} \text{ N/mm}^2 \left( \frac{1.122/ Q \text{tf/cm}^2}{7.122} \right) \]

\[ f_p = 17.5 \text{ kN/cm}^2 \left( \frac{1.784 \text{ tf/cm}^2}{11.33 \text{Ltf/in}^2} \right) \]

\[ C = 1.0 \text{ for steel vessels} \]
\[ = 0.90 \text{ for aluminum vessels} \]
\[ = 0.80 \text{ for fiber-reinforced plastic vessels} \]

\[ Q = 1.0 \text{ for ordinary strength steel} \]
\[ = 0.78 \text{ for grade H32 steel} \]
\[ = 0.72 \text{ for grade H36 steel} \]

Q for Aluminum:

\[ q_5 = 115/\sigma_y \left( \frac{12}{\sigma_y, 17000/\sigma_y} \right) \]
\[ Q_o = 635/ \left( \sigma_y + \sigma_u \right) \left[ \frac{65}{\left( \sigma_y + \sigma_u \right)}, 92000 / \left( \sigma_y + \sigma_u \right) \right] \]

\[ \sigma_y = \text{minimum yield strength of unwelded aluminum in N/mm}^2 (\text{kgf/mm}^2, \text{psi}) \text{ (not to be greater than 0.7}\sigma_u) \]

\[ \sigma_u = \text{minimum ultimate strength of welded aluminum in N/mm}^2 (\text{kgf/mm}^2, \text{psi}) \]

Q for Fiber Reinforced Plastic:

\[ = 400/0.75 \sigma_u \left( \frac{41/0.75 \sigma_u, 58000/0.75 \sigma_u} \right) \]

\[ \sigma_u = \text{minimum ultimate tensile or compressive strength, whichever is less, verified by approved test results, in N/mm}^2 (\text{kgf/mm}^2, \text{psi}). \text{ See Section 2-6-5. Strength properties in the longitudinal direction of the vessel are to be used.} \]

Global Transverse Strength of Multihulls:

\[ \sigma_a = \text{design transverse bending stress, 0.66}\sigma_y \text{ for aluminum and steel vessels and 0.33}\sigma_u \text{ for FRP vessels, in N/mm}^2 (\text{kgf/mm}^2, \text{psi}) \]

\[ \sigma_{ab} = \text{design torsional or combined stress, 0.75}\sigma_y \text{ for aluminum and steel vessels and 0.367}\sigma_u \text{ for FRP vessels, in N/mm}^2 (\text{kgf/mm}^2, \text{psi}) \]

\[ \tau_a = \text{design transverse shear stress, 0.38}\sigma_y \text{ for aluminum and steel vessels and 0.40 for FRP vessels, in N/mm}^2 (\text{kgf/mm}^2, \text{psi}) \]

\[ \sigma_y = \text{minimum yield strength of material, in N/mm}^2 (\text{kgf/mm}^2, \text{psi}). \text{ For aluminum the yield strength is to be for the unwelded condition and not to be greater than 0.7}\sigma_{uw} \]

\[ \sigma_u = \text{minimum tensile or compressive strength, whichever is less, in N/mm}^2 (\text{kgf/mm}^2, \text{psi}) \]

\[ \sigma_{uw} = \text{ultimate tensile strength of material in the welded condition, in N/mm}^2 (\text{kgf/mm}^2, \text{psi}) \]

\[ \delta_m = \text{maximum deflection for FRP vessels, (}\sigma_a/\pi\text{)}L_t, \text{ in m (in.)} \]

\[ \tau_u = \text{minimum ultimate through thickness shear strength, in N/mm}^2 (\text{kgf/mm}^2, \text{psi}) \]
\[ L_i = \text{mean span of cross structure, in cm (in.), as indicated in 3-2-A2/3 FIGURE 2} \]
\[ E = \text{tensile or compressive modulus of the FRP laminate, whichever is lesser, in N/mm}^2 \]
\( (\text{kgf/mm}^2, \text{psi}) \)

11.3.4 Buckling and Ultimate Strength

Plate panels, stiffened panels and primary supporting members are to be checked against buckling and ultimate strength using the stresses obtained from the finite element analyses by the criteria in 5C-1-5/5.3.1 and 5C-1-5/5.3.2 of the ABS Rules for Building and Classing Marine Vessels.

Plate buckling between stiffeners in the elastic range is considered acceptable provided that the plate satisfies the ultimate strength requirements.

Plate panels and stiffened panels are subjected to loads due to hull girder bending and shear and water pressure. Combined loads include bi-axial compression/tension, edge shear and compression/tension, in-plane loads and lateral pressure. The effects of combined load components are to be accounted for, and the interaction formulae for combined loads is to be applied. Proper modifications to the buckling and ultimate strength criteria are to be made, taking into account the differences in gross and net scantling.

The local stiffness and geometric proportions given in 5C-1-A2/11 of the ABS Rules for Building and Classing Marine Vessels to limit local buckling failures are to be observed in highly stressed areas. The ABS Requirements for Buckling and Ultimate Strength Assessment for Offshore Structures may be used for reference.
1 Naval Ship Safety Certificate

NavalSafe(x) is an optional notation assigned to ships complying with the performance requirements defined in the NSC and after the Naval Ship Safety Certificate is issued. The index x in NavalSafe(x) notation represents: S (Structure), BSC (Buoyancy, Stability and Controllability), ES (Engineering Systems), SS (Seamanship Systems), FS (Fire Safety), EER (Escape, Evacuation and Rescue), C (Communication), N (Navigation), DG (Dangerous Goods), or All if all entries are applicable.

Refer to Chapter 6-4 of the ABS Guide for Building and Classing International Naval Ships for more information.

3 Ballistic and Fragment Hazards

BFP1, BFP2 and BFP3 are optional notations indicating ballistic and fragment hazard protection. They are available for ships complying with this Section.

Refer to Section 6-5-1 of the ABS Guide for Building and Classing International Naval Ships for more information.

5 Air Blast

AB (Weight, Range) is an optional notation available for ship structures which can resist Air Blast with only superficial damage*. This notation covers the entire structure above the waterline. Noncritical spaces may be exempted upon agreement with the Naval Administration. Exempted spaces are to be identified in the submitted documents.

Refer to Section 6-5-2 of the ABS Guide for Building and Classing International Naval Ships for more information.

Note: * Superficial damage is generally defined as damage having no impact on the ship’s ability to continue carrying out its mission.

7 Underwater Explosion

UNDEX (Weight, Range) is a notation available for ship structures which can resist underwater shock with only superficial damage*. This notation covers the entire structure below the waterline, and secondary shock effects on equipment and outfitting. Additionally, this may be presented as a series of notations
covering multiple scenarios, annotated as **UNDEX (W1, R1, W2, R2, etc.)** to address multiple Concept of Operations (ConOps) events.

Refer to Section 6-5-3 of the ABS *Guide for Building and Classing International Naval Ships* for more information.

**Note:** *Superficial damage is generally defined as damage having no impact on the ship’s ability to continue carrying out its mission.*
CHAPTER 2
Hull Structures and Arrangements

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CHAPTER 2
Hull Structures and Arrangements

SECTION 1
Primary Hull Strength

1 Longitudinal Hull Girder Strength – Monohulls

The equations are, in general, valid for vessels having breadths, \( B \), not greater than twice their depths, \( D \), as defined in Section 3-1-1. Finite element analysis of the longitudinal hull girder strength is an acceptable alternate analysis to the requirements in 3-2-1/1 through 3-2-1/5. The failure criteria, seaway loads, and finite element method is to be submitted for review. Based on this information, ABS will establish criteria that are acceptable to the Naval Administration, see Section 3-1-3 and the ABS Guidance Notes on Structural Direct Analysis for High-Speed Craft.

1.1 Section Modulus

1.1.1 All Vessels (2007)

The required hull girder section modulus \( SM \) at amidships is to be not less than given by the following equation:

\[
SM = C_1 C_2 L^2 B (C_b + 0.7) K_3 C Q \quad \text{cm}^2 - \text{m} (\text{in}^2 - \text{ft})
\]

where

\[
C_1 = \begin{cases} 0.044L + 3.75 & L < 90 \text{ m} \\ 10.75 - \left( \frac{300 - L}{100} \right)^{1.5} & 90 \text{ m} \leq L \end{cases}
\]

\[
C_1 = \begin{cases} 0.0134L + 3.75L & < 295 \text{ ft} \\ 10.75 - \left( \frac{984 - L}{328} \right)^{1.5} & 295 \text{ ft} \leq L \end{cases}
\]

\[
C_2 = 0.01 \ (0.01, 1.44 \times 10^{-4})
\]

\( L \) = length of vessel, in m (ft), as defined in Section 3-1-1

\( B \) = breadth, in m (ft), as defined in Section 3-1-1

\( V \) = maximum speed in calm water, in knots, for the loading condition under consideration
\[ C_b = \text{block coefficient at the design draft, based on the length, } L, \text{ measured on the design load waterline. } C_b \text{ is not to be taken as less than 0.45 for } L < 35 \text{ m (115 ft) or 0.6 for } L \geq 61 \text{ m (200 ft). } C_b \text{ for lengths between 35 m (115 ft) and 61 m (200 ft) is to be determined by interpolation.} \]

\[ K_3 = \begin{cases} 0.70 + 0.30 \left( \frac{V}{L} \right)^{2.36} & \text{SI/MKS units,} \\ 0.70 + 0.30 \left( \frac{V}{L} \right)^{1.30} & \text{US Units;} \end{cases} \]

\[ K_3 \text{ is not to be taken less than 1, nor more than 1.30.} \]

\[ C = 1.0 \text{ for steel vessels} \]
\[ 0.90 \text{ for aluminum vessels} \]
\[ 0.80 \text{ for fiber-reinforced plastic vessels} \]

\[ Q \text{ for steel:} \]
\[ = 1.0 \text{ for ordinary strength steel} \]
\[ = 0.78 \text{ for grade H32 steel} \]
\[ = 0.72 \text{ for grade H36 steel} \]

For other steel grades:

\[ Q_{other} = \frac{490}{\left( \sigma_y + 0.66 \sigma_u \right)} \left[ \frac{50}{\left( \sigma_y + 0.66 \sigma_u \right)} \right], 70900/\left( \sigma_y + 0.66 \sigma_u \right)], \text{ where } \sigma_y \text{ is not to be greater than 70% } \sigma_u \]

\[ Q \text{ for aluminum:} \]
\[ = 0.9 + q_5 \text{ but not less than } Q_o \]
\[ q_5 = \frac{115}{\sigma_y}, \left( \frac{12}{\sigma_y}, 17000/\sigma_y \right) \]
\[ Q_o = \frac{635}{\left( \sigma_y + \sigma_u \right)}, \left( 65/\sigma_y + \frac{92000}{\sigma_y} \right) \]
\[ \sigma_y = \text{minimum yield strength of unwelded aluminum in N/mm}^2 \text{ (kgf/mm}^2, \text{ psi)} \text{ (not to be greater than 0.7} \sigma_u \]

\[ Q \text{ for fiber reinforced plastic:} \]
\[ = \frac{400}{0.75 \sigma_u}, \left( \frac{41}{0.75 \sigma_u}, 58000/0.75 \sigma_u \right) \]
\[ \sigma_u = \text{minimum ultimate tensile or compressive strength, whichever is less, verified by approved test results, in N/mm}^2 \text{ (kgf/mm}^2, \text{ psi). See Section 2-6-5. Strength properties in the longitudinal direction of the vessel are to be used.} \]

1.1.2 Vessels 24 m (79 ft) in Length and Over

In addition to meeting the above criteria in 3-2-1/1.1.1, vessels of 24 m (79 ft) in length or greater are to comply with the following requirements:

1.1.2(a) Sign Convention of Bending Moment and Shear Force

The sign convention of bending moment and shear force is as shown in 3-2-1/1.1.2(a) FIGURE 1.
1.1.2(b) Wave Bending Moment Amidships

The wave bending moment, expressed in kN-m (tf-m, Ltf-ft), may be obtained from the following equations:

\[ M_{ws} = -k_1 C_1 L^2 B (C_b + 0.7) \times 10^{-3} \] Sagging Moment

\[ M_{wh} = +k_2 C_1 L^2 B C_b \times 10^{-3} \] Hogging Moment

where

\[ k_1 = 110 \ (11.22, \ 1.026) \]

\[ k_2 = 190 \ (19.37, \ 1.772) \]

\( C_1, L, B \) and \( C_b \) are as defined in 3-2-1/1.1.

1.1.2(c) Still Water Bending Moment

The maximum still water bending moment in both the hogging and sagging condition is to be submitted. In case the detailed information is not available in the early stages of design, or the still water bending moment is not required to be submitted, the still water bending moment in kN-m (Ltf-ft) can be determined by the following:

\[ M_{sws} = 0 \] Sagging Moment

\[ M_{swh} = 0.375f_p C_1 C_2 L^2 B (C_b + 0.7) \] Hogging Moment

where

\[ f_p = 17.5 \text{ kN/cm}^2, \ (1.784 \text{ tf/cm}^2, \ 11.33 \text{ Ltf/in}^2) \]

\( C_1, C_2, L, B, C_b \) are as defined in 3-2-1/1.1.

1.1.2(d) Slamming Induced Bending Moment (1 July 2021)
The slamming induced bending moment in kNm (Ltf-ft), which applies only for vessels with a speed $V / \sqrt{L}$ not less than 2.36 (1.3), can be determined by the following equation:

$$M_{s\ell} = C_3 \Delta (1 + n_{cg}) (L - \ell_s) \text{ kN-m (tf-m, Ltf-ft)}$$

where

- $C_3 = 1.25 (0.125, 0.125)$
- $\Delta = \text{full load displacement, in metric tons (long tons)}$
- $\ell_s = \text{length of slam load, in m (ft)}$
  $$\ell_s = \frac{A_R}{B_{wl}}$$
- $A_R = 0.697 \Delta / d \text{ m}^2 (25 \Delta / d \text{ ft}^2)$
- $B_{wl} = \text{waterline breadth at the LCG, in m (ft)}$
- $n_{cg} = \text{maximum vertical acceleration as defined in 3-2-2/1.1, but } (1 + n_{cg}) \text{ is not to be taken less than indicated in 3-2-1/1.1.2(d) TABLE 1.}$

$L$ is as defined in 3-2-1/1.1.1.

### TABLE 1

**Minimum Vertical Acceleration**

<table>
<thead>
<tr>
<th>$\Delta$ (metric tons, long tons)</th>
<th>Minimum Vertical Acceleration, $(n_{cg} + 1) \text{ (g)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>180 (177)</td>
<td>3</td>
</tr>
<tr>
<td>400 (394)</td>
<td>2</td>
</tr>
<tr>
<td>$\geq 1200$ (1181)</td>
<td>1</td>
</tr>
</tbody>
</table>

**Notes:**

1. Intermediate values of $n_{cg}$ are to be determined by interpolation.
2. The minimum value of $(1+n_{cg})$ is applicable for 3-2-1/1.1.2(d) only.

#### 1.1.2(e) Section Modulus.

The required hull-girder section modulus for $0.4L$ amidships is to be obtained from the following equation:

$$SM = \frac{M_{tCQ}}{f_p} \text{ cm}^2 - \text{ m} (\text{in}^2 - \text{ft})$$

where

- $M_t = \text{maximum total bending moment. To be taken as the greatest of the following:}$
  $$= M_{swh} + M_{wh}$$
  $$= M_{swh} - M_{ws}$$
  $$= M_{sl}$$
\[ M_{\text{swh}} = \text{maximum still-water bending moment in the hogging condition, in kN-m (tf-m, Ltf-ft), as determined in 3-2-1/1.1.2(c).} \]
\[ M_{\text{sws}} = \text{maximum still water bending moment in the sagging condition, in kN-m (tf-m, Ltf-ft), as determined in 3-2-1/1.1.2(c).} \]
\[ M_{\text{wh}} = \text{maximum wave induced bending moment in the hogging condition, in kN-m (tf-m, Ltf-ft), as determined in 3-2-1/1.1.2(b).} \]
\[ M_{\text{ws}} = \text{maximum wave induced bending moment in the sagging condition, in kN-m (tf-m, Ltf-ft), as determined in 3-2-1/1.1.2(b).} \]
\[ M_{\text{sl}} = \text{maximum slamming induced bending moment, in kN-m (tf-m, Ltf-ft), as determined in 3-2-1/1.1.2(d).} \]
\[ f_p = 17.5 \text{ kN/cm}^2, (1.784 \text{ tf/cm}^2, 11.33 \text{ Ltf/in}^2) \]

\( C \) and \( Q \) are as defined in 3-2-1/1.1.

Consideration may be given to a seakeeping analysis based on vessel speed and sea state to determine \( M_{\text{ws}} \) and \( M_{\text{wh}} \).

### 1.3 Extension of Midship Section Modulus

Where the still-water bending moment envelope is not submitted or where 3-2-1/1.1.1 governs, the scantlings of all continuous and all effectively developed longitudinal material are to be maintained throughout \( 0.4L \) amidships and may be gradually tapered beyond. The area of the strength deck and other effective decks comprising of plating and longitudinal members may be reduced linearly from \( 0.4L \) amidships to the ends. The ends of all continuous and effectively developed longitudinal members are to terminate with back-up brackets extending to and attached to an adjacent transverse member. The bracket is to extend for a distance not less than the depth of the member.

Structure that is not continuous throughout the midships \( 0.4L \) and beyond, but is effectively developed by brackets and welding to provide continuity of area, may be taken to contribute to the hull girder section modulus, provided the buckling strength required by 3-2-4/1.5 is maintained in way of the brackets.

Where the scantlings are based on the envelope curve of still-water bending moments, items included in the hull-girder section modulus amidships are to be extended as necessary to meet the hull-girder section modulus required at the location being considered, taking into account the distance required for the member to become fully effective (See 3-2-1/1.7.2).

The envelope curve of \( M_{\text{ws}} \) and \( M_{\text{wh}} \) may be obtained by multiplying the midship value by the distribution factor \( M \) in 3-2-1/1.3 FIGURE 2.
1.5 Moment of Inertia

The hull-girder moment of inertia, \( I \), at amidships is to be not less than given by the following equation:

\[
I = \frac{L}{QC} SM \frac{cm^2}{m} - m^2 \left( \text{in}^2 \cdot \text{ft}^2 \right)
\]

where

\[
SM = \text{required hull-girder section modulus in 3-2-1/1.1.1 or 3-2-1/1.1.2, whichever is greater, in cm}^2 \cdot \text{m (in}^2 \cdot \text{ft)}
\]

\[
K = \text{factor dependent on the material and vessel length as given in 3-2-1/1.5 TABLE 2 below}
\]

\( L, C \) and \( Q \) are as defined in 3-2-1/1.1.1.

### TABLE 2

<table>
<thead>
<tr>
<th>( L ) (m, ft)</th>
<th>Steel</th>
<th>Aluminum</th>
<th>FRP (Basic Laminate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 (33)</td>
<td>10.89</td>
<td>3.63</td>
<td>0.36</td>
</tr>
<tr>
<td>30 (100)</td>
<td>16.50</td>
<td>5.50</td>
<td>0.55</td>
</tr>
<tr>
<td>50 (165)</td>
<td>22.10</td>
<td>7.37</td>
<td>0.74</td>
</tr>
<tr>
<td>70 (230)</td>
<td>27.40</td>
<td>9.13</td>
<td>0.91</td>
</tr>
<tr>
<td>90 (295)</td>
<td>33.00</td>
<td>11.00</td>
<td>1.10</td>
</tr>
</tbody>
</table>
Note:
For fiber reinforced plastic laminates that are greater than the ABS basic laminate (as defined in Part 2, Section 6) the value for $K$ can be adjusted by the ratio of $E_o / E_b$ where:

$$E_o = \text{the elastic modulus of the actual hull laminate in N/mm}^2 (\text{kgf/mm}^2, \text{psi})$$

$$E_b = 6890 \text{ N/mm}^2 (703 \text{ kgf/mm}^2, 1,000,000 \text{ psi})$$

1.7 Section Modulus and Moment of Inertia Calculation

1.7.1 Items Included in the Calculation

In general, the following items may be included in the calculation of the section modulus and moment of inertia provided they are continuous or effectively developed within midship $0.4L$, have adequate buckling strength, and are gradually tapered beyond the midship $0.4L$.

- Deck plating (strength deck and other effective decks)
- Shell and inner bottom plating
- Deck and bottom girders
- Plating and longitudinal stiffeners of longitudinal bulkheads
- All longitudinals of deck, sides, bottom, and inner bottom

1.7.2 Effective Areas Included in the Calculation

In general, the net sectional areas of longitudinal strength members are to be used in the hull girder section modulus calculations, except that small isolated openings need not be deducted provided the openings and the shadow area breadths of other openings in any one transverse section do not reduce the section modulus by more than 3%. The breadth or depth of such openings is not to be greater than 25% of the breadth or depth of the member in which it is located with a maximum of 75 mm (3 in.) for scallops. The shadow area of an opening is the area forward and aft of the opening enclosed by the lines tangential to the corners of the opening intersecting each other to form an included angle of 30 degrees.

1.7.3 Section Modulus to the Deck or Bottom

The section modulus to the deck or bottom is obtained by dividing the moment of inertia by the distance from the neutral axis to the molded deck at side amidships or baseline, respectively. Where a long deckhouse or superstructure is considered as part of the hull girder, the section modulus to the deck is obtained by dividing the moment of inertia by the distance from the neutral axis to the top of the bulwark, deckhouse or superstructure.

1.7.4 Breaks

Vessels having partial superstructures are to be specially strengthened in way of breaks to limit the local increase in stresses at these locations. The main deck plate and side shell plate thickness is to be increased a minimum of 25%, but the increase need not exceed 6.5 mm (0.25 in.). This increase is to extend well beyond the break in both directions in such a fashion to provide a long gradual taper. Where breaks of the superstructure (e.g., long forecastle) are appreciably beyond the amidships $0.5L$, these requirements may be modified. Gangways, large freeing ports and other openings in the shell or bulwarks are to be kept well clear of breaks, and any holes which must be unavoidably be cut in the plating are to be kept as small as possible and are to be circular or oval in form.

1.9 Hull Girder Shear Strength Calculation – For Vessels 24 m (79 ft) in Length and Over

1.9.1 General

The nominal total shear stresses due to still-water and wave-induced loads are to be based on the maximum algebraic sum of the shear force in still-water, $F_{sw}$, the wave-indicated shear force, $F_{w}$, and the slam induced shear force, $F_{sl}$, at the location being considered. The thickness of the side
shell is to be such that the nominal total shear stress as obtained by 321/1.9.3 are not greater than 11.0/Q kN/cm² (1.122/Q tf/cm², 7.122/Q Ltf/in²) where Q is as defined in 3-2-1/1.1.1. Consideration is also to be given to the shear buckling strength of the side shell plating.

1.9.2 Wave Shear Forces

The envelopes of maximum shearing forces induced by waves, \( F_w \), as shown in 3-2-1/1.9.2 FIGURE 3 and 3-2-1/1.9.2 FIGURE 4 may be obtained from the following equations:

\[
F_{wp} = + kF_1C_1LB(C_b + 0.7) \times 10^{-2}
\]

For positive shear force

\[
F_{wn} = - kF_2C_1LB(C_b + 0.7) \times 10^{-2}
\]

For negative shear force

where

\[
F_{wp}, F_{wn} = \text{maximum shearing force induced by wave, in kN (tf, Ltf)}
\]

\[
k = 30 (3.059, 0.2797)
\]

\[
F_1 = \text{distribution factor as shown in 3-2-1/1.9.2 FIGURE 3}
\]

\[
F_2 = \text{distribution factor as shown in 3-2-1/1.9.2 FIGURE 4}
\]

\( C_1, L, B \) and \( C_b \) are as defined in 3-2-1/1.1.1.
1.9.3 Slam Induced Shear Force (1 July 2021)

The slamming induced shear force, which applies only for vessels with a speed \( V / \sqrt{L} \) not less than 2.36 (1.3), can be determined by the following equation:

\[
F_{sl} = C_4 F_1 \Delta (n_{cg} + 1) \text{ kN (tf, Ltf)}
\]

For positive shear force

\[
F_{sl} = C_4 F_2 \Delta (n_{cg} + 1) \text{ kN (tf, Ltf)}
\]

where

\[
C_4 = 4.9 (0.5)
\]

\( \Delta \) = full load displacement in metric tons (long tons)

\( n_{cg} \) = maximum vertical acceleration as defined in 3-2-2/1.3.1

1.9.4 Shear Strength

For vessels without continuous longitudinal bulkheads, the nominal total shear stress \( f_s \) in the side shell plating may be obtained from the greater of the following equations:

\[
f_s = (F_{sw} + F_w)m / 2t_s I
\]

\[
f_s = F_{sl}m / 2t_s I
\]

where

\( f_s \) = nominal total shear stress, in kN/cm\(^2\) (tf/cm\(^2\), Ltf/in\(^2\))

\( I \) = moment of inertia of the hull girder section, in cm\(^4\) (in\(^4\)), at the section under consideration

\( m \) = first moment about the neutral axis, of the area of the effective longitudinal material between the horizontal level at which the shear stress is being determined and the vertical extremity of effective longitudinal material, taken at the section under consideration, in cm\(^3\) (in\(^3\))
Shearing Strength for Vessels with Two or Three Longitudinal Bulkheads

For vessels having continuous longitudinal bulkheads the total shear stresses in the side shell and longitudinal bulkhead plating are to be calculated by an acceptable method. In determining the still-water shear force, consideration is to be given to the effect of non-uniform athwartship distribution of loads. The methods described in Appendix 3-2-A1 of the Rules for Building and Classing Marine Vessels may be used as a guide in calculating the nominal total shear stress related to the shear flow in the side shell or longitudinal bulkhead plating. Alternative methods of calculation will also be considered. One acceptable method is shown in Appendix 5C-2-A1 of the Rules for Building and Classing Marine Vessels.

Hull Girder Shear Strength – FRP Vessels

Hull girder shear strength will be specially considered on fiber reinforced plastic vessels over 24 m (79 ft) in length.

Vessels of Unusual Proportion

Vessels having unusual proportions will be specially considered.

Hull Girder Torsional Loads

Torsional calculations may be required for vessels with large deck openings. Racking load calculations may be required for vessels with tall superstructures.

Primary Hull Strength – Twin-Hulled Craft

The following applies to catamarans, surface effect craft, and similar configuration twin hulled craft.

The longitudinal strength requirements for twin-hulled craft are as given in 3-2-1/1.1, with the following modifications:

i) B is to be taken as the sum of the waterline breadths of each hull.

ii) For craft less than 24 m (79 ft), longitudinal shear strength need not be considered unless they have unusual or highly concentrated loads. For craft over 24 m (79 ft) the shear strength will be specially considered.

iii) Items as listed in 3-2-1/1.7 may be included in the longitudinal strength calculation for the total cross section of the hulls, with the addition of the cross deck bridging structure. Consideration is to be given to the length over which the cross-deck structure becomes fully effective.

Catamaran Transverse Loadings (1 July 2022)

The transverse primary hull loadings are determined by the following equations:

\[ M_{tb} = K_1 \Delta B_{cl} \left(1 + n_{cg}\right) \text{ kN-m (kgf-m, ft-lbs)} \]

\[ M_{tt} = K_2 \Delta L \left(1 + n_{cg}\right) \text{ kN-m (kgf-m, ft-lbs)} \]
\[ Q_t = K_1 \Delta \left( 1 + n_{cg} \right) \text{kN (kgf,lbs)} \]

where

- \( M_{tb} \) = design transverse bending moment acting upon the cross structure connecting the hulls
- \( M_{tt} \) = design pitch torsional moment about the transverse axis acting upon the transverse structure connecting the hulls
- \( Q_t \) = design vertical shear force acting upon the transverse structure connecting the hulls
- \( K_1 \) = 2.5 (0.255, 0.255)
- \( K_2 \) = 1.25 (0.1275, 0.1275)
- \( \Delta \) = craft displacement in tonnes (kg, lbs).
- \( B_{cl} \) = distance between the hull centerlines, in meters (feet)
- \( L \) = length of craft, in meters (feet), as defined in 3-1-1/3.
- \( n_{cg} \) = vertical acceleration at the craft’s center of gravity, see 3-2-2/1.1, but \((1 + n_{cg})\) is not to be taken less than indicated in 3-2-1/1.2(b) TABLE 1.

### 3.5 Transverse Strength for Catamarans and Surface Effect Craft

#### 3.5.1 Direct Analysis

The design loads that are to be applied to the structure are the transverse bending moment, \( M_{tb} \), the torsional moment, \( M_{tt} \), and vertical shear force, \( Q_t \), as defined in 3-2-1/3.3 and the longitudinal bending moments as given in 3-2-1/1.1.2. The requirements for the direct analysis are given in Section 3-1-3.

#### 3.5.2 Analysis for Simple Structures

Guidance for the analysis of cross deck structures that are symmetrical forward and aft of a transverse axis at amidships can be found in Appendix 3-2-A2.

#### 3.5.3 Design Stresses and Deflections

Regardless of the method of analysis used, the design stresses are as follows:

- \( \sigma_a \) = design transverse bending stress, \( 0.66 \sigma_y \) for aluminum and steel craft and \( 0.33 \sigma_u \) for FRP craft, in N/mm\(^2\) (kgf/mm\(^2\), psi)
- \( \sigma_{ab} \) = design torsional or combined stress, \( 0.75 \sigma_y \) for aluminum and steel craft and \( 0.367 \sigma_u \) for FRP craft, in N/mm\(^2\) (kgf/mm\(^2\), psi)
- \( \tau_a \) = design transverse shear stress, \( 0.38 \sigma_y \) for aluminum and steel craft and \( 0.40 \tau_u \) for FRP craft, in N/mm\(^2\) (kgf/mm\(^2\), psi)
- \( \sigma_y \) = minimum yield strength of the material, in N/mm\(^2\) (kgf/mm\(^2\), psi). For aluminum the yield strength is to be for the unwelded condition and not to be greater than \( 0.7 \sigma_{uw} \)
- \( \sigma_u \) = minimum tensile or compressive strength, whichever is less, in N/mm\(^2\) (kgf/mm\(^2\), psi)
- \( \sigma_{uw} \) = ultimate tensile strength of material in the welded condition, in N/mm\(^2\) (kgf/mm\(^2\), psi)
- \( \delta_m \) = maximum deflection for FRP craft, \((\sigma_a/E)L_1\), in m (in.)
- \( \tau_u \) = minimum ultimate through thickness shear strength, in N/mm\(^2\) (kgf/mm\(^2\), psi)
\[ L_i = \text{mean span of cross structure, in cm (in.), as indicated in 3-2-A2/3 FIGURE 2} \]

\[ E = \text{tensile or compressive modulus of the FRP laminate, whichever is lesser, in N/mm}^2 \quad \text{(kgf/mm}^2, \text{psi)} \]

### 3.7 Items included in Transverse Moment of Inertia and Section Modulus Calculation

The following items may be included in the calculation of the transverse section modulus and moment of inertia provided that they are continuous or effectively developed over the entire breadth of the cross structure or wet deck, and have adequate buckling strength:

- Deck plating, main deck and bottom plating of wet deck
- Transverse stiffeners on wet deck
- Transverse bulkheads or web frames which span the wet deck, and are effectively developed into the hulls
- Transverse box beams, that are effectively developed into the hulls
- Continuous transom plating and attached horizontal stiffeners

In general, the effective sectional area of the deck for use in calculating the section modulus is to exclude hatchways and other large openings in the deck.

Superstructures and house tops are generally not to be included in the calculation of sectional properties of the cross structure. Craft having unusual configuration such as cross-deck structure out-of-line with the main hull structure will be specially considered.

### 3.9 Craft with More Than Two Hulls

Transverse and torsional strength of craft with more than two hulls will be specially considered.

### 3.11 Hull Girder Torsional Loads

Torsional calculations may be required for craft with large deck openings. Racking load calculations may be required for craft with high superstructures.

### 5 Strength Considerations for Hydrofoil Borne Craft

#### 5.1 Longitudinal Strength

The hull weight curve showing full load, lightship and partial load (if more severe) is to be submitted. The support reactions for each of the hydrofoils are to be shown. The resulting shear and bending moment diagrams, as derived from these curves, are to be submitted for approval.

Hull deflection under the condition of maximum bending moment is not to exceed 1/200 of the distance between the forward and aft foil attachment points.

#### 5.3 Calculation of Loads from Hydrofoil Appendages

The maximum forces transmitted by any hydrofoil to the craft structure is given by the following equations:

\[ F_L = C_U C_L V^2 A_p \]

\[ F_D = C_U V^2 (C_{DF} A_{FP} + C_{DS} A_{FS}) + \text{(Wetted surfacedrag)} \]

where
\[ F_L = \text{maximum lift force on craft exerted by hydrofoil, in kgf (lbs). This force is assumed to act perpendicular to the plane of the foil.} \]
\[ F_D = \text{maximum drag force on craft exerted by hydrofoil plus strut, in kgf (lbs). This force is assumed to act directly aft from the center of the foil.} \]
\[ C_U = 13.847 (2.835) \]
\[ C_L = \text{peak coefficient of lift for the foil selected.} \]
\[ C_{DF} = \text{peak coefficient of drag for the foil selected.} \]
\[ C_{DS} = \text{peak coefficient of drag for the strut section selected.} \]
\[ V = \text{maximum craft speed, in knots.} \]
\[ A_P = \text{plan view area of foil, in m}^2 \text{ (ft}^2) \]
\[ A_{FF} = \text{frontal area of foil, in m}^2 \text{ (ft}^2) \]
\[ A_{FS} = \text{frontal area of strut, in m}^2 \text{ (ft}^2) \]

Total drag of the foil and strut (or similar appendage) is given by the drag term \( F_D \) that includes the frictional drag coefficient, as a function of wetted surface and Reynolds number.

The strength of the foils and struts are to be based on \( F_L \) and \( F_D \) and the resulting bending moments, shear forces, and vertical forces. The strength of the connections of the struts to the hull is to be based on the bending moments, shear forces, and vertical forces applied through the struts. A factor of safety on the yield strength of the material (aluminum use the as-welded condition) is to be not less than 2.0. Calculations of the bending moment, shear forces, and stiffness, are to be carried out and submitted by the designer.

Additionally, calculations supporting the “Fail-Safe” performance of each foil attachment structure are to be submitted.

Watertight integrity of the shell is to be maintained in the event of a collision of the hydrofoil appendages with a solid object in the water. A design safety factor of 2.0 on the yield strength or 3.0 on the ultimate strength of the foil strut bearing is to be used to assess the strength of the foil for the collision condition.

7 Effective Decks

To be considered effective for use in calculating the hull girder section modulus, the thickness of the deck plating is to comply with the requirements of Section 3-2-3. The deck areas are to be maintained throughout the midship 0.4L and may be gradually reduced to one half their midship value at 0.15L from the ends. Only that portion of deck which is continuous through the transverse structure may be considered effective.

9 Operating Manual (1 July 2022)

Vessels are to be furnished with an ABS approved operating manual providing guidance on:

\( i \) Loading conditions on which the design of the vessel has been based, including cargo loading on decks, loading ramps, and double bottoms.

\( ii \) Permissible limits of still-water bending moments and shear forces, for vessels 24 m (79 ft) in length or greater.

\( iii \) Maximum operational speeds for the various sea-states (significant wave heights) in which the vessel is intended to operate, exceeding the design significant wave height defined in 3-2-2/1.1.3 TABLE 1 in conjunction with the OE notation (see 1-1-3/5 TABLE B).
Commentary:

If the vessel receives a Cargo Ship Safety Construction Certificate or a High-Speed Craft Safety Certificate, there will be a need for other items to be included such as safety plan, firefighting procedures, means of escape, evacuation procedures, operation of life saving appliances, and requirements for safe operation of the vessel.

End of Commentary
Monohulls (1 July 2021)

The bottom and side pressures are to be checked using the displacement ($\Delta$), speed ($V$), draft ($d$), and running trim ($\tau$) in the full load, half load, and light load conditions. If the vessel is receiving a freeboard assignment, the parameters used in the full load condition are to coincide with the assigned freeboard. If the vessel is not receiving a freeboard assignment, the parameters used in the full load condition are to correspond to the condition of the vessel with the maximum operating deadweight. The parameters used in the half load condition are to correspond to the condition of the vessel with 50% of the maximum operating deadweight, and the parameters used in the light load condition are to correspond to the condition of the vessel with 10% of the maximum operating deadweight plus the maximum speed of the vessel.

Where maximum speed in knots $V/\sqrt{L}$ is less than 2.36 (1.3) and Length ($L$) is less than 130 m (427 ft), which at maximum speed has negligible dynamic lift, the design pressure is to follow 3-2-2/1.1.

Where the maximum speed in knots $V/\sqrt{L}$ is not less than 2.36 (1.3) and $L$ is less than 130 m (427 ft), which at maximum speed has significant dynamic lift, the design pressure is to follow 3-2-2/1.3.

Displacement Vessels (1 July 2021)

Displacement vessel is defined as a vessel having speed $V/\sqrt{L}$ less than 2.36 (1.3).

Wastage limits for displacement vessels may be specially considered and approved by engineering based on direct analysis.

The design pressures below apply only to monohulls. Aluminum, composite and multi-hull vessels will be given special consideration by ABS.

1.1.1 Bottom Design Pressure

The bottom design pressure applies to hull bottoms below the chines or the upper turn of the bilge.

$$P_B = N_3(0.64H + d) \quad \text{kN/m}^2 \quad \text{(tf/m}^2, \text{psi)}$$

where
\( N_3 = 9.8 \ (1.0, 0.44) \)

\( H = \) wave parameter, \( 0.0172L + 3.653 \) m (\( 0.0172L + 11.98 \) ft), generally not to be taken as less than the maximum survival wave height for the vessel, see 3-2-2/1.3.1(c) TABLE 1

\( d = \) stationary draft, in m (ft), vertical distance from outer surface of shell measured at centerline to design waterline at middle of design waterline length, but generally not to be taken as less than \( 0.04L \). See 3-2-2/1

\( L \) is as defined in Section 3-1-1.

Bottom slamming pressure is to be considered and is to be determined by model testing or hydrodynamic analysis. If the detailed information is not available in the early stages of design, the bottom plate thickness is to be increased by 25%.

### 1.1.2 Side and Transom Structure, Design Pressure

The side design pressure is as follows:

\[
P_S = N_3(H_S - y) \quad \text{kN/m}^2 \ (\text{tf/m}^2, \ \text{psi})
\]

where:

\( H_S = 0.083L + d \) in meters (feet), but it is not to be taken less than \( D + 1.22 \) (\( D + 4 \)) for vessels less than 30 m (100 ft)

\( = 0.64H + d \) in meters (feet) for vessels over 30 m (100 ft); where \( H \) is defined in 3-2-2/1.1.1

\( y = \) distance above base line of location being considered, in m (ft)

\( D \) is as defined in Section 3-1-1.

Side slamming pressure is to be considered and is to be determined by model testing or hydrodynamic analysis. If the detailed information is not available in the early stages of design, the side slamming pressure can be excluded.

### 1.1.3 Fore End

Fore End design pressure is to be no less than the side design pressure (3-2-2/1.1.2) and the bow slamming pressure.

The bow slamming pressure is to be determined by model testing or hydrodynamic analysis. If the detailed information is not available in the early stages of design, the side design pressure can be used, and the bow area plate thickness is to be increased by 25%.

### 1.1.4 Vertical Acceleration

Where needed in other sections of these Rules, the vessel's vertical acceleration can be determined as follows:

\[
n_{cg} = a_z / 9.8 \quad \text{g's}
\]

\[
n_{xx} = n_{cg}K_v
\]

where:
Planing vessel is defined as a vessel having speed \( \frac{V}{\sqrt{L}} \) not less than 2.36 (1.3).

### 1.3.1 Bottom Design Pressure

The bottom design pressure is to be the greater of those, as given in the following equations, for the location under consideration. Bottom structure design pressures are dependent upon the service in which the vessel operates. The bottom design pressure applies to hull bottoms below the chines or the upper turn of the bilge.

#### 1.3.1(a) Bottom Slamming Pressure

\[
P_{b cg} = \frac{N_1 \Delta}{I_w b_w} \left[ 1 + n_{cg} \right] F_D \ kN/m^2 (tf/m^2, psi)
\]

\[
P_{b xx} = \frac{N_1 \Delta}{I_w b_w} \left[ 1 + n_{cg} \right] \left[ \frac{70 - \beta_{b x}}{70 - \beta_{cg}} \right] F_D \ kN/m^2 (tf/m^2, psi)
\]

#### 1.3.1(b) Bottom Slamming for Vessels Less Than 61 meters (200 feet)

The design pressure may be:

\[
P_{b xx} = \frac{N_1 \Delta}{I_w b_w} \left[ 1 + n_{cg} \right] F_D F_v \ kN/m^2 (tf/m^2, psi)
\]

#### 1.3.1(c) Hydrostatic Pressure (1 July 2021)

\[
P_d = N_3 (0.64H + d) \ kN/m^2 (tf/m^2, psi)
\]

where

- \( p_{b cg} \) = bottom design pressure at LCG, kN/m² (tf/m², psi)
- \( p_{b xx} \) = bottom design pressure at any section clear of LCG, kN/m² (tf/m², psi)
- \( p_d \) = bottom design pressure based on hydrostatic forces, kN/m² (tf/m², psi)
- \( n_{cg} \) = the vertical acceleration of the vessel as determined by a model test, theoretical computation, or service experience (see Section 3-1-3). If this information is not readily available during the early stages of design, the following formula utilizing the average 1/100 highest vertical accelerations at LCG can be used:

\[
n_{cg} = N_2 \left[ \frac{12h_{1/3}}{b_w} + 1.0 \right] \left[ 50 - \beta_{cg} \right] \frac{V^2 (g_{w})^2}{\Delta} \ g's
\]

note that g’s are the dimensionless ratio of the acceleration at sea level (9.8 m/s², 32.2 ft/s²).

The vertical acceleration, \( n_{cg} \), is typically not to be taken greater than the following:

\[
n_{cg} = 1.39 + k_n \frac{V}{\sqrt{L}}
\]
for speeds greater than $18\sqrt{L}(9.94\sqrt{L})$ the maximum $n_{cg}$ is 6.0 g (7.0 g for search and rescue type vessels). The vertical accelerations are typically not to be taken less than 1.0 g for vessels lengths less than 24 m (79 ft) and 2.0 g for vessels lengths less than 12 m (39 ft). Intermediate values can be determined by interpolation. The vertical acceleration will need to be specially considered for vessels fitted with seat belts or special shock mitigation seats.

$$k_n = 0.256 \text{ (0.463)}$$

$$n_{xx} = \text{average of the 1/100 highest vertical accelerations, at any section clear of LCG, in g's. Can be determined by the following equation:}$$

$$n_{cg}K_v$$

$$N_1 = 0.1 \text{ (0.01, 0.069)}$$

$$N_2 = 0.0078 \text{ (0.0078, 0.0016)}$$

$$N_3 = 9.8 \text{ (1.0, 0.44)}$$

$$\Delta = \text{displacement at design waterline, in kg (lbs), see 3-2-2/1}$$

$$L_w = \text{vessel length on the waterline with the vessel at the design displacement and in the displacement mode, in m (ft)}$$

$$B_w = \text{maximum waterline beam, in m (ft)}$$

$$H = \text{wave parameter, 0.0172L + 3.653 m (0.0172L + 11.98 ft), generally not to be taken less than the maximum survival wave height for the vessel, see 3-2-2/1.3.1(c) TABLE 1}$$

$$h_{1/3} = \text{significant wave height, m (ft), see 3-2-2/1.3.1(c) TABLE 1}$$

$$\tau = \text{running trim at } V, \text{ in degrees, but generally not to be taken less than 4° for vessels } L< 50 \text{ m (165 ft), nor less than 3° for } L > 50 \text{ m (165 ft). Special consideration will be given to designers values predicted from model tests.}$$

$$\beta_{cg} = \text{deadrise at LCG, degrees, generally not to be taken less than 10° nor more than 30°.}$$

$$\beta_{bx} = \text{deadrise at any section clear of LCG, in degrees, not to be taken less than 10° nor greater than 30°, see 3-2-2/1.3.1(c) FIGURE 1.}$$

$$V = \text{vessel design speed in knots, see 3-2-2/1.3.1(c) TABLE 1.}$$

$$F_D = \text{design area factor given in 3-2-2/11.7 FIGURE 6 for given values of } A_D \text{ and } A_R. \text{ Generally not to be taken less than 0.4. See 3-2-2/1.3.1(c) TABLE 2 for minimum values of } F_D \text{ for vessels less than 24 m (79 ft) in length.}$$

$$F_V = \text{vertical acceleration distribution factor given in 3-2-2/11.7 FIGURE 8.}$$

$$K_V = \text{vertical acceleration distribution factor given in 3-2-2/11.7 FIGURE 7.}$$

$$A_D = \text{design area, cm}^2 \text{ (in}^2\text{). For plating it is the actual area of the shell plate panel but not to be taken as more than 2.5s}^2. \text{ For longitudinals, stiffeners, transverses and girders it is the shell area supported by the longitudinal stiffener, transverse or girder; for transverses and girders the area used need not be taken less than 0.33 } \ell^2.$$ 

$$A_R = \text{reference area, cm}^2 \text{ (in}^2\text{), 6.95\Delta/d cm}^2 \text{ (1.61\Delta/d in}^2\text{).}$$

$$s = \text{spacing of longitudinals or stiffeners, in cm (in.)}$$
\( \ell \) = unsupported span of internals, in cm (in.). See 3-2-4/1.3.1.

\( d \) = stationary draft, in m (ft), vertical distance from outer surface of shell measured at centerline to design waterline at middle of design waterline length, but generally not to be taken as less than \( 0.04L \). See 3-2-2/1.

### TABLE 1
Design Significant Wave Heights, \( h_{1/3} \), and Speeds, \( V \)

<table>
<thead>
<tr>
<th>Operational Condition</th>
<th>Survival Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( h_{1/3} )</td>
</tr>
<tr>
<td>Naval Craft</td>
<td>4 m (13 ft)</td>
</tr>
<tr>
<td>Coastal Naval Craft</td>
<td>2.5 m (8.5 ft)</td>
</tr>
<tr>
<td>Riverine Naval Craft</td>
<td>0.5 m (1.75 ft)</td>
</tr>
</tbody>
</table>

**Notes:**

1. Not to be taken less than \( L/12 \)
2. \( V_m \) = maximum speed for the vessel in the design condition specified in 3-2-2/1
3. This speed is to be verified by the Naval Administration.

### TABLE 2
Minimum Values for \( F_D \) \((L \leq 24 \text{ m}, 79 \text{ ft})\)

<table>
<thead>
<tr>
<th>( s ) ( \text{mm (in.)} )</th>
<th>( F_D )</th>
</tr>
</thead>
<tbody>
<tr>
<td>250 (9.75)</td>
<td>0.85</td>
</tr>
<tr>
<td>500 (16.75)</td>
<td>0.75</td>
</tr>
<tr>
<td>750 (29.5)</td>
<td>0.60</td>
</tr>
<tr>
<td>1000 (39.25)</td>
<td>0.50</td>
</tr>
<tr>
<td>1250 (49.25)</td>
<td>0.40</td>
</tr>
</tbody>
</table>
1.3.2 Side and Transom Structure, Design Pressure

The side design pressure, $p_s$, is to be not less than given by the equations:

1.3.2(a) Slamming Pressure

$$p_{sx} = \frac{N_1}{\rho_{SW}} \left[ 1 + n_{\Delta x} \right] \left[ 70 - \frac{\beta_{sx}}{\beta_{cg}} \right] F_D$$ kN/m$^2$ (tf/m$^2$, psi)

1.3.2(b) Hydrostatic Pressure

$$p_s = N_3 (H_s - y)$$ kN/m$^2$ (tf/m$^2$, psi)

1.3.2(c) Fore End (1 July 2021)

$$p_{sf} = 0.28 F_d C_F N_3 (0.22 + 0.15 \tan \alpha)(0.4V \sin \beta + 0.6\sqrt{L})^2$$ kN/m$^2$ (tf/m$^2$)

$$p_{sf} = 0.92 F_d C_F N_3 (0.22 + 0.15 \tan \alpha)(0.4V \sin \beta + 0.33\sqrt{L})^2$$ psi

where $L$ is generally not to be taken less than 30 m (98 ft)
For vessels greater than 24 m (79 ft) in length, the side design slamming pressure applies both along the entire length below \( L/12 \) above baseline and to the region forward of 0.125\( L \).

\[
P_{sx} = \text{side design slamming pressure at any section clear of LCG, in kN/m}^2 (\text{tf/m}^2, \text{psi}).
\]

\[
\text{For vessels greater than 24 m (79 ft) in length, the side design slamming pressure applies both along the entire length below } L/12 \text{ above baseline and to the region forward of 0.125L.}
\]

\[
P_s = \text{side design pressure due to hydrostatic forces, in kN/m}^2 (\text{tf/m}^2, \text{psi}), \text{but is not to be taken less than the following:}
\]

\[
= 0.05N_3L \text{ kN/m}^2 (\text{tf/m}^2, \text{psi}) \text{ at or below } L/15 \text{ above the base line or any height above base line forward of 0.125L from the stem}
\]

\[
= 0.033N_3L \text{ kN/m}^2 (\text{tf/m}^2, \text{psi}) \text{ above } L/15 \text{ above the base line, aft of 0.125L from the stem}
\]

\[
P_{sf} = \text{side design pressure for forward of 0.125L from the stem}
\]

\[
H_s = 0.083L+ d \text{ in meters (feet), but it is not to be taken less than } D+ 1.22 \text{ (D+ 4) for vessels less than 30 m (100 ft)}
\]

\[
= 0.64H+ d \text{ in meters (feet) for vessels over 30 m (100 ft); where } H \text{ is defined in 3-2-2/1.1.1}
\]

\[
y = \text{distance above base line of location being considered, in m (ft)}
\]

\[
L = \text{vessel length as defined in 3-1-1/3}
\]

\[
\beta_{sx} = \text{deadrise of side at any section clear of LCG, in degrees, not to be taken greater than } 55^\circ, \text{ see 3-2-2/1.3.1(c) FIGURE 1}
\]

\[
C_F = 0.0125L \text{ for } L< 80 \text{ m (0.00381} \text{L for } L< 262 \text{ ft)}
\]

\[
= 1.0 \text{ for } L \geq 80 \text{ m (262 ft)}
\]

\[
F_a = 3.25 \text{ for plating and 1.0 for longitudinals, transverses and girders}
\]

\[
\alpha = \text{flare angle, the angle between a vertical line and the tangent to the side shell plating, measured in a vertical plane at 90\(^\circ\) to the horizontal tangent to the side shell, see 3-2-2/1.3.1(c) FIGURE 1.}
\]

\[
\beta = \text{entry angle, the angle between a longitudinal line, parallel to the centerline and the horizontal tangent to the side shell, see 3-2-2/1.3.1(c) FIGURE 1.}
\]

\[
N_1, N_3, \Delta, L_w, B_w, V, n_{xx}, \beta_{cg}, H, d \text{ and } F_D \text{ are as defined in 3-2-2/1.3.1.}
\]

3 Multi-Hull and Surface Effect Craft

The bottom and side pressures are to be checked using the displacement (\( \Delta \)), speed (\( V \)), draft (\( d \)) and running trim (\( \tau \)) in the full load, half load and lightship conditions. If the craft is receiving a freeboard assignment, the parameters used in the full load condition are to coincide with the approved freeboard assignment. If the craft is not receiving a freeboard assignment, the parameters used in the full load condition are to correspond to the maximum operating deadweight. The parameters used in the half load condition are to correspond to 50% of the maximum operating deadweight, and the parameters used in the lightship condition are to correspond to 10% of the maximum operating deadweight plus the maximum speed of the craft. The on-cushion speed is to be used for surface effect craft.
3.1 Bottom Design Pressure
The bottom design pressure is to be the greater of the following equations, for the location under consideration. Bottom design pressures are dependent upon the service in which the craft operates. The bottom design pressure applies to hull bottoms below the chines or the upper turn of the bilge for catamarans, trimarans or other multihulled craft and surface effect craft. Bottoms of twin hull surface effect craft shall be considered as catamaran hulls for the purpose of calculation of the bottom slamming pressure.

3.1.1 Bottom Slamming Pressure
\[
p_{bcg} = \frac{N_1 \Delta}{r \Delta N_h B_w} [1 + n_{cg}] F_D \quad \text{kN/m}^2 (\text{tf/m}^2, \text{psi})
\]
\[
p_{bxx} = \frac{N_1 \Delta}{r \Delta N_h B_w} [1 + n_{xx}] \left[ \frac{70 - \beta_{xx}}{70 - \beta_{cg}} \right] F_D \quad \text{kN/m}^2 (\text{tf/m}^2, \text{psi})
\]

3.1.2 Bottom Slamming for Craft Less Than 61 meters (feet)
The design pressure may be:
\[
p_{bxx} = \frac{N_1 \Delta}{r \Delta N_h B_w} [1 + n_{cg}] F_D F_V \quad \text{kN/m}^2 (\text{tf/m}^2, \text{psi})
\]

3.1.3 Hydrostatic Pressure (1 July 2021)
\[
p_d = N_3 (0.64H + d) \quad \text{kN/m}^2 (\text{tf/m}^2, \text{psi})
\]
where
\[
n_{cg} = \text{the vertical acceleration of the craft as determined by a model test, theoretical computation, or service experience (see Section 3-1-3). If this information is not readily available during the early stages of design, the following formula utilizing the average 1/100 height vertical accelerations at LCG can be used:}
\[
n_{cg} = N_2 \left[ \frac{12h}{N_h B_w} + 1.0 \right] \left[ 50 - \beta_{cg} \right] \frac{V^2 (N_h B_w)^2}{\Delta} \quad \text{g’s}
\]
The maximum and minimum vertical accelerations defined in 3-2-2/1.3.1 are applicable to multihull craft.

\[
\beta_w = \text{maximum waterline beam of one hull, in m (ft)}
\]
\[
N_h = \text{number of hulls}
\]
For multi-hull form with hulls of different breadths, "\(N_h B_w\)" is to be taken as the sum of the maximum waterline beam of each hull.

3.3 Side and Transom Structure, Design Pressure
The side design pressure, \(p_s\), is to be not less than given by the equations:

3.3.1 Slamming Pressure
\[
p_{sxx} = \frac{N_1 \Delta}{r \Delta N_h B_w} [1 + n_{xx}] \left[ \frac{70 - \beta_{xx}}{70 - \beta_{cg}} \right] F_D \quad \text{kN/m}^2 (\text{tf/m}^2, \text{psi})
\]

3.3.2 Hydrostatic Pressure
\[
p_x = N_3 (H_s - y) \quad \text{kN/m}^2 (\text{tf/m}^2, \text{psi})
\]

3.3.3 Fore End (1 July 2021)
\[
p_{sf} = 0.28F_D C_F N_3 (0.22 + 0.15 \tan \alpha) (0.4V \sin \beta + 0.6 \sqrt{L})^2 \quad \text{kN/m}^2 (\text{tf/m}^2)
\]
\[ p_{sf} = 0.28 F_a C_F N_3 (0.22 + 0.15 \tan \alpha)(0.4 V \sin \beta + 0.33 \sqrt{D})^2 \text{ psi} \]

where \( L \) is generally not to be taken less than 30 m (98 ft)

where

\[ p_{sxx} = \text{side design slamming pressure at any section clear of LCG, in kN/m}^2 (\text{tf/m}^2, \text{psi}). \]

For craft greater than 24 m (79 ft) in length, the side design slamming pressure applies both along the entire length below \( L/12 \) above baseline and to the region forward of 0.125\( L \)

\[ p_s = \text{side design pressure due to hydrostatic forces, in kN/m}^2 (\text{tf/m}^2, \text{psi}), \]

but is not to be taken less than the following:

\[ = 0.05 N_3 L \text{ kN/m}^2 (\text{tf/m}^2, \text{psi}) \text{ at or below } L/15 \text{ above the base line or at any height above base line forward of } 0.125L \text{ from the stem.} \]

\[ = 0.33 N_3 L \text{ kN/m}^2 (\text{tf/m}^2, \text{psi}) \text{ at or below } L/15 \text{ above the base line, aft of } 0.125L \text{ from the stem.} \]

\[ p_{sf} = \text{side design pressure for forward of } 0.125L \text{ from the stem.} \]

\[ y = \text{distance above base line, m (ft), of location being considered.} \]

\[ L = \text{craft length, as defined in 3-1-3/3} \]

\[ F_a = 3.25 \text{ for plating and 1.0 for longitudinals, transverses and girders} \]

\[ C_F = 0.0125 L \text{ for } L < 80 \text{ m (0.00381 } L \text{ for } L < 262 \text{ ft)} \]

\[ = 1.0 \text{ for } L \geq 80 \text{ m (262 ft)} \]

\[ a = \text{flare angle, the angle between a vertical line and the tangent to the side shell plating, measured in a vertical plane at } 90^\circ \text{ to the horizontal tangent to the side shell, see 3-2-2/1.3.1(c) FIGURE 1.} \]

\[ \beta = \text{entry angle, the angle between a longitudinal line, parallel to the centerline and the horizontal tangent to the side shell, see 3-2-2/1.3.1(c) FIGURE 1.} \]

\[ N_1, N_3, \Delta, L_w, B_w, V, n_{xx}, \beta_{cy}, H, d \text{ and } F_D \text{ are as defined in } 3-2-2/1.3.1, b_{sx}, \text{ is as defined in } 3-2-2/1.3.2, N_h \text{ and } B_w \text{ are as defined in } 3-2-2/3.1. \]

### 3.5 Wet Deck or Cross Structure

The wet deck design pressure is to be determined by the following equations:

#### 3.5.1 Wet Deck Design Pressure for Craft Less Than 61 meters (200 feet) (1 July 2021)

\[ p_{wd} = 30 N_1 F_p F_V V_1 \left(1 - 0.85 h_a / h_{1/3} \right) \text{ kN/m}^2 (\text{tf/m}^2, \text{psi}) \]

#### 3.5.2 Wet Deck Design Pressure for Craft 61 meters (200 feet) or Greater (1 July 2021)

For craft greater than 61 meters (200 feet), the design pressure should be determined by the direct analysis or model test. The equation below is to be used in the early stages of design prior to the direct analysis or model test:
\[ p_{wd} = 55F_D V_1^{0.1} V_1 \left( 1 - 0.35 \frac{h_a}{h_{1/3}} \right) \text{ kN/m}^2 (\text{tf/m}^2, \text{psi}) \]

where

\[ N_1 = 0.10 \ (0.010, 0.00442) \]

\[ h_a = \text{vertical distance, in m (ft), from lightest draft waterline to underside of wet deck, at design point in question for } L < 61 \text{ m (200 feet)} \]

\[ h_a = \text{vertical distance, in m (ft), from actual draft waterline to underside of wet deck, at design point in question for } L \geq 61 \text{ m (200 feet)} \]

\[ h_a \text{ is not to be greater than } 1.176 h_{1/3} \]

\[ F_1 = \text{wet deck pressure distribution factor as given in 3-2-2/11.7 FIGURE 9} \]

\[ V_1 = \text{relative impact velocity as given below:} \]

\[ V_1 = \begin{cases} \frac{4h_{1/3}}{\sqrt{L}} + 1 \text{ m/s} & \frac{7.24h_{1/3}}{\sqrt{L}} + 3.28 \text{ ft/s} \text{ for } L < 61 \text{ m (200 feet)} \\ \frac{5h_{1/3}}{L} + 1 \text{ m/s} & \frac{16.4h_{1/3}}{L} + 3.28 \text{ ft/s} \text{ for } L \geq 61 \text{ m (200 feet)} \end{cases} \]

\[ V, h_{1/3} \text{ and } F_D \text{ are as defined in 3-2-2/1.3.1. } V \text{ is not to be greater than 20 knots for craft greater than 61 m (200 feet).} \]

5 \ Deck Design Pressures – All Vessels

The design pressures, \( p_d \), are to be as given in 3-2-2/11.7 TABLE 4, see 3-2-2/11.7 FIGURE 4 and 3-2-2/11.7 FIGURE 5.

7 \ Superstructures and Deckhouses – All Vessels

The design pressures, \( p \), are to be given by the equation below, but are not to be taken less than the pressures in 3-2-2/11.7 TABLE 5 (also see 3-2-2/11.7 FIGURE 4 and 3-2-2/11.7 FIGURE 5).

\[ p = N_3 a [(b f) - y] c \text{ kN/m}^2 (\text{tf/m}^2, \text{psi}) \]

where

\[ N_3 = 9.8 \ (1.0, 0.44) \]

\[ a = \text{coefficient given in 3-2-2/7 TABLE 3} \]

\[ b = 1.0 + \left[ \frac{(x/L - 0.45)}{C_b + 0.20} \right]^2 \text{ where } x/L \leq 0.45 \]

\[ b = 1.0 + 1.5 \left[ \frac{(x/L - 0.45)}{C_b + 0.20} \right]^2 \text{ where } x/L > 0.45 \]

\[ C_b = \text{block coefficient as defined in 3-1-1/17.3, not to be taken less than 0.60, nor greater than 0.80.} \]

For aft end bulkheads forward of amidships, \( C_b \) need not be taken less than 0.80.

\[ x = \text{distance, in m (ft), between the after perpendicular and the bulkhead being considered.} \]

Deckhouse side bulkheads are to be divided into equal parts not exceeding 0.15\( L \) in length and \( x \) is to be measured from the after perpendicular to the center of each part considered.

\[ L = \text{length of vessel, in m (ft), as defined in 3-1-1/3} \]
\[ f = \left( L/10 \right) \left( e^{-L/300} \right) - \left[ 1 - \left( L/150 \right)^2 \right] \text{ for } L \text{ in m} \]
\[ f = \left( L/10 \right) \left( e^{-9L/100} \right) - \left[ 3.28 - \left( L/272 \right)^2 \right] \text{ for } L \text{ in ft} \]

\[ y = \text{ vertical distance in m (ft), from the summer load waterline to the midpoint of the stiffener span} \]

\[ c = (0.3 + 0.7b_1/B_1), \text{ but is not to taken as less than 1.0 for exposed machinery casing bulkheads.} \]
\[ \text{In no case is } b_1/B_1 \text{ to be taken as less than 0.25.} \]

\[ b_1 = \text{ breadth of deckhouse at position being considered} \]
\[ B_1 = \text{ actual breadth of vessel at the freeboard deck at the position being considered} \]

### TABLE 3

**Values of \( \alpha \)**

<table>
<thead>
<tr>
<th>Bulkhead Location</th>
<th>Metric Units</th>
<th>US Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unprotected front Lowest tier</td>
<td>2.0 + L/120</td>
<td>2.0 + L/394</td>
</tr>
<tr>
<td>Unprotected front Second tier</td>
<td>1.0 + L/120</td>
<td>1.0 + L/394</td>
</tr>
<tr>
<td>Unprotected front Third tier and above</td>
<td>0.5 + L/150</td>
<td>0.5 + L/492</td>
</tr>
<tr>
<td>Protected front, all tiers</td>
<td>0.5 + L/150</td>
<td>0.5 + L/492</td>
</tr>
<tr>
<td>Sides, all tiers</td>
<td>0.5 + L/150</td>
<td>0.5 + L/492</td>
</tr>
<tr>
<td>Aft ends, aft of amidships, all tiers</td>
<td>0.7 + (L/1000) – 0.8(x/L)</td>
<td>0.7 + (L/3280) – 0.8(x/L)</td>
</tr>
<tr>
<td>Aft end, forward of amidships, all tiers</td>
<td>0.5 + (L/1000) – 0.4(x/L)</td>
<td>0.5 + (L/3280) – 0.4(x/L)</td>
</tr>
</tbody>
</table>

**9 Bulkhead Structure, Design Pressure – All Vessels**

#### 9.1 Tank Boundaries (1 July 2021)

The design pressure for tank boundaries, for both integral and non-integral tanks is to be not less than the following equations, whichever is greater:

\[ p_t = N_3 h \quad \text{kN/m}^2 (\text{tf/m}^2, \text{psi}) \]

\[ p_1 = \rho g (1 + 0.5n_{xx})h_2 \quad \text{kN/m}^2 (\text{tf/m}^2, \text{psi}) \]

where

\[ N_3 = \text{as defined in 3-2-2/1.1.1} \]
\[ h = \text{greatest of the following distances, in m (ft), from lower edge of plate panel or center of area supported by stiffener, to:} \]

1. A point located above the top of the tank, at a distance of two-thirds the height from the top of the tank to the top of the overflow.
2. A point located at two-thirds of the distance to the main weather deck.
3. A point located above the top of the tank, not less than the greater of the following:
   1. 0.01L + 0.15 m (0.01L + 0.5 ft)
   2. 0.46 m (1.5 ft)

where \( L \) is the vessel length as defined in 3-1-1/3.
\[ \rho g = \text{specific weight of the liquid, not to be taken less than } 10.05 \text{ kN/m}^3 (1.025 \text{ tf/m}^3, 0.44 \text{ lb/ft}^3) \]
\[ n_{xx} = \text{vertical acceleration at midspan of the tank, as defined in 3-2-2/1.1.4 for vessels having speed } V/\sqrt{L} \text{ less than 2.36 (1.3) and 3-2-2/1.3 for vessels having speed } V/\sqrt{L} \text{ not less than 2.36 (1.3)} \]
\[ h_2 = \text{distance from lower edge of plate panel or center of area supported by stiffener to the top of the tank, in m (ft)} \]

The heights of overflows are to be clearly indicated on the plans submitted for approval.

Pressurized tanks will be subject to special consideration.

9.3 Watertight Boundaries (1 July 2021)

The design pressure for watertight boundaries is to be not less than given by the following equation:

\[ p_w = N_3 h \quad \text{kN/m}^2 (\text{tf/m}^2, \text{psi}) \]

where

\[ N_3 = \text{as defined in 3-2-2/1.1.1} \]
\[ h = \text{distance, in m (ft), from the lower edge of plate panel or the center of area supported by the stiffener to the bulkhead deck at centerline} \]

11 Military Mission Loads

Loads on the hull structure are dependent on the vessel’s mission, payload and operational environment. For classification purposes, the following military mission loads must be accounted for in addition to the other loads and pressures defined in this Section:

i) The effect of a vessel’s own weaponry

ii) Vehicle and human loads (see 3-2-3/1.9 and 3-2-4/1.15)

iii) Take-off, landing, and stowage of helicopters

iv) Masts

v) Loads specified by the Naval Administration

11.1 Loads Imposed Against Own-Vessel Weapons Firing Effects

11.1.1 Weapon Foundations (1 July 2021)

The design of structure under weapon foundations is to withstand a point load not less than the following:

\[ F_w = W(1 + 0.5n_{xx}) + 1.3R \]

where

\[ W = \text{weight of weapon, in kN (tf, lbf)} \]
\[ n_{xx} = \text{vertical acceleration at location of weapon, as defined in 3-2-2/1.1.4 for vessels having speed } V/\sqrt{L} \text{ less than 2.36 (1.3) and 3-2-2/1.3 for vessels having speed } V/\sqrt{L} \text{ not less than 2.36 (1.3)} \]
\[ R = \text{rated break load of the gun recoil mechanism, in kN (tf, lbf)} \]
11.1.2 Gun Blast

The design pressure of structure, including bulwarks, in the vicinity of gun muzzles is not to be less than the following:

\[ P_{gb} = \frac{N_4(1 + \cos x)^2}{(r/c)^{1.5}} \text{ kN/m}^2 (\text{tf/m}^2, \text{psi}) \]

where

\[ N_4 = 1381 \ (141, 200) \]
\[ X = \text{angle of incidence, in degrees, see 3-2-2/11.1.2 FIGURE 2} \]
\[ r = \text{distance from end of gun muzzle to the point in question in mm (in.), see 3-2-2/11.1.2 FIGURE 2} \]
\[ C = \text{caliber (diameter) of the gun, in mm (in.)} \]

Special consideration will be given to grenade launchers, mortars, or other weapons that have a high caliber with a low blast effect due to the low speed of the projectile.

FIGURE 2

\[ X = \text{Arctan} \ (B/A) \]

11.1.3 Missile Blast

The design pressure of structure in the way of missile blasts is not to be less than the following:

\[ P_{mh} = \frac{T[\sin y + (0.225/\sin y)]}{A} \text{ kN/m}^2 (\text{tf/m}^2, \text{psi}) \]

where

\[ T = \text{total thrust of missile, in kN (tf, lbf)} \]
\[ Y = \text{angle of incidence in degrees, see 3-2-2/11.1.3 FIGURE 3} \]
\[ A = \text{impinged area of the surface, in m}^2 \text{ (in}^2), \text{ bounded by the blast cone} \]
11.3 Human Loads
Composite deck structures are to withstand a point load equivalent to the weight of a man (90.7 kg, 200 lbf) in the middle of the plate or the midspan stiffener.

11.5 Helicopter Decks
11.5.1 General
Helicopter decks, where provided, are to meet the following structural and safety requirements. The attention of owners, builders and designers is directed to various Naval Administration regulations and guides regarding the operational and other design requirements for helicopters on vessels. See also 4-6-4/3.9.2 and 4-6-6/7.

Plans showing the arrangement, scantlings and details of the helicopter deck are to be submitted. The arrangement plan is to show the overall size of the helicopter deck and the designated landing area. If the arrangement provides for the securing of a helicopter or helicopters to the deck, the predetermined position(s) selected to accommodate the secured helicopter, in addition to the locations of deck fittings, for securing the helicopter are to be shown. The type of helicopter to be considered is to be specified and calculations for appropriate loading conditions are to be submitted.

11.5.2 Overall Distributed Loading
For a platform type helicopter decks, a minimum distributed loading of 2010 N/m² (205 kgf/m², 42 lbf/ft²) is to be taken over the entire helicopter deck. For all other helicopter decks, the minimum overall distributed load is to be as specified in 3-2-2/11.7 TABLE 4.

11.5.3 Helicopter Landing and Impact Loading
A load of not less than 75% of the helicopter maximum take-off weight is to be taken on each of two square areas, 0.3 m × 0.3 m (1 ft × 1 ft). Alternatively, the manufacturer’s recommended wheel impact loading will be considered. The deck is to be considered for helicopter landings at any location within the designated landing area. The structural weight of the helicopter deck is to be added to the helicopter impact loading when considering girders, stanchions, truss supports, etc. Where the upper deck of a superstructure or deckhouse is used as a helicopter deck and the spaces below are normally manned (quarters, bridge, control room, etc.) the impact loading is to be multiplied by a factor of 1.15.

11.5.4 Stowed Helicopter Loading (1 July 2021)
If provisions are made to accommodate helicopter secured to the deck in a predetermined position, the structure is to be considered for a local loading not to be taken less than:

\[ P_{HC} = W_{to}(1 + 0.5n_{xx}) + C_e \quad \text{kN/m}^2 (\text{tf/m}^2, \text{psi}) \]

where
\( W_{to} = \) maximum take-off weight

\( n_{xx} = \) average vertical acceleration at the location under consideration as defined in 3-2-2/1.4 for vessels having speed \( V/\sqrt{L} \) less than 2.36 (1.3) and 3-2-2/1.3 for vessels having speed \( V/\sqrt{L} \) not less than 2.36 (1.3)

\( C_e = 0.49 \) (0.05, 0.07)

### 11.5.5 Special Landing Gear

Helicopters fitted with landing gear other than wheels will be specially considered

### 11.7 Masts

Masts are to be designed to a combined load that includes the effects of wind, gravity, and ship motion. In general, the wind load is not to be taken less than 1.45 kN/m² (0.145 tf/ft², 0.21 psi). The ship motion dynamic loads are to include roll, pitch, heave, and slam induced loads. It is also to be demonstrated that the natural frequency of the mast will not be reached during all intended operating conditions of the vessel. Masts constructed in position 1 (see 3-2-9/3) are to also consider the effects of green sea impact loads.

### TABLE 4

**Deck Design Pressures, \( p_d \) (1 July 2021)**

<table>
<thead>
<tr>
<th>Location</th>
<th>( kN/m^2 )</th>
<th>( tf/m^2 )</th>
<th>( psi )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposed freeboard deck, and superstructure and deckhouse decks forward of 0.25L</td>
<td>0.20L + 7.6</td>
<td>0.020L + 0.77</td>
<td>0.008L + 1.10</td>
</tr>
<tr>
<td>Freeboard deck inside enclosed superstructures and deckhouses, exposed superstructure and deckhouse decks aft of 0.25L, and internal decks included in the hull girder bending moment</td>
<td>0.10L + 6.1</td>
<td>0.010L + 0.62</td>
<td>0.004L + 0.88</td>
</tr>
<tr>
<td>Enclosed accommodations decks</td>
<td>5.0</td>
<td>0.5</td>
<td>0.71</td>
</tr>
<tr>
<td>Concentrated deck cargo loads</td>
<td>( W (1 + 0.5n_{xx}) )</td>
<td>( W (1 + 0.5n_{xx}) )</td>
<td>( W (1 + 0.5n_{xx}) )</td>
</tr>
<tr>
<td>Enclosed store rooms, machinery spaces, etc.</td>
<td>( \rho h (1 + 0.5n_{xx}) )</td>
<td>( \rho h (1 + 0.5n_{xx}) )</td>
<td>( (\rho/144)h (1 + 0.5n_{xx}) )</td>
</tr>
</tbody>
</table>

**Note:**

\( W = \) deck cargo load in kN/m² (tf/ft² psi).

\( n_{xx} = \) average vertical acceleration at the location under consideration as defined in 3-2-2/1.4 for vessels having speed \( V/\sqrt{L} \) less than 2.36 (1.3) and 3-2-2/1.3 for vessels having speed \( V/\sqrt{L} \) not less than 2.36 (1.3)

\( \rho = \) cargo density in kN/m³, tf/ft³, lb/ft³, not to be taken less than 7.04 (0.715, 44.8)

\( h = \) height of enclosed store room, machinery space, etc., in m (ft)

\( L = \) vessel length as defined in 3-1-1/3.

### TABLE 5

**Superstructures and Deckhouses Design Pressures**

**SI Units:**
### Table: Design Pressures

<table>
<thead>
<tr>
<th>Location</th>
<th>( L \leq 12.2m ) (kN/m²)</th>
<th>( 12.2m &lt; L \leq 30.5m ) (kN/m²)</th>
<th>( 30.5m &lt; L \leq 61m ) (kN/m²)</th>
<th>( 61m &lt; L \leq 90m ) (kN/m²)</th>
<th>( L &gt; 90m ) (kN/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superstructure and Deckhouse Front, forward of 0.4L - 1st Tier</td>
<td>37.9</td>
<td>2.45L + 7.97</td>
<td>82.8</td>
<td>0.55L + 49.5</td>
<td>98.7</td>
</tr>
<tr>
<td>Superstructure and Deckhouse Front, aft of 0.4L - 1st Tier</td>
<td>24.1</td>
<td>0.75L + 15</td>
<td>37.9</td>
<td>2.1L - 90</td>
<td>98.7</td>
</tr>
<tr>
<td>Superstructure and Deckhouse Front - 2nd Tier and above</td>
<td>9.8(2 + L/200)</td>
<td>9.8(2 + L/200)</td>
<td>0.46L + 7.2</td>
<td>0.46L + 7.2</td>
<td>0.46L + 7.2</td>
</tr>
<tr>
<td>Superstructure and Deckhouse Aft Ends and House Sides 1st Tier</td>
<td>10.3</td>
<td>0.19L + 8</td>
<td>13.8</td>
<td>0.27L - 2.6</td>
<td>0.27L - 2.6</td>
</tr>
<tr>
<td>Superstructure and Deckhouse Aft Ends and House Sides 2nd Tier and Above</td>
<td>10.3</td>
<td>10.3</td>
<td>10.3</td>
<td>0.22L - 3.1</td>
<td>9.8(1.25 + L/200)</td>
</tr>
<tr>
<td>House Tops forward of L/2</td>
<td>6.9</td>
<td>0.09L + 5.75</td>
<td>8.6</td>
<td>8.6</td>
<td>8.6</td>
</tr>
<tr>
<td>House Tops aft of L/2</td>
<td>3.4</td>
<td>0.19L + 1.1</td>
<td>6.9</td>
<td>6.9</td>
<td>6.9</td>
</tr>
</tbody>
</table>

#### MKS Units:

<table>
<thead>
<tr>
<th>Location</th>
<th>( L \leq 12.2m ) (tf/m²)</th>
<th>( 12.2m &lt; L \leq 30.5m ) (tf/m²)</th>
<th>( 30.5m &lt; L \leq 61m ) (tf/m²)</th>
<th>( 61m &lt; L \leq 90m ) (tf/m²)</th>
<th>( L &gt; 90m ) (tf/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superstructure and Deckhouse Front, forward of 0.4L - 1st Tier</td>
<td>3.87</td>
<td>0.25L + 0.81</td>
<td>8.44</td>
<td>0.05L + 5.05</td>
<td>10</td>
</tr>
<tr>
<td>Superstructure and Deckhouse Front, aft of 0.4L - 1st Tier</td>
<td>2.46</td>
<td>0.076L + 1.5</td>
<td>3.87</td>
<td>0.21L - 9.2</td>
<td>10</td>
</tr>
<tr>
<td>Superstructure and Deckhouse Front - 2nd Tier and above</td>
<td>2 + (L/200)</td>
<td>2 + (L/200)</td>
<td>0.047L + 0.73</td>
<td>0.047L + 0.73</td>
<td>0.047L + 0.73</td>
</tr>
<tr>
<td>Superstructure and Deckhouse Aft Ends and House Sides 1st Tier</td>
<td>1.05</td>
<td>0.02L + 0.82</td>
<td>1.41</td>
<td>0.027L - 0.26</td>
<td>0.027L - 0.26</td>
</tr>
<tr>
<td>Superstructure and Deckhouse Aft Ends and House Sides 2nd Tier and Above</td>
<td>1.05</td>
<td>1.05</td>
<td>1.05</td>
<td>0.022L - 0.32</td>
<td>1.25 + L/200</td>
</tr>
<tr>
<td>House Tops forward of L/2</td>
<td>0.7</td>
<td>0.009L + 0.59</td>
<td>0.88</td>
<td>0.88</td>
<td>0.88</td>
</tr>
<tr>
<td>House Tops aft of L/2</td>
<td>0.35</td>
<td>0.02L + 0.11</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
</tr>
</tbody>
</table>

#### US Units:

<table>
<thead>
<tr>
<th>Location</th>
<th>( L \leq 12.2m ) (tf/m²)</th>
<th>( 12.2m &lt; L \leq 30.5m ) (tf/m²)</th>
<th>( 30.5m &lt; L \leq 61m ) (tf/m²)</th>
<th>( 61m &lt; L \leq 90m ) (tf/m²)</th>
<th>( L &gt; 90m ) (tf/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superstructure and Deckhouse Front, forward of 0.4L - 1st Tier</td>
<td>3.87</td>
<td>0.25L + 0.81</td>
<td>8.44</td>
<td>0.05L + 5.05</td>
<td>10</td>
</tr>
<tr>
<td>Superstructure and Deckhouse Front, aft of 0.4L - 1st Tier</td>
<td>2.46</td>
<td>0.076L + 1.5</td>
<td>3.87</td>
<td>0.21L - 9.2</td>
<td>10</td>
</tr>
<tr>
<td>Superstructure and Deckhouse Front - 2nd Tier and above</td>
<td>2 + (L/200)</td>
<td>2 + (L/200)</td>
<td>0.047L + 0.73</td>
<td>0.047L + 0.73</td>
<td>0.047L + 0.73</td>
</tr>
<tr>
<td>Superstructure and Deckhouse Aft Ends and House Sides 1st Tier</td>
<td>1.05</td>
<td>0.02L + 0.82</td>
<td>1.41</td>
<td>0.027L - 0.26</td>
<td>0.027L - 0.26</td>
</tr>
<tr>
<td>Superstructure and Deckhouse Aft Ends and House Sides 2nd Tier and Above</td>
<td>1.05</td>
<td>1.05</td>
<td>1.05</td>
<td>0.022L - 0.32</td>
<td>1.25 + L/200</td>
</tr>
<tr>
<td>House Tops forward of L/2</td>
<td>0.7</td>
<td>0.009L + 0.59</td>
<td>0.88</td>
<td>0.88</td>
<td>0.88</td>
</tr>
<tr>
<td>House Tops aft of L/2</td>
<td>0.35</td>
<td>0.02L + 0.11</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Location</td>
<td>$L \leq 40$ ft (psi)</td>
<td>$40 \text{ ft } &lt; L \leq 100$ ft (psi)</td>
<td>$100 \text{ ft } &lt; L \leq 200$ ft (psi)</td>
<td>$200 \text{ ft } &lt; L \leq 295$ ft (psi)</td>
<td>$L &gt; 295$ ft (psi)</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>----------------------</td>
<td>----------------------------------------</td>
<td>----------------------------------------</td>
<td>----------------------------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>Superstructure and Deckhouse Front, forward of 0.4$L$ - 1st Tier</td>
<td>5.5</td>
<td>0.11$L$ + 1.17</td>
<td>12</td>
<td>0.026$L$ + 6.74</td>
<td>14.5</td>
</tr>
<tr>
<td>Superstructure and Deckhouse Front, aft of 0.4$L$ - 1st Tier</td>
<td>3.5</td>
<td>0.033$L$ + 2.17</td>
<td>5.5</td>
<td>0.095$L$ - 13.42</td>
<td>14.5</td>
</tr>
<tr>
<td>Superstructure and Deckhouse Front - 2nd Tier and above</td>
<td>0.44(6.6 + $L$/200)</td>
<td>0.44(6.6 + $L$/200)</td>
<td>0.02$L$ + 1.05</td>
<td>0.02$L$ + 1.05</td>
<td>0.02$L$ + 1.05</td>
</tr>
<tr>
<td>Superstructure and Deckhouse Aft Ends and House Sides 1st Tier</td>
<td>1.5</td>
<td>0.008$L$ + 1.17</td>
<td>2</td>
<td>0.012$L$ - 0.43</td>
<td>0.012$L$ - 0.43</td>
</tr>
<tr>
<td>Superstructure and Deckhouse Aft Ends and House Sides 2nd Tier and Above</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>0.01$L$ - 0.5</td>
<td>0.44(4.1 + $L$/200)</td>
</tr>
<tr>
<td>House Tops forward of $L$/2</td>
<td>1.0</td>
<td>0.004$L$ + 0.83</td>
<td>1.25</td>
<td>1.25</td>
<td>1.25</td>
</tr>
<tr>
<td>House Tops aft of $L$/2</td>
<td>0.5</td>
<td>0.008$L$ + 0.17</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

**FIGURE 4**
Decks, Superstructures, and Deckhouse Pressures
FIGURE 5
Decks, Superstructures, and Deckhouse Pressures

FIGURE 6
Design Area Factor $F_D$
FIGURE 7
Vertical Acceleration Distribution Factor $K_V$

$K_V$

Distance Along $L_w$ from Afterward End of $L_{sw}$

FIGURE 8
Vertical Acceleration Distribution Factor $F_V$

$F_V$

Distance Along $L_w$ from Forward End of $L_{sw}$

Extend to Forward Extent of Horizontal Chine or Running Stake in Bottom Shell
FIGURE 9
Wet Deck Pressure Distribution Factor $F_1$ (1 July 2021)

Distance Along $L_w$ from Afterward End of $L_w$
1 Aluminum or Steel

1.1 General (1 July 2021)

The bottom shell is to extend from the keel to the chine or upper turn of bilge. In general the side shell is to be of the same thickness from its lower limit to the gunwale.

All plating is to meet the requirements for thickness as given in 3-2-3/1.3.

In addition those areas of plating associated with primary hull strength are to meet the buckling criteria as given in 3-2-3/1.5. Where plate panels are subjected to other bending, biaxial, or a combination of stresses, they will be specially considered.

The thickness of the shell plating in way of skegs, shaft struts, hawse pipes, etc. is to be increased by 50% over that obtained from 3-2-3/1.3.

The thickness of water jet tunnels and transverse thruster tubes is to be in accordance with 3-2-3/1.7.

Where the plating forms decks for the access, operation or stowage of vehicles, the plating is in addition to meet the requirements of 3-2-3/1.9.

For all steel vessels with notation DV Naval Craft, Naval Craft, DV Coastal Naval Craft, and Coastal Naval Craft where Rule required minimum thickness is 6 mm (0.25 inches) or less, the Surveyor may apply standard gauging allowances. However, any major structural areas (i.e., deck, shell, tank, void, space boundaries, etc.) found to be less than 6 mm (0.25 inches) thickness and not renewed, are to be considered suspect areas. If the original thickness is going to be less than 6 mm (0.25 inches), it will require coatings and a requirement for maintenance of coatings to prevent excessive wastage between surveys.

Wastage limits for naval, coast guard or public government owned steel hull, standard displacement vessels of monohull design may be specially considered and approved by Engineering based on direct analysis.

1.3 Thickness

The thickness of the shell, deck or bulkhead plating is to be not less than obtained by the following equations, whichever is greater:
1.3.1 Lateral Loading

\[ t = s \sqrt{\frac{pk}{1000\sigma_a}} \text{ mm} \]

\[ t = s \sqrt{\frac{pk}{\sigma_a}} \text{ in.} \]

Where

- \( s \) = spacing, in mm (in.), of the shell, deck, superstructure, deckhouse or bulkhead longitudinals or stiffeners.
- \( p \) = design pressure, in kN/m² (tf/m², psi), given in Section 3-2-2
- \( k \) = plate panel aspect ratio factor, given in 3-2-3/1.3.1 TABLE 1
- \( \sigma_a \) = design stress, in N/mm² (kgf/mm², psi), given in 3-2-3/1.3.1 TABLE 2

### TABLE 1
Aspect Ratio Coefficient for Isotropic Plates

<table>
<thead>
<tr>
<th>( \ell / s )</th>
<th>( k )</th>
<th>( k_1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;2.0</td>
<td>0.500</td>
<td>0.028</td>
</tr>
<tr>
<td>2.0</td>
<td>0.497</td>
<td>0.028</td>
</tr>
<tr>
<td>1.9</td>
<td>0.493</td>
<td>0.027</td>
</tr>
<tr>
<td>1.8</td>
<td>0.487</td>
<td>0.027</td>
</tr>
<tr>
<td>1.7</td>
<td>0.479</td>
<td>0.026</td>
</tr>
<tr>
<td>1.6</td>
<td>0.468</td>
<td>0.025</td>
</tr>
<tr>
<td>1.5</td>
<td>0.454</td>
<td>0.024</td>
</tr>
<tr>
<td>1.4</td>
<td>0.436</td>
<td>0.024</td>
</tr>
<tr>
<td>1.3</td>
<td>0.412</td>
<td>0.021</td>
</tr>
<tr>
<td>1.2</td>
<td>0.383</td>
<td>0.019</td>
</tr>
<tr>
<td>1.1</td>
<td>0.348</td>
<td>0.017</td>
</tr>
<tr>
<td>1.0</td>
<td>0.308</td>
<td>0.014</td>
</tr>
</tbody>
</table>

Note:

- \( s \) = shorter edge of plate panel, in mm (in.)
- \( \ell \) = longer edge of plate panel, in mm (in.)

Intermediate values may be determined by linear interpolation.

### TABLE 2
Design Stress, \( \sigma_a \), Aluminum and Steel

<table>
<thead>
<tr>
<th>Location</th>
<th>Design Stress, ( \sigma_a ) (¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom Shell</td>
<td>Slamming Pressure: 0.90( \sigma_y ) (²)</td>
</tr>
<tr>
<td></td>
<td>Hydrostatic Pressure: 0.55( \sigma_y )</td>
</tr>
</tbody>
</table>
### Design Stress, $\sigma_a^{(1)}$

<table>
<thead>
<tr>
<th>Location</th>
<th>Slamming Pressure</th>
<th>Hydrostatic Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Jet Tunnels</td>
<td>$0.60\sigma_y$</td>
<td>$0.55\sigma_y$</td>
</tr>
<tr>
<td>Side Shell</td>
<td>Below Bulkhead Deck</td>
<td>$0.90\sigma_y$</td>
</tr>
<tr>
<td></td>
<td>Above Bulkhead Deck (i.e. foc’sles)</td>
<td>$0.90\sigma_y$</td>
</tr>
<tr>
<td>Deck Plating</td>
<td>Strength Deck</td>
<td>$0.60\sigma_y$</td>
</tr>
<tr>
<td></td>
<td>Lower Decks/Other Decks</td>
<td>$0.60\sigma_y$</td>
</tr>
<tr>
<td></td>
<td>Wet Decks</td>
<td>$0.90\sigma_y$</td>
</tr>
<tr>
<td></td>
<td>Superstructure and Deckhouse Decks</td>
<td>$0.60\sigma_y$</td>
</tr>
<tr>
<td>Bulkheads</td>
<td>Deep Tank</td>
<td>$0.60\sigma_y$</td>
</tr>
<tr>
<td></td>
<td>Watertight</td>
<td>$0.95\sigma_y$</td>
</tr>
<tr>
<td>Superstructure aft of 0.25$L$ from F.P. &amp; Deckhouses</td>
<td>Front, Sides, Ends, Tops</td>
<td>$0.60\sigma_y$</td>
</tr>
</tbody>
</table>

**Notes:**

1. $\sigma_y =$ yield strength of steel or of welded aluminum in N/mm² (kgf/mm² psi), but not to be taken greater than 70% of the ultimate strength of steel or welded aluminum

2. The design stress for bottom shell plates under slamming pressure may be taken as $\sigma_y$ for plates outside the midship 0.4$L$.

3. The design stress for steel deckhouse plates may be taken as $0.90\sigma_y$.

#### 1.3.2 Thickness Based on Secondary Stiffening

\[ t_s = 0.01s \text{ mm(in.)} \]

\[ t_{al} = 0.012s \text{ mm(in.)} \]

where

\[ t_s = \text{required thickness for steel vessels} \]

\[ t_{al} = \text{required thickness for aluminum vessels} \]

$s$ is as defined in 3-2-3/1.3.1.

#### 1.3.3 Minimum Thickness

The thickness of shell plating, decks and bulkheads is to be not less than obtained from the following equations:

1.3.3(a) Bottom Shell

\[ t_s = 0.44\sqrt{Lq_s} + 2.0 \text{ mm} \]

\[ t_s = 0.009\sqrt{Lq_s} + 0.08 \text{ in.} \]
\[ t_{al} = 0.70 \sqrt{Lq_a} + 1.0 \text{ mm} \]
\[ t_{al} = 0.015 \sqrt{Lq_a} + 0.04 \text{ in.} \]

where

- \( L \) = vessel length, as defined in 3-1-1/3
- \( q_s \) = 1.0 for ordinary strength steel; 245/\( \sigma_{ys} \), (25/\( \sigma_{ys} \), 34000/\( \sigma_{ys} \)) for higher strength steels, but not to be taken less than 0.72
- \( \sigma_{ys} \) = yield strength for higher strength steel, in N/mm\(^2\) (kgf/mm\(^2\), psi)
- \( q_a \) = 115/\( \sigma_{ya} \), (12/\( \sigma_{ya} \), 17000/\( \sigma_{ya} \)) for aluminum alloys
- \( \sigma_{ya} \) = minimum unwelded yield strength for aluminum alloys, in N/mm\(^2\) (kgf/mm\(^2\), psi), but not to be taken as more than 0.7 of the ultimate tensile strength in the as-welded condition

\( t_s \) and \( t_{al} \) as defined in 3-2-3/1.3.2. However, \( t_s \) is not to be taken less than 3.5 mm (0.14 in.) and \( t_{al} \) is not to be taken less than 4.0 mm (0.16 in.)

1.3.3(b) Side Shell
\[ t_s = 0.40 \sqrt{Lq_s} + 2.0 \text{ mm} \]
\[ t_s = 0.009 \sqrt{Lq_s} + 0.08 \text{ in.} \]
\[ t_{al} = 0.62 \sqrt{Lq_a} + 1.0 \text{ mm} \]
\[ t_{al} = 0.013 \sqrt{Lq_a} + 0.04 \text{ in.} \]

where \( t_s \) and \( t_{al} \) are as defined in 3-2-3/1.3.2. However, \( t_s \) is not to be taken less than 3.0 mm (0.12 in.) and \( t_{al} \) is not to be taken less than 3.5 mm (0.14 in.)

\( q_s, q_a, \) and \( L \) are as defined in 3-2-3/1.3.3(a).

1.3.3(c) Strength Deck
\[ t_s = 0.40 \sqrt{Lq_s} + 1.0 \text{ mm} \]
\[ t_s = 0.009 \sqrt{Lq_s} + 0.04 \text{ in.} \]
\[ t_{al} = 0.62 \sqrt{Lq_a} + 1.0 \text{ mm} \]
\[ t_{al} = 0.013 \sqrt{Lq_a} + 0.04 \text{ in.} \]

where \( t_s \) and \( t_{al} \) are as defined in 3-2-3/1.3.2. However, \( t_s \) is not to be taken less than 3.0 mm (0.12 in.) and \( t_{al} \) is not to be taken less than 3.5 mm (0.14 in.)

\( q_s, q_a, \) and \( L \) are as defined in 3-2-3/1.3.3(a).

1.3.3(d) Lower Decks, W.T. Bulkheads, Deep Tank Bulkheads
\[ t_s = 0.35 \sqrt{Lq_s} + 1.0 \text{ mm} \]
\[ t_s = 0.007 \sqrt{Lq_s} + 0.04 \text{ in.} \]
\[ t_{al} = 0.52 \sqrt{Lq_a} + 1.0 \text{ mm} \]
\[ t_{al} = 0.011 \sqrt{Lq_a} + 0.04 \text{ in.} \]

where \( t_s, t_{al}, q_s, q_a \) and \( L \) are as defined in 3-2-3/1.3.2. However, \( t_s \) is not to be taken less than 3.0 mm (0.12 in.) and \( t_{al} \) is not to be taken less than 3.5 mm (0.14 in.).

Where the use is made of special purpose aluminum extrusions or special welding techniques are utilized the minimum plate thickness, as given in 3-2-3/1.3.3 above, will be specially considered based on location, purpose and material grades.

1.5 Buckling Criteria

1.5.1 Uni-axial Compression

1.5.1(a) Ideal Elastic Stress

\[ \sigma_E = 0.9 m_1 E \left( \frac{t_b}{s} \right)^2 \text{ N/mm}^2(\text{kgf/mm}^2, \text{psi}) \]

Where

- \( m_1 = \) buckling coefficient as given in 3-2-3/1.5.2(d) TABLE 3.
- \( E = \) for steel: \( 2.06 \times 105 \text{ N/mm}^2 (21,000 \text{ kgf/mm}^2, 30 \times 106 \text{ psi}) \)
  for aluminum: \( 6.9 \times 104 \text{ N/mm}^2 (7,000 \text{ kgf/mm}^2, 10 \times 106 \text{ psi}) \)
- \( t_b = \) thickness of plating, in mm (in.)
- \( s = \) shorter side of plate panel, in mm (in.)
- \( \ell = \) longer side of plate panel, in mm (in.)

1.5.1(b) Critical Buckling Stress

The critical buckling stress in compression, \( \sigma_c \), is determined as follows:

\[ \sigma_c = \sigma_E \text{ when } \sigma_E \leq 0.5 \sigma_y \]

\[ = \sigma_y \left( 1 - \frac{\sigma_y}{\sigma_E} \right) \text{ when } \sigma_E > 0.5 \sigma_y \]

where

- \( \sigma_y = \) yield stress of material, in N/mm\(^2\) (kgf/mm\(^2\), psi)
- \( \sigma_E = \) ideal elastic buckling stress calculated in 3-2-3/1.5.1

1.5.1(c) Calculated Compressive Stress

The compressive stresses are given in the following formula:

\[ \sigma_a = c_5 \left( \frac{M_t}{I} \right) \text{ N/mm}^2(\text{kgf/mm}^2, \text{psi}) \]

where

\[ c_5 = \left( \frac{Lq_a}{Lq_a + L} \right)^{0.5} \]
\[ \sigma_a = \ \text{working compressive stress in panel being considered, N/mm}^2 (\text{kgf/mm}^2, \text{psi}), \text{but}
\]
generally not less than the following:
\[ \frac{f_p \, SM_R}{C \, SM_A} \, \text{N/mm}^2(\text{kgf/mm}^2, \text{psi}) \]
\[ c_5 = 10^5 (10^3, 322,560) \]
\[ M_t = \ \text{maximum total bending moment as given in 3-2-1/1.1.2(e), kN-m (tf-m, Ltf-ft)} \]
\[ y = \ \text{vertical distance, in m (ft), from the neutral axis to the considered location} \]
\[ I = \ \text{moment of inertia of the hull girder, cm}^4 (\text{in}^4) \]
\[ f_p = 175 \, \text{N/mm}^2 (17.84 \, \text{kgf/mm}^2, 25,380 \, \text{psi}) \]
\[ Q = \ \text{applicable factor for steel or aluminum as defined in 3-2-1/1.1.2(e)} \]
\[ SM_R = \ \text{hull girder section modulus as required in Section 3-2-1, cm}^3\text{-m (in}^3\text{-ft)} \]
\[ SM_A = \ \text{section modulus of the hull girder at the location being considered, cm}^3\text{-m (in}^3\text{-ft)} \]

1.5.1(d) Permissible Buckling Stress

The design buckling stress, \( \sigma_c \), of plate panels [as calculated in 3-2-3/1.5.1(b)] is to be such that:
\[ \sigma_c \geq \sigma_a \]

1.5.2 Shear

1.5.2(a) Ideal Elastic Buckling Stress
\[ \tau_E = 0.9 m_2 E \left( \frac{t}{s} \right)^2 \, \text{N/mm}^2(\text{kgf/mm}^2, \text{psi}) \]

Where
\[ m_2 = \ \text{buckling coefficient as given in 3-2-3/1.5.2(d) TABLE 3} \]
\[ E = \ \text{for steel:} \quad 2.06 \times 10^5 \, \text{N/mm}^2 (21,000 \, \text{kgf/mm}^2, 30 \times 10^6 \, \text{psi}) \]
\[ \text{for aluminum:} \quad 6.9 \times 10^4 \, \text{N/mm}^2 (7,000 \, \text{kgf/mm}^2, 10 \times 10^6 \, \text{psi}) \]
\[ t_b = \ \text{thickness of plating, in mm (in.)} \]
\[ s = \ \text{shorter side of plate panel, in mm (in.)} \]
\[ l = \ \text{longer side of plate panel, in mm (in.)} \]

1.5.2(b) Critical Buckling Stress

The critical buckling stress in shear, \( \tau_c \), is determined as follows:
\[ \tau_c = \tau_E \quad \text{when} \quad \tau_E \leq 0.5 \tau_y \]
\[ \tau_c = \tau_y \left( 1 - \frac{\tau_y}{4 \tau_E} \right) \quad \text{when} \quad \tau_E > 0.5 \tau_y \]

where
\[ \tau_y = \ \text{minimum shear yield stress of material, in N/mm}^2 (\text{kgf/mm}^2, \text{psi}) \]
\[ = \frac{\sigma_{yw}}{\sqrt{3}} \]
\[ \sigma_{yw} = \text{welded yield strength of material, in N/mm}^2 (\text{kgf/mm}^2, \text{psi}). \]

\[ \tau_E = \text{ideal elastic buckling stress calculated in 3-2-3/1.5.2(a)} \]

1.5.2(c) Calculated Shear Stress
The working shear stress, \( \tau_a \), in the side shell or longitudinal bulkhead plating is to be calculated by an acceptable and recognized method.

1.5.2(d) Permissible Buckling Stress
The design buckling stress, \( \tau_c \), of plate panels [as calculated in 3-2-3/1.5.2(b)] is to be such that:

\[ \tau_c \geq \tau_a \]

**TABLE 3**
Buckling Coefficients \( m_1 \) and \( m_2 \)

A Uniaxial compression

1. Plates with longitudinal framing, \( \ell \geq s \)

   \[ m_1 = \begin{cases} 4 & \text{for } \sigma' = \sigma \\ 5.8 & \text{for } \sigma' = \sigma/3 \end{cases} \]

   c. For intermediate values \( m_1 \) may be obtained by interpolation between a and b

2. Plates with transverse framing, \( \ell \geq s \)

   \[ m_1 = \begin{cases} C_2[1 + (s/\ell)^2]^2 & \text{for } \sigma' = \sigma \\ 1.45C_2[1 + (s/\ell)^2]^2 & \text{for } \sigma' = \sigma/3 \end{cases} \]

   c. For intermediate values \( m \) may be obtained by interpolation between a and b

Values of \( C_2 \)

\[ \begin{align*} C_2 & = 1.30 \text{ where supported by floors or deep members} \\ & = 1.21 \text{ where stiffeners are T-sections or angle bars} \\ & = 1.10 \text{ where stiffeners are bulb plates} \end{align*} \]
= 1.05 where stiffeners are flat bars

B Edge Shear

\[ M_2 = 5.34 + 4(s/\ell)^2 \]

1.7 Water Jet Tunnels and Transverse Thruster Tubes

1.7.1 Water Jet Tunnels

The thickness for the water jet tunnel plating is to be not less than required by 3-2-3/1.3, neither is it to be less than the greater of the jet manufacturer’s recommended thickness or that obtained from the following equation:

\[ t = s \sqrt{\frac{p_t k}{1000 \sigma_a}} \] mm
\[ t = s \sqrt{\frac{p_t k}{\sigma_a}} \] in.

where

\[ p_t = \text{maximum positive or negative tunnel design pressure, in kN/m}^2 \text{ (tf/ft}^2 \text{, psi), as provided by the jet manufacturer.} \]

\[ s, k \text{ and } \sigma_a \text{ are as given in 3-2-3/1.3.} \]

1.7.2 Transverse Thruster Tunnels (2020)

The thickness of the tunnel plating for the transverse thrusters is to be not less than required by 3-2-3/1.3, nor less than obtained from the following equation:

\[ t = 0.008d \sqrt{Q} + 3.0 \] mm
\[ t = 0.008d \sqrt{Q} + 0.12 \] in.

where

\[ d = \text{inside diameter of the tunnel in mm (in.), but is taken as not less than 968 mm (38 in.) for vessels over 40 m (131 ft) in length or not less than 600 mm (24 in.) for vessels 40 m (131 ft) or less in length} \]

In any case, \( t \) is not to be taken less than plating thickness for thruster tunnels recommended in the vendor’s drawing, as applicable.

\( Q \) is as given in 3-2-1/1.1.
1.9 Decks Provided for the Operation or Stowage of Vehicles (1 July 2021)

\[ t = \sqrt{\frac{\beta W(1 + 0.5n_{xx})}{\sigma_a}} \text{ mm(in.)} \]

where

- \( W \) = static wheel load, in N (lbf)
- \( n_{xx} \) = average vertical acceleration at the location under consideration as defined in 3-2-2/1.1.4 for displacement vessels and 3-2-2/1.3 for vessels with a speed \( V/\sqrt{L} \) not less than 2.36 (1.3)
- \( \beta \) = as given in 3-2-3/1.9 FIGURE 1
- \( \sigma_a \) = design stress for decks, in N/mm\(^2\) (kgf/mm\(^2\), psi), given in 3-2-3/1.3.1 TABLE 2

For wheel loading, strength deck plating thickness is to be not less than 110% of that required by the above equation, and platform deck plating thickness is to be not less than 90% of that required by the above equation.

Where the wheels are close together, special consideration will be given to the use of combined imprint and load. Where the intended operation is such that only the larger dimension of the wheel imprint is perpendicular to the longer edge of the plate panel, then \( b \) below may be taken as the smaller wheel imprint dimension, in which case, \( a \) is to be the greater one.

![FIGURE 1 Values for \( \beta \)](image)

<table>
<thead>
<tr>
<th>( b/s )</th>
<th>( \ell/s = 1 )</th>
<th>( \ell/s = 1.4 )</th>
<th>( \ell/s \geq 2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( a/s )</td>
<td>0 0.2 0.4 0.6 0.8 1</td>
<td>0 0.2 0.4 0.8 1.2 1.4</td>
<td>0 0.4 0.8 1.2 1.6 2</td>
</tr>
<tr>
<td>0</td>
<td>1.82 1.38 1.12 0.93 0.76</td>
<td>2.00 1.55 1.12 0.84 0.75</td>
<td>1.64 1.20 0.97 0.78 0.64</td>
</tr>
<tr>
<td>0.2</td>
<td>1.82 1.28 1.08 0.90 0.76 0.63</td>
<td>1.78 1.43 1.23 0.95 0.74 0.64</td>
<td>1.73 1.31 1.03 0.84 0.68 0.57</td>
</tr>
<tr>
<td>0.4</td>
<td>1.39 1.07 0.84 0.72 0.62 0.52</td>
<td>1.39 1.13 1.00 0.80 0.62 0.55</td>
<td>1.32 1.08 0.88 0.74 0.60 0.50</td>
</tr>
<tr>
<td>0.6</td>
<td>1.12 0.90 0.74 0.60 0.52 0.43</td>
<td>1.10 0.91 0.82 0.68 0.53 0.47</td>
<td>1.04 0.90 0.76 0.64 0.54 0.44</td>
</tr>
<tr>
<td>0.8</td>
<td>0.92 0.76 0.62 0.51 0.42 0.36</td>
<td>0.90 0.76 0.68 0.57 0.45 0.40</td>
<td>0.87 0.76 0.63 0.54 0.44 0.38</td>
</tr>
<tr>
<td>1</td>
<td>0.76 0.63 0.52 0.42 0.35 0.30</td>
<td>0.75 0.62 0.57 0.47 0.38 0.33</td>
<td>0.71 0.61 0.53 0.45 0.38 0.30</td>
</tr>
</tbody>
</table>

**Note:**

- \( s \) = spacing of deck beams or deck longitudinals, in mm (in.)
\[ \ell = \text{length of plate pane, in mm (in.)} \]

\[ a = \text{wheel imprint dimension, in mm (in.), paralleled to the shorter edge, } s, \text{ of the plate panel} \]

\[ b = \text{wheel imprint dimension, in mm (in.), parallel to the longer edge, } \ell, \text{ of the plate panel} \]

### 3 Aluminum Extruded Planking, Aluminum Sandwich Panels and Corrugated Panels

#### 3.1 Aluminum Extruded Planking

Extruded planking is to be reviewed similar to a conventional stiffener and plate combination. The required thickness of the planking between stiffeners is given in 3-2-3/1.3 and 3-2-3/1.5. For box and truss type extrusion, the plate spacing is to be taken as the maximum unsupported span of plate as indicated in 3-2-3/3.1 FIGURE 2. The stiffeners on the planking are to comply with the requirements in 3-2-4/1.3, 3-2-4/1.5 and 3-2-4/1.7. The geometry of stiffeners in box and truss type extrusions is as indicated in 3-2-3/3.1 FIGURE 2. The individual planking pieces are to be attached by continuous welding for the main deck and can be welded intermittently for interior accommodation decks. The intermittent weld for the interior decks is to be sized in accordance with 3-2-13/1 for beams and stiffeners to deck. The use of adhesives for attaching planking members used for weather coverings is to be specially considered.

![FIGURE 2 Extruded Planking](image)

#### 3.3 Aluminum Sandwich Panels

An aluminum sandwich panel is a panel with thin aluminum skins attached to a thicker core material. These panels are to be typically used on enclosed decks or bulkheads. Where exposed panels are proposed the effects due to heat and the coefficients of thermal expansion are to be addressed. In general, the inner and outer skins are to be of the same thickness. The use of aluminum sandwich panels for helicopter decks and wheel loading will be specially considered. Aluminum sandwich panels are to comply with the equations given below:

### 3.3.1 Section Modulus of Skins

The section modulus about the neutral axis of a strip of sandwich panel, 1 cm (1 in.) wide is not to be less than the following equation:

\[ SM = \frac{s^2 pk}{6 \times 10^7 \sigma_a} \quad \text{cm}^3 \]

\[ SM = \frac{s^2 pk}{6\sigma_a} \quad \text{in}^3 \]
where

\[ s = \text{spacing of the shell or deck longitudinals or superstructure, deckhouse or bulkhead stiffener, in mm (in.). It is always to be the lesser dimension of the unsupported plate panels} \]

\[ p = \text{design pressure, given in Section 3-2-2} \]

\[ k_1 = \text{coefficient varying with plate panel aspect ratio, given in 3-2-3/1.3.1 TABLE 1} \]

\[ \sigma_a = \text{design stress, given in 3-2-3/1.3.1 TABLE 2} \]

### 3.3.2 Moment of Inertia of Skins

The moment of inertia about the neutral axis of a strip of sandwich panel, 1 cm (1 in.) wide is not to be less than the following equation:

\[
I = \frac{s^3 p k_1}{120 \times 10^5 \cdot 0.24 E} \text{ cm}^4
\]

\[
I = \frac{s^3 p k_1}{0.24 E} \text{ in}^4
\]

where

\[ s = \text{spacing of the shell or deck longitudinals or superstructure, deckhouse or bulkhead stiffener, in mm (in.). It is always to be the lesser dimension of the unsupported plate panels} \]

\[ p = \text{design pressure, given in Section 3-2-2} \]

\[ k_1 = \text{coefficient varying with plate panel aspect ratio, given in 3-2-3/1.3.1 TABLE 1} \]

\[ E = \text{tensile modulus of aluminum, in N/mm}^2 \text{ (kgf/mm}^2, \text{ psi), as defined in 3-2-3/1.5.2} \]

### 3.3.3 Core Shear Strength

The thickness of core and sandwich is to be not less than given by the following equation:

\[
\frac{d_o + d_c}{2} = \frac{v p s}{1000 \sigma_a} \text{ mm}
\]

\[
\frac{d_o + d_c}{2} = \frac{v p s}{\tau} \text{ in}
\]

where

\[ d_o = \text{overall thickness of sandwich, in mm (in.)} \]

\[ d_c = \text{thickness of core, in mm (in.)} \]

\[ v = \text{coefficient varying with plate panel aspect ratio, given in 3-2-3/5.7.3 TABLE 6} \]

\[ s = \text{lesser dimension of plate panel, in mm (in.)} \]

\[ p = \text{design pressure, in kN/m}^2 \text{ (tf/m}^2, \text{ psi), as defined in Section 3-2-2} \]

\[ \tau = \text{design stress, N/mm}^2 \text{ (kgf/mm}^2, \text{ psi), as shown in 3-2-3/5.7.3 TABLE 7} \]

### 3.3.4 Testing

The core material and the attachment of the skins to the core are to be tested in accordance with the requirements in 2-6-5/9
3.3.5 Attachment

Typically, beams and stiffeners are not to be considered as effectively attached. Panels are not to be welded to unless the possible damage from heat is addressed. The panels are to be bolted to surrounding structure. The use of adhesives will be specially considered.

3.5 Corrugated Panels

3.5.1 Plating

The plating of corrugated panels is to be of the thickness required by 3-2-3/1.3 with the following modification. The spacing to be used is the greater of dimensions $a$ or $c$ as indicated in 3-2-4/1.7.1 FIGURE 3.

5 Fiber Reinforced Plastic

5.1 General (1 July 2021)

The shell, decks and bulkheads may be either single skin or sandwich construction. Where both are used, a suitable transition is to be obtained between them with a minimum 12:1 taper ratio.

The bottom shell is to extend to the chine or upper bilge turn. A suitable transition is to be obtained between the bottom and side shell plating. The shell thickness in way of the keel is to be 50% greater and in way of shaft struts and skegs is to be 100% greater than the thickness required by 3-2-3/5.5.1 or 3-2-3/5.5.2, as applicable. For this purpose, pressure $p_b$ as obtained from 3-2-2/1.3.1 or 3-2-2/3.1 and actual frame spacing at the location of the member are to be used for 3-2-3/5.5.1. Suitable framing reinforcement is to be provided in way of shaft struts. Bow thruster tube thickness is to be equivalent to the surrounding shell thickness.

The shell, deck or bulkhead laminates may be bi-directional (having essentially same strength and elastic properties in the two in-plane principal axes of the shell, deck or bulkhead) or uni-directional (having different strength or elastic properties in the two principal axes of the shell, deck or bulkhead panels). Bonding angles or tapes are to have essentially same strength and elastic properties as the plating laminate being bonded, and are in general to be in accordance with Section 3-2-6.

5.3 Fiber Reinforcement

The basic laminate given in Part 2, Chapter 6 or other approved laminate of glass, aramid or carbon fiber in mat, woven roving, cloth, knitted fabric or non-woven uni-directional reinforcing, plies may be used. Equivalent strength and thickness of other than E-glass base laminate is to be assessed in a laminate stack program on the basis of first ply failure. For the shell and deck a sufficient number of plies are to be laid-up with the warp in the 0° (longitudinal) axis. Warp and fill directions are to be aligned parallel to the respective edges of the shell and deck panels as closely as practicable. Depending on the directionality and fiber orientation of these plies, other plies may be required or permitted in the 90° (transverse) axis; reinforcing plies in other axes such as +45° (diagonal) may also be used, when approved.

Where the strength and stiffness in the two principal axes of the panel are different, panel bending in each of the panel principal axes is to be considered. See 3-2-3/5.5.2 and 3-2-3/5.7.2.

5.5 Single Skin Laminate

5.5.1 With Essentially Same Properties in 0° and 90° Axes

The thickness of the shell, deck or bulkhead plating is to be not less than given by the following equations:

$5.5.1(a)$ All Plating

$$t = sc \sqrt{\frac{pk}{1000\sigma_a}} \text{ mm}$$

$$t = sc \sqrt{\frac{pk}{\sigma_a^2}} \text{ in}.$$
5.5.1(b) All Plating
\[ t = s c \sqrt[3]{\frac{p k_1}{10000 k_2 E F}} \text{ mm} \]
\[ t = s c \sqrt[3]{\frac{p k_1}{k_2 E F}} \text{ in.} \]

5.5.1(c) Strength Deck and Shell
\[ t = k_3 (c_1 + 0.26L) l_1 \text{ mm} \]
\[ t = k_3 (c_1 + 0.0031L) l_1 \text{ in.} \]

L is generally not to be taken less than 12.2 m (40 ft).

5.5.1(d) Strength Deck and Bottom Shell
\[ t = \frac{s}{k_b} \sqrt{\frac{0.6 \sigma_u c}{E_c} \frac{S_{MR}}{S_{MA}}} \text{ mm(in.)} \]

where

- \( s \) = spacing of the shell or deck longitudinals or superstructure, deckhouse or bulkhead stiffeners, in mm (in.). It is always to be the lesser dimension of the unsupported plate panels
- \( c \) = factor for plate curvature in the direction parallel to s, given by \((1 – A/s)\), but is not to be taken less than 0.70
- \( A \) = distance, in mm (in.), measured perpendicular from the chord length, s, to the highest point of the curved plate arc between the panel edges
- \( p \) = design pressure given in Section 3-2-2
- \( k \) or \( k_1 \) = coefficient varying with plate panel aspect ratio, given in 3-2-3/1.3.1 TABLE 1
- \( k_b \) = 2.5 with longitudinal framing
- \( = 2.5 \) with transverse framing and panel aspect ratio of 1.0
- \( = 1.0 \) with transverse framing and panel aspect ratio 2.0 to 4.0
- \( \sigma_u \) = design stress given in 3-2-3/5.5.1(d) TABLE 4
- \( k_2 \) = for bottom plating: 0.015 for patrol boats and similar service vessels, 0.01 for other vessels
- = for side plating: 0.020 for patrol boats and similar service vessels, 0.015 for other vessels
- = for superstructures and deckhouse fronts: 0.025
- = for other plating: 0.010
- \( E_F \) = flexural modulus of laminate, in N/mm² (kgf/mm², psi), in the direction parallel to s
- \( q_1 \) = \( 170/F \) (15.5/F, 25,000/F)
- \( L \) = vessel length, in m (ft), as defined in 3-1-1/3
- \( c_1 \) = 5.7 mm (0.225 in.)
- \( k_3 \) = 1.2 for bottom shell structure
- = 1.0 for side shell and deck structure
- \( E_c \) = compressive modulus of elasticity in N/mm² (kgf/mm², psi)
- \( F \) = minimum flexural strength of laminate, in N/mm² (kgf/mm², psi)
- \( \sigma_{uc} \) = minimum compressive strength of laminate, in N/mm² (kgf/mm², psi)
SMR = required hull-girder section modulus given in Section 3-2-1
SM_A = proposed hull-girder section modulus of midship section

### TABLE 4
**Design Stresses for FRP, \( \sigma_u \)**

<table>
<thead>
<tr>
<th>Part</th>
<th>Hull Construction and Equipment</th>
<th>Chapter</th>
<th>Hull Structures and Arrangements</th>
<th>Section</th>
<th>Plating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section 3-2-3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bottom Shell</th>
<th>0.33( \sigma_u )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side Shell</td>
<td>0.33( \sigma_u )</td>
</tr>
<tr>
<td>Decks</td>
<td>0.33( \sigma_u )</td>
</tr>
<tr>
<td>Superstructure and Deckhouses</td>
<td>0.33( \sigma_u )</td>
</tr>
<tr>
<td>Tank Bulkheads</td>
<td>0.33( \sigma_u )</td>
</tr>
<tr>
<td>Watertight Bulkheads</td>
<td>0.33( \sigma_u )</td>
</tr>
</tbody>
</table>

For single skin laminates:

\[ \sigma_u = \text{minimum flexural strength, in N/mm}^2 \text{ (kgf/mm}^2, \text{ psi)} \]

For sandwich laminates:

\[ \sigma_u = \text{for shell or deck outer skin, minimum tensile strength, in N/mm}^2 \text{ (kgf/mm}^2, \text{ psi)} \]
\[ \sigma_u = \text{for shell or deck inner skin, minimum compressive strength, in N/mm}^2 \text{ (kgf/mm}^2, \text{ psi)} \]
\[ \sigma_u = \text{for bulkheads, lesser of tensile or compressive strength, in N/mm}^2 \text{ (kgf/mm}^2, \text{ psi)} \]

**Note:** \( \sigma_u \) is to be verified from the approved test results. See Section 2-6-5.

#### 5.5.2 With Different Properties in 0° and 90° Axes

For laminates with different strength and elastic properties in the 0° and 90° axes where the strength is less or the stiffness greater in the panel direction perpendicular to \( s \), the thickness is to be also not less than given by the following equations:

**5.5.2(a)**

\[
t = sC \sqrt{\frac{pk_s}{1000\sigma_{as}}} \text{ mm}
\]

\[
t = sC \sqrt{\frac{pk_s}{\sigma_{as}}} \text{ in.}
\]

**5.5.2(b)**

\[
t = sC \sqrt{\frac{pk_E}{1000\sigma_{as}}} \sqrt{\frac{E_s}{E_s}} \text{ mm}
\]

\[
t = sC \sqrt{\frac{pk_E}{\sigma_{as}}} \sqrt{\frac{E_s}{E_s}} \text{ in.}
\]

where

\[ k_s, k_E = \text{coefficient for plate panel aspect ratio, given in 3-2-3/5.5.2(b) TABLE 5} \]

\[ \sigma_{as} = \text{design stress, given in 3-2-3/5.5.1(d) TABLE 4, based on strength properties in the direction parallel to } s \]

\[ E_s = \text{flexural modulus of laminate, in N/mm}^2 \text{ (kgf/mm}^2, \text{ psi), in the direction parallel to } s \]
σ_{al} = \text{design stress, given in 3-2-3/5.5.1(d) TABLE 4, based on strength properties in the direction perpendicular to } s

E_\ell = \text{flexural modulus of laminate, in N/mm}^2 \text{ (kgf/mm}^2, \text{ psi), in the direction perpendicular to } s

s, c and p are as defined in 3-2-3/5.5.

### TABLE 5
Aspect Ratio Coefficient for Isotropic Plates

<table>
<thead>
<tr>
<th>(\ell/s)^4 \sqrt{E_s/E_\ell}</th>
<th>k_s</th>
<th>k_\ell</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 2.0</td>
<td>0.500</td>
<td>0.342</td>
</tr>
<tr>
<td>2.0</td>
<td>0.497</td>
<td>0.342</td>
</tr>
<tr>
<td>1.9</td>
<td>0.493</td>
<td>0.342</td>
</tr>
<tr>
<td>1.8</td>
<td>0.487</td>
<td>0.342</td>
</tr>
<tr>
<td>1.7</td>
<td>0.479</td>
<td>0.342</td>
</tr>
<tr>
<td>1.6</td>
<td>0.468</td>
<td>0.342</td>
</tr>
<tr>
<td>1.5</td>
<td>0.454</td>
<td>0.342</td>
</tr>
<tr>
<td>1.4</td>
<td>0.436</td>
<td>0.342</td>
</tr>
<tr>
<td>1.3</td>
<td>0.412</td>
<td>0.338</td>
</tr>
<tr>
<td>1.2</td>
<td>0.383</td>
<td>0.333</td>
</tr>
<tr>
<td>1.1</td>
<td>0.348</td>
<td>0.323</td>
</tr>
<tr>
<td>1.0</td>
<td>0.308</td>
<td>0.308</td>
</tr>
</tbody>
</table>

#### 5.7 Sandwich Laminate

##### 5.7.1 Laminate with Essentially Same Bending Strength and Stiffness in 0° and 90° Axes

In general the outer and inner skins are to be similar in lay-up and in strength and elastic properties. Special consideration will be given where this is not the case. In general, single skin laminate is to be used in way of the keel and in way of hull appendages such as shaft struts, skegs and rudders and in way of deck fittings, bolted connections, and other areas of concentrated local loads.

The section modulus and moment of inertia about the neutral axis of a strip of sandwich panel, 1 cm (1 in.) wide are to be not less than given by the following equations:

5.7.1(a)

\[ S_{M_o} = \frac{(sc)^2 pk}{6 \times 10^5 \sigma_{ao}} \text{ cm}^3 \]

\[ S_{M_i} = \frac{(sc)^2 pk}{6 \times 10^5 \sigma_{ai}} \text{ cm}^3 \]

5.7.1(b)

\[ S_{M_o} = \frac{(sc)^2 pk}{6 \sigma_{ao}} \text{ in}^3 \]

\[ S_{M_i} = \frac{(sc)^2 pk}{6 \sigma_{ai}} \text{ in}^3 \]

5.7.1(c)
\[ I = \frac{(sc)^3 pk_1}{120 \times 10^5 k_2 E_{tc}} \text{ cm}^4 \]
\[ I = \frac{(sc)^3 pk_1}{12k_2 E_{tc}} \text{ in}^4 \]

where

\[ SM_o = \text{required section modulus, in cm}^3 (\text{in}^3), \text{ to outer skin.} \]
\[ SM_i = \text{required section modulus, in cm}^3 (\text{in}^3), \text{ to inner skin.} \]
\[ I = \text{required moment of inertia, in cm}^4 (\text{in}^4) \]
\[ \sigma_{ao} = \text{design stress, for outer skin, given in 3-2-3/5.5.1(d) TABLE 4, based on strength of outer skin in direction parallel to } s. \]
\[ \sigma_{ai} = \text{design stress, for inner skin, given in 3-2-3/5.5.1(d) TABLE 4, based on strength of inner skin in direction parallel to } s. \]
\[ E_{tc} = 0.5(E_c + E_t) \]
\[ E_c = \text{mean of compressive moduli of inner and outer skins, in N/mm}^2 (\text{kgf/cm}^2, \text{psi}) \]
\[ E_t = \text{means of tensile moduli of inner and outer skins, in N/mm}^2 (\text{kgf/cm}^2, \text{psi}) \]

\[ s, c, p, k, k_1 \text{ and } k_2 \text{ are as defined in 3-2-3/5.5.} \]

**5.7.2 Laminates with Different Bending Strength and Stiffness in 0° and 90° Axes**

Where the strength is less or the stiffness greater in the direction perpendicular to \( s \), the section modulus and moment of inertia about the neutral axis of a strip of sandwich, 1 cm (1 in.) wide are also to be not less than given by the following equations:

**5.7.2(a) In Direction Parallel to \( s \)**
\[ SM_o = \frac{(sc)^2 pk_s}{6 \times 10^5 \sigma_{aso}} \text{ cm}^3 \]
\[ SM_o = \frac{(sc)^2 pk_s}{6 \sigma_{aso}} \text{ in}^3 \]

**5.7.2(b) In Direction Parallel to \( \ell \)**
\[ SM_o = \frac{(sc)^2 pk_s}{6 \times 10^5 \sigma_{aso}} \sqrt{\frac{E_c}{E_s}} \text{ cm}^3 \]
\[ SM_o = \frac{(sc)^2 pk_s}{6 \sigma_{aso}} \sqrt{\frac{E_c}{E_s}} \text{ in}^3 \]

**5.7.2(c) In Direction Parallel to \( s \)**
\[ SM_i = \frac{(sc)^2 pk_s}{6 \times 10^5 \sigma_{asi}} \text{ cm}^3 \]
\[ SM_i = \frac{(sc)^2 pk_s}{6 \sigma_{asi}} \text{ in}^3 \]

**5.7.2(d) In Direction Parallel to \( \ell \)**
\[ SM_i = \frac{(sc)^2 pk_s}{6 \times 10^5 \sigma_{asi}} \sqrt{\frac{E_c}{E_s}} \text{ cm}^3 \]
5.7.2(e) In Direction Parallel to s

\[ I = \frac{(sc)^2 p k_1}{120 \times 10^{-5} k_2 E_s} \text{ cm}^4 \]

\[ I = \frac{(sc)^2 p k_1}{12 k_2^2 E_s} \text{ in}^4 \]

where

- \( SM_o \) = required section modulus, in \( \text{cm}^3 \) (in\(^3\)), to outer skin.
- \( SM_i \) = required section modulus, in \( \text{cm}^3 \) (in\(^3\)), to inner skin.
- \( k_ℓ , k_s \) = modified coefficient for plate panel aspect ratio, given in 3-2-3/5.5.2(b) TABLE 5.
- \( \sigma_{aso} \) = design stress, for outer skin, given in 3-2-3/5.5.1(d) TABLE 4, based on strength properties in direction parallel to \( s \).
- \( \sigma_{aℓo} \) = design stress, for outer skin, given in 3-2-3/5.5.1(d) TABLE 4, based on strength properties in direction perpendicular to \( s \).
- \( \sigma_{asi} \) = design stress for inner skin, given in 3-2-3/5.5.1(d) TABLE 4, based on strength properties in direction parallel to \( s \).
- \( \sigma_{aℓi} \) = design stress, for inner skin, given in 3-2-3/5.5.1(d) TABLE 4, based on strength properties in direction perpendicular to \( s \).
- \( E_s \) = \( 0.5 (E_{ts} + E_{cs}) \)
- \( E_{ℓ} \) = \( 0.5 (E_{tℓ} + E_{cℓ}) \)
- \( E_{ts} , E_{cs} \) = respectively, mean of tensile moduli of inner and outer skins, and mean of compressive moduli of inner and outer skins, in N/mm\(^2\) (kgf/cm\(^2\), psi) in direction parallel to \( s \).
- \( E_{tℓ} , E_{cℓ} \) = respectively, mean of tensile moduli of inner and outer skins, and mean of compressive moduli of inner and outer skins, in N/mm\(^2\) (kgf/cm\(^2\), psi) in direction parallel to \( ℓ \).

\( s , c, p, k_1, k_2 \) and \( E_{tc} \) are as defined in 3-2-3/5.5.

5.7.3 Shear Strength

The thickness of core and sandwich laminate is to be not less than given by the following equation. Special consideration will be given where cores differing from those in Part 2, Chapter 6 are proposed. See also 3-2-3/5.7.5 for minimum thickness of skin.

\[ \frac{d_o + d_c}{2} = \frac{vps}{100007} \text{ mm} \]

\[ \frac{d_o + d_c}{2} = \frac{vps}{t} \text{ in} \]

where

- \( d_o \) = overall thickness of sandwich, excluding gel coat, in mm (in.)
- \( d_c \) = thickness of core, in mm (in.)
\( \nu = \) coefficient varying with plate panel aspect ratio, given in 3-2-3/5.7.3 TABLE 6. Where the elastic properties of the skins are different in the principal axes, \( \nu \) is to be taken not less than 0.5.

\( s = \) lesser dimension of plate panel, in mm (in.)

\( p = \) design pressure, in kN/m\(^2\) (tf/m\(^2\), psi), as defined in Section 3-2-2.

\( \tau = \) design stress, in N/mm\(^2\) (kgf/mm\(^2\), psi), as shown in 3-2-3/5.7.3 TABLE 7.

Where cores are scored to facilitate fitting, the scores are to be filled with putty or resin.

The density of polyvinyl chloride foam cores in the shell plating is to be not less than given in the following table:

<table>
<thead>
<tr>
<th>Location</th>
<th>Density kg/m(^3) (lbs/ft(^3))</th>
<th>Minimum Density kg/m(^3) (lbs/ft(^3))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom forward of 0.4LWL; ( V \geq 25 ) kts</td>
<td>( 4d_c \ (6.4d_c) )</td>
<td>120 (7.5)</td>
</tr>
<tr>
<td>Bottom forward of 0.4LWL; ( V &lt; 25 ) kts</td>
<td>( 4d_c \ (6.4d_c) )</td>
<td>100 (6.25)</td>
</tr>
<tr>
<td>elsewhere; ( V \geq 25 ) kts</td>
<td>( 3d_c \ (4.8d_c) )</td>
<td>100 (6.25)</td>
</tr>
<tr>
<td>elsewhere; ( V &lt; 25 ) kts</td>
<td>( 3d_c \ (4.8d_c) )</td>
<td>80 (5.00)</td>
</tr>
<tr>
<td>Side forward 0.4LWL</td>
<td>( 2.5d_c \ (4.0d_c) )</td>
<td>100 (6.25)</td>
</tr>
<tr>
<td>elsewhere</td>
<td>( 2.0d_c \ (3.2d_c) )</td>
<td>80 (5.00)</td>
</tr>
</tbody>
</table>

**TABLE 6**

**Coefficient \( \nu \) for FRP Sandwich Panels Shear Strength**

<table>
<thead>
<tr>
<th>Plate Panel Aspect Ratio ( \frac{\ell}{s} )</th>
<th>( \nu )</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 2.0</td>
<td>0.500</td>
</tr>
<tr>
<td>2.0</td>
<td>0.500</td>
</tr>
<tr>
<td>1.9</td>
<td>0.499</td>
</tr>
<tr>
<td>1.8</td>
<td>0.499</td>
</tr>
<tr>
<td>1.7</td>
<td>0.494</td>
</tr>
<tr>
<td>1.6</td>
<td>0.490</td>
</tr>
<tr>
<td>1.5</td>
<td>0.484</td>
</tr>
<tr>
<td>1.4</td>
<td>0.478</td>
</tr>
<tr>
<td>1.3</td>
<td>0.466</td>
</tr>
<tr>
<td>1.2</td>
<td>0.455</td>
</tr>
<tr>
<td>1.1</td>
<td>0.437</td>
</tr>
<tr>
<td>1.0</td>
<td>0.420</td>
</tr>
</tbody>
</table>

\( s = \) shorter edge of plate panel, in mm (in.)

\( \ell = \) longer edge of plate panel, in mm (in.)

**Note:** Values of \( \nu \) less than 0.5 may be used only where the inner and outer skins have essentially the same strength and elastic properties in the 0° and 90° axes.
TABLE 7
Core Shear Design Strength

<table>
<thead>
<tr>
<th>Core Material</th>
<th>Design Core Shear Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balsa Wood</td>
<td>0.3(\tau_u)</td>
</tr>
<tr>
<td>PVC*</td>
<td>0.4(\tau_u)</td>
</tr>
</tbody>
</table>

\* May be taken as 0.55\(\tau_u\) where shear elongation exceeds 40%.

\(\tau_u\) = minimum core shear strength, in N/mm\(^2\) (kgf/mm\(^2\), psi)

5.7.4 Skin Stability
The skin buckling stress \(\sigma_c\), given by the following equation, is in general to be not less than
2.0\(\sigma_{ai}\) and 2.0\(\sigma_{ao}\).

\[
\sigma_c = 0.63\sqrt{E_s \cdot E_{cc} \cdot G_{cc}}
\]

where

\(E_s\) = compressive modulus of skins, in N/mm\(^2\) (kgf/mm\(^2\), psi), in 0° and 90° in-plane axis of panel

\(E_{cc}\) = compressive modulus of core, in N/mm\(^2\) (kgf/mm\(^2\), psi), perpendicular to skins

\(G_{cc}\) = core shear modulus, in N/mm\(^2\) (kgf/mm\(^2\), psi), in the direction parallel to load

5.7.5 Minimum Skin Thickness
After all other requirements are met, the skin thicknesses of laminates complying with basic laminate requirements of Part 2, Chapter 6 are in general to be not less than given by the following equations:

\[
t_{os} = 0.35k_3(C_1 + 0.26L) \quad \text{mm}
\]
\[
t_{os} = 0.35k_3(C_1 + 0.0031L) \quad \text{in.}
\]
\[
t_{is} = 0.25k_3(C_1 + 0.26L) \quad \text{mm}
\]
\[
t_{is} = 0.25k_3(C_1 + 0.0031L) \quad \text{in.}
\]

where

\(t_{os}\) = thickness of outer skin, in mm (in.)
\(t_{is}\) = thickness of inner skin, in mm (in.)
\(k_3\) = 1.2 Bottom Shell
\(\quad = 1.0 \quad \text{Side Shell and Deck}
\(C_1\) = 5.7 mm (0.225 in.)
\(L\) = vessel length, in m (ft), as defined in 3-1-1/3, generally not to be taken as less than 12.2 m (40 ft).
5.7.6 Wheel Loading
Special consideration will be given to the required thickness where provision is made for the operation or stowage of vehicles having rubber tires after all other requirements are met.

7 Plating Subject to Military Mission Loads
A first principles analysis is to be performed for all plates that are subject to a military mission load. The maximum stresses and deflections in these plates are not to exceed the stresses given in 3-2-3/7 TABLE 8.

| TABLE 8 |
|-----------------|-----------------|-----------------|
| Part 3 Hull Construction and Equipment | Chapter 2 Hull Structures and Arrangements | Section 3 Plating |

| Part 3 Hull Construction and Equipment | Chapter 2 Hull Structures and Arrangements | Section 3 Plating |

<table>
<thead>
<tr>
<th>Own vessel weapon firing effects</th>
<th>Weapon Foundation</th>
<th>0.5σ_y</th>
<th>0.5σyw</th>
<th>0.33σ_u</th>
<th>0.01s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gun Blast</td>
<td>0.80σ_y</td>
<td>0.75σyw</td>
<td>0.33σ_u</td>
<td>0.01s</td>
<td></td>
</tr>
<tr>
<td>Missile Blast</td>
<td>σ_y</td>
<td>σyw</td>
<td>See Note 3</td>
<td>See Note 3</td>
<td></td>
</tr>
<tr>
<td>Human Load</td>
<td>_</td>
<td>_</td>
<td>0.33σ_u</td>
<td>0.01 s</td>
<td></td>
</tr>
<tr>
<td>Helicopter Decks (4)</td>
<td>Overall Dist. Loading</td>
<td>0.60σ_y</td>
<td>0.6σyw</td>
<td>See Note 3</td>
<td>See Note 3</td>
</tr>
<tr>
<td>Landing Impact Loading</td>
<td>σ_y</td>
<td>σyw</td>
<td>See Note 3</td>
<td>See Note 3</td>
<td></td>
</tr>
<tr>
<td>Stowed Aircraft Loading</td>
<td>σ_y</td>
<td>σyw</td>
<td>See Note 3</td>
<td>See Note 3</td>
<td></td>
</tr>
<tr>
<td>Masts (1)</td>
<td>0.4σ_y²</td>
<td>0.4σyw(2)</td>
<td>See Note 3</td>
<td>See Note 3</td>
<td></td>
</tr>
</tbody>
</table>

σ_y = yield strength of steel in N/mm² (kgf/mm², psi)
σyw = welded yield strength of aluminum in N/mm² (kgf/mm², psi)
s = panel spacing

For single skin laminates:

σ_u = minimum flexural strength, in N/mm² (kgf/mm², psi)

For sandwich laminates:

σ_u = for shell or deck outer skin, minimum tensile strength, in N/mm² (kgf/mm², psi)
σ_u = for shell or deck inner skin, minimum compressive strength, in N/mm² (kgf/mm², psi)
σ_u = for bulkheads, lesser of tensile or compressive strength, in N/mm² (kgf/mm², psi)

Notes: σ_u is to be verified from the approved test results. See Section 2-6-5

1 The pretension of stays are to be 0.020Bs. The maximum tension in the stays is 0.40Bs or 0.35Bs for masts with two levels of stays
2 Stayed masts are to be checked in the unstayed position with an allowable stress of 0.80σ_y for steel or 0.80σyw for aluminum
3 Composites will be specially considered for use in this location.
4 The minimum plate thickness is generally not to be less than obtained from the following:
<table>
<thead>
<tr>
<th>Beam Spacing</th>
<th>$t_s$</th>
<th>$t_{al}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>460 mm (18 in.)</td>
<td>4.0 mm (0.16 in.)</td>
<td>$0.9 t_s \sqrt{Q}$</td>
</tr>
<tr>
<td>610 mm (24 in.)</td>
<td>5.0 mm (0.20 in.)</td>
<td>$0.9 t_s \sqrt{Q}$</td>
</tr>
<tr>
<td>760 mm (30 in.)</td>
<td>6.0 mm (0.24 in.)</td>
<td>$0.9 t_s \sqrt{Q}$</td>
</tr>
</tbody>
</table>

$t_s$ = required thickness for steel  
$t_{al}$ = required thickness for aluminum  
$Q$ = material factor as defined in 3-2-1/1.1
1 Aluminum and Steel

1.1 General

1.1.1 Structural Arrangements (1 July 2021)

Structural arrangements and details are to be in accordance with Sections 3-2-5 and 3-2-6. Reference is to be made to 1-1-4/5 regarding requirement for direct analysis of primary structure (i.e., transverse webs and girders). The scantlings given in this section are minimum values. Direct analysis may be specifically required by these Rules or may be submitted by designers in support of alternative arrangements and scantlings. ABS may, when requested, carry out direct analysis on behalf of designers.

1.1.2 Slamming Pressure Effects on Displacement Vessels (1 July 2021)

For vessels subject to slamming loading during routine operations or missions, the slamming pressures are to be determined by model testing or hydrodynamic analysis. If the detailed information is not available in the early stages of design, the bottom and side frames, girders, webs and stringers section moduli are to be increased by 25%. All bottom and side structural members in the impacted region are to have end connections with brackets. Scallop welds are not to be used in connections between side frames and shell plating.

1.3 Strength and Stiffness

1.3.1 Section Modulus

The ends of members are to be effectively attached to the supporting structure. The section modulus of each longitudinal, stiffener, transverse web, stringer and girder is to be not less than given by the following equation:

\[
SM = \frac{83.3 \times p s \ell^2}{\sigma_a} \text{ cm}^3
\]

\[
SM = \frac{144 \times p s \ell^2}{\sigma_a} \text{ in}^3
\]

where

\[p = \text{design pressure, in kN/m}^2 (\text{tf/m}^2, \text{psi}), \text{given in 3-2-2/1 or 3-2-2/3}\]

\[s = \text{spacing, in m (ft), of the longitudinal, stiffener, transverse web or girder, etc.}\]
\[ \ell = \text{length, in m (ft), of the longitudinal, stiffener, transverse web or girder, between supports; where bracketed end connections are supported by bulkheads, } \ell \text{ may be measured onto the bracket, the distance given on 3-1-2/1.9 FIGURE 1, provided both bracket arms are about the same length. Where transverse members span chines or “knuckles,” } \ell \text{ is to be measured as shown in 3-2-4/1.3.1 FIGURE 1 and 3-2-4/1.3.1 FIGURE 2.} \]

\[ \sigma_a = \text{design stress, in N/mm}^2 \text{ (kgf/mm}^2 \text{, psi) as given in 3-2-4/1.3.1 TABLE 1} \]

Stiffeners without end attachments are permitted on watertight bulkheads provided the section modulus is increased by 50%, and provided the bulkhead plating and boundary can transmit the shear forces on the stiffeners.

**FIGURE 1**
Transverse Side Frame

**FIGURE 2**
Transverse Side Frame
TABLE 1

Design Stress, $\sigma_a$

<table>
<thead>
<tr>
<th>Location</th>
<th>Steel and Aluminum</th>
<th>FRP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom Longitudinals – Slamming Pressure</td>
<td>0.65$\sigma_y$</td>
<td>0.33$\sigma_u$</td>
</tr>
<tr>
<td>Bottom Longitudinals – Sea Pressure</td>
<td>0.50$\sigma_y$</td>
<td>0.40$\sigma_u$</td>
</tr>
<tr>
<td>Side Longitudinals – Slamming Pressure</td>
<td>0.60$\sigma_y$</td>
<td>0.40$\sigma_u$</td>
</tr>
<tr>
<td>Side Longitudinals – Sea Pressure</td>
<td>0.50$\sigma_y$</td>
<td>0.40$\sigma_u$</td>
</tr>
<tr>
<td>Deck Longitudinals – Strength Decks</td>
<td>0.33$\sigma_y$</td>
<td>0.40$\sigma_u$</td>
</tr>
<tr>
<td>Deck Longitudinals – Other Decks</td>
<td>0.40$\sigma_y$</td>
<td>0.40$\sigma_u$</td>
</tr>
<tr>
<td>Wet Deck Longitudinals</td>
<td>0.75$\sigma_y$</td>
<td>0.40$\sigma_y$</td>
</tr>
<tr>
<td>Bottom Transverse and Girders – Slamming Pressure</td>
<td>0.80$\sigma_y$</td>
<td>0.33$\sigma_u$</td>
</tr>
<tr>
<td>Bottom Transverses and Girders – Sea Pressure</td>
<td>0.60$\sigma_y$</td>
<td>0.33$\sigma_u$</td>
</tr>
<tr>
<td>Side Transverses and Girders – Slamming Pressure</td>
<td>0.80$\sigma_y$</td>
<td>0.33$\sigma_u$</td>
</tr>
<tr>
<td>Side Transverses and Girders – Sea Pressure</td>
<td>0.60$\sigma_y$</td>
<td>0.33$\sigma_u$</td>
</tr>
<tr>
<td>Deck Transverses and Girders – Strength Deck</td>
<td>0.75$\sigma_y$</td>
<td>0.33$\sigma_u$</td>
</tr>
<tr>
<td>Deck Transverses and Girders – Other Decks</td>
<td>0.75$\sigma_y$</td>
<td>0.33$\sigma_u$</td>
</tr>
<tr>
<td>Wet Deck Transverses and Girders</td>
<td>0.75$\sigma_y$</td>
<td>0.33$\sigma_u$</td>
</tr>
<tr>
<td>Watertight Bulkheads</td>
<td>0.85$\sigma_y$</td>
<td>0.50$\sigma_u$</td>
</tr>
<tr>
<td>Tank Bulkheads</td>
<td>0.60$\sigma_y$</td>
<td>0.33$\sigma_u$</td>
</tr>
<tr>
<td>Superstructure and Deckhouse</td>
<td>0.70$\sigma_y$</td>
<td>0.33$\sigma_u$</td>
</tr>
</tbody>
</table>

$\sigma_y$ = minimum yield strength, unwelded condition, in N/mm$^2$ (kgf/mm$^2$, psi). For aluminum, minimum yield stress, welded condition, in N/mm$^2$, (kgf/mm$^2$, psi)

$\sigma_u$ = ultimate tensile strength, in N/mm$^2$ (kgf/mm$^2$, psi)

1.3.2 Moment of Inertia

The moment of inertia of each longitudinal, stiffener, transverse web, stringer or girder, including the plating to which it is attached, is to be not less than given by the following equation:

$$I = \frac{260p_{se}E}{K_4} \text{ cm}^4$$

$$I = \frac{54p_{se}E}{K_4} \text{ in}^4$$

where

$K_4 = 0.0015$ for shell and deep tank girders, stringers and transverse webs, longituadinals, and stiffeners constructed of steel.

$K_4 = 0.0011$ for deck girders, transverses, longitudinals, and stiffeners constructed of steel.
for shell and deep tank stringers and transverse webs, longitudinals, and stiffeners constructed of aluminum.

- 0.0018 for deck girders, transverses, longitudinals, and stiffeners constructed of aluminum.

\[ E = 2.06 \times 10^5 \text{ N/mm}^2 (21,000 \text{ kgf/mm}^2, 30 \times 10^6 \text{ psi}) \text{ for steel} \]

\[ E = 6.9 \times 10^4 \text{ N/mm}^2 (7,000 \text{ kgf/mm}^2, 10 \times 10^6 \text{ psi}) \text{ for aluminum} \]

\[ p, s \text{ and } \ell \text{ are as given in 3-2-4/1.3.1.} \]

### 1.5 Elastic Buckling of Longitudinal Members

The moment of inertia of the deck or shell longitudinal together with attached plating is not to be less than to satisfy the following criteria:

#### 1.5.1 Axial Compression

The critical buckling stress \( \sigma_E \) of a beam-column (i.e., the longitudinal and the associated effective plating) with respect to axial compression may be obtained from the following equation:

\[
\sigma_E = \frac{E I_a}{c_1 A \ell^2} \text{ N/mm}^2(\text{kgf/mm}^2, \text{psi})
\]

where

- \( E = \) as defined in 3-2-4/1.3.2
- \( I_a = \) moment of inertia, \( \text{cm}^4 \text{ (in}^4 \text{)}, \) of longitudinal, including plate flange
- \( c_1 = \) 1000 (1000, 14.4)
- \( A = \) cross-sectional area, \( \text{cm}^2 \text{ (in}^2 \text{)}, \) of longitudinal, including plate flange
- \( \ell = \) span of longitudinal, in m (ft)

#### 1.5.2 Torsional/Flexural Buckling

The critical torsional/flexural buckling stress with respect to axial compression of a longitudinal including its associated plate may be obtained from the following equation:

\[
\sigma_E = \frac{\pi^2 E I_w}{10 c_1 I_p \ell^2} \left( m^2 + \frac{K}{m^2} \right) + 0.385 E I_t I_p^2 \text{ N/mm}^2(\text{kgfmm}^2, \text{psi})
\]

where

- \( K = c_2 \frac{c_3^4}{\pi^4 E I_w} \)
- \( m = 1 \) for \( 0 < K \leq 4 \)
  - 2 for \( 4 < K \leq 36 \)
  - 3 for \( 36 < K \leq 144 \)
  - 4 for \( 144 < K \leq 400 \)
- \( E = \) as defined in 3-2-4/1.3.2
- \( c_2 = 10^6 (10^4, 20736) \)
- \( I_t = \) St. Venant’s moment of inertia, \( \text{cm}^4 \text{ (in}^4 \text{)}, \) of profile (without plate flange)
\[ c_3 = \frac{h_w^3}{3} \quad \text{for flat bars (slabs)} \]

\[ c_3 = \frac{h_w^3}{3} + b_f t_f^3 \left( 1 - 0.63 \frac{l_f}{t_f} \right) \quad \text{for flanged profiles} \]

\[ c_3 = 10^{-4}(10^{-4}, 1.0) \]

\[ l_p = \text{polar moment of inertia, in cm}^4 \text{ (in}^4\text{), of profile about connection of stiffener to plate} \]

\[ l_p = c_3 \frac{h_w^3 t_w}{3} \quad \text{for flat bars (slabs)} \]

\[ l_p = c_3 \left( \frac{h_w^3}{3} + h_w^2 b_f t_f \right) \quad \text{for flanged profiles} \]

\[ l_w = \text{warping constant, in cm}^6 \text{ (in}^6\text{), of profile about connection of stiffener to plate} \]

\[ l_w = c_4 \frac{b_f^3 h_w^2}{36} \quad \text{for flat bars (slabs)} \]

\[ l_w = c_4 \left( \frac{12}{t_f (b_f + h_w)} \right) \quad \text{for "Tee" profiles} \]

\[ l_w = c_4 \left( \frac{b_f^3 h_w^2}{12 (b_f + h_w)} \right) \left[ t_f \left( b_f^2 + 2b_f h_w + 4h_w^2 \right) + 3t_w b_f h_w \right] \quad \text{for angles and bulb profiles} \]

\[ c_4 = 10^{-4}(10^{-4}, 1.0) \]

\[ h_w = \text{web height, in mm (in.)} \]

\[ t_w = \text{web thickness, in mm (in.)} \]

\[ b_f = \text{flange width, in mm (in.)} \]

\[ t_f = \text{flange thickness, in mm (in.)} \]

\[ \ell = \text{span of member, in m (ft)} \]

\[ s = \text{spacing of member, in mm (in.)} \]

\[ C = \text{spring stiffness exerted by supporting plate panel} \]

\[ C = \frac{k_p m_p^3}{3s \left( 1 + \frac{1.33k_p h_w^3 t_p^3}{st_w^2} \right)} \quad \text{N(kgf, lbf)} \]

\[ k_p = 1 - \eta_p, \text{ not to be taken less than zero. For flanged profiles } k_p \text{ need not be taken less than 0.1.} \]

\[ t_p = \text{plate thickness, in mm (in.)} \]

\[ \eta_p = \frac{\sigma_a}{\sigma_{Ep}} \]

\[ \sigma_a = \text{calculated compressive stress. For longitudinals, members see 3-2-4/1.5.4} \]

\[ \sigma_{Ep} = \text{elastic buckling stress of supporting plate as calculated in 3-2-3/1.5.1(a)} \]

### 1.5.3 Critical Buckling Stress

The critical buckling stress in compression, \( \sigma_c \), is determined as follows:
\[ \sigma_c = \sigma_E \quad \text{when } \sigma_E \leq 0.5\sigma_y \]
\[ = \sigma_y \left(1 - \frac{\sigma_y}{4\sigma_E}\right) \quad \text{when } \sigma_E > 0.5\sigma_y \]

where

\[ \sigma_y = \text{yield strength of material, in N/mm}^2 (\text{kgf/mm}^2, \text{psi}) \]

\[ \sigma_E = \text{ideal elastic buckling stress calculated in 3-2-4/1.5.1} \]

1.5.4 **Calculated Compressive Stress**

\[ \sigma_a = c_5 \frac{(M_y)^y}{I} \text{ N/mm}^2 (\text{kgf/mm}^2, \text{psi}) \]

where

\[ \sigma_a = \text{working compressive stress in panel being considered, N/mm}^2 (\text{kgf/mm}^2, \text{psi}), \text{but generally not less than the following:} \]
\[ = \frac{C_1 SM_R}{Q SM_A} \text{ N/m}^2 (\text{kgf/mm}^2, \text{psi}) \]
\[ c_5 = 10^5 (10^5, 322,560) \]
\[ M_t = \text{maximum total bending moment as given in 3-2-1/1.1.2(e), kN-m (tf-m, Ltf-ft)} \]
\[ y = \text{vertical distance, in m (ft), from the neutral axis to the considered location} \]
\[ I = \text{moment of inertia of the hull girder, cm}^4 (\text{in}^4) \]
\[ C_1 = 175 \text{ N/mm}^2 (17.84 \text{ kgf/mm}^2, 25,380 \text{ psi}) \]
\[ SM_R = \text{hull girder section modulus, as required in Section 3-2-1, cm}^2 \text{-m (in}^2 \text{-ft)} \]
\[ SM_A = \text{section modulus of the hull girder at the location being considered, cm}^2 \text{-m (in}^2 \text{-ft)} \]
\[ Q = \text{material factor as given in 3-2-1/1.1} \]

1.5.5 **Design Buckling Stress**

The design buckling stress, \( \sigma_c \), is to be such that:

\[ \sigma_c \geq \beta \sigma_a \]

where

\[ \beta = 1.10 \quad \text{for the web plating of members} \]
\[ = 1.20 \quad \text{for overall buckling of members} \]

1.5.6 **Web and Flange Buckling (2007)**

Local buckling is considered satisfactory provided the following proportions are not exceeded.

1.5.6(a) **Flat bars**

\[ d_w/t_w \leq 0.5 \left(\frac{E}{\sigma_y}\right)^{1/2} C_2 \]
1.5.6(b) Built-up Sections, Angle Bars and Tee Bars
\[ \frac{d_w}{t_w} \leq 1.5 \left( \frac{E}{\sigma_y} \right)^{1/2} C_2 \]

1.5.6(c) Bulb Plates
\[ \frac{d_w}{t_w} \leq 0.85 \left( \frac{E}{\sigma_y} \right)^{1/2} C_2 \]

1.5.6(d) Outstanding Face Bars and Flanges
\[ \frac{d_w}{t_w} \leq 0.5 \left( \frac{E}{\sigma_y} \right)^{1/2} C_2 \]

where
- \( t_w \) = total required thickness, in mm (in.)
- \( d_w \) = depth of the web, in mm (in.)
- \( E \) = as defined in 3-2-4/1.3.2
- \( \sigma_y \) = yield strength of material, in N/mm² (kgf/mm², psi)

Note:
Generally the unwelded yield strength may be used, but due account is to be made for critical or extensive weld zones.

\[ C_2 = 1 \quad \text{where} \quad \sigma_a > 0.80\sigma_y \]
\[ = 0.80\sigma_y / \sigma_a \quad \text{where} \quad \sigma_a < 0.80\sigma_y, \text{ and } \sigma_a \text{ is to be taken not less than } 0.55\sigma_y \]

For webs and flanges that do not satisfy these limits, a detailed analysis of buckling strength using an acceptable method is to be submitted for review. The ABS Requirements for Buckling and Ultimate Strength Assessment for Offshore Structures may be used for reference.

1.7 Corrugated Panels
1.7.1 Stiffeners
The section modulus, \( SM \), for corrugated bulkhead is to be not less than obtained by the requirements in 3-2-4/1.3 with \( \ell \) being the distance between supporting members in m (ft), and \( s \) is equal to \( a + b \) where \( a \) and \( b \) are as defined in 3-2-4/1.7.1 FIGURE 3 in m (ft).
The developed section modulus, $SM$, may be obtained from the following equation, where $a$, $t$, and $d$ are as indicated in 3-2-4/1.7.1 FIGURE 3.

$$SM = \frac{td^2}{6} + \left(\frac{adt}{2}\right)$$

1.7.2 End Connections

The structural arrangements and size of welding at the ends of corrugations are to be designed to develop the required strength of corrugation stiffeners. Joints within 10% of the depth of corrugation from the outer surface of corrugation, $d_1$, are to have double continuous welds with fillet size, $w$, not less than 0.7 times the thickness of the bulkhead plating or penetration welds of equal strength (3-2-4/1.7.2 FIGURE 4).

1.9 Web Thickness

The thickness of the webs of structural members is not to be less than determined by the following equation:

1.9.1 Webs (1 July 2022)

$$\frac{d_w}{tw} = 1.54 \left(\frac{E}{f_y}\right)^{1/2}$$

- in general

$$\frac{d_w}{tw} = 1.15 \left(\frac{E}{f_y}\right)^{1/2}$$

- in slamming area
where

\[ t_w = \text{total required thickness, in mm (in.)} \]
\[ d_w = \text{depth of the web, in mm (in.)} \]
\[ \tau_y = \text{minimum shear yield strength of steel or aluminum in the unwelded condition, N/mm}^2 (\text{kgf/mm}^2, \text{psi}) \]
\[ E = \text{as defined in 3-2-4/1.3.2} \]

The web thickness is also not to be less than the following:

\[ t = \frac{1000ps\ell}{2d_w\tau a} \text{ mm} \]
\[ t = \frac{144ps\ell}{2d_w\tau a} \text{ in.} \]

where

\[ t = \text{total required thickness, in mm (in.)} \]
\[ p = \text{design pressure, in kN/m}^2 (\text{tf/m}^2, \text{psi}), \text{as given in Section 3-2-2} \]
\[ s = \text{width of shell or deck supported by the member, in m (ft)} \]
\[ \ell = \text{length of member, in m (ft)} \]
\[ d_w = \text{depth of the web, in mm (in.)} \]
\[ \tau_a = \text{design shear stress, in N/mm}^2 (\text{kgf/mm}^2, \text{psi}) \]
\[ \tau_y = \text{minimum shear, unwelded condition, in N/mm}^2 (\text{kgf/mm}^2, \text{psi}) \]
\[ \tau_{yw} = \text{minimum shear yield strength welded condition, in N/mm}^2 (\text{kgf/mm}^2, \text{psi}) \]

1.11 Attachments

1.11.1 Lug Attachments

The lug weld attachment of the longitudinals to the transverse webs are to have total weld throat area not less than the following equations:

\[ a_w = \frac{1000ps\ell}{2\tau a} \text{ mm}^2 \]
\[ a_w = \frac{144ps\ell}{2\tau a} \text{ in}^2 \]

where

\[ a_w = t_w \times \ell_w \]
\[ t_w = \text{weld throat, in mm (in.)} \]
\[ \ell_w = \text{total length of weld, in mm (in.)} \]
\[ p = \text{design pressure, in kN/m}^2 (\text{tf/m}^2, \text{psi}), \text{as given in Section 3-2-2} \]
\[ s = \text{width of shell or deck supported by the member, in m (ft)} \]
\( \ell \) = length of member, in m (ft)

\( \tau_a \) = design shear stress, in N/mm\(^2\) (kgf/mm\(^2\), psi), as defined in 3-2-4/1.9.1

1.11.2 End Attachments

The welded end attachments of members, including bracket connections, are to develop the required strength of the member being attached, considering the member as fix ended.

1.13 Direct Analysis Methods

Local structure may be designed using advanced analysis techniques such as non-prismatic beam, grillage, and finite element analysis. The requirements for the use of these types of analysis techniques are in Section 3-1-3.

1.15 Decks Exposed to Vehicle Loads

All longitudinals, beams, and girders of decks that are subject to vehicle loads are to be checked under all possible combinations of these loads. The maximum allowable design stress for these members are given in 3-2-4/1.3.1 TABLE 1.

3 Fiber Reinforced Plastic

3.1 General

The structural arrangements and details are to be in accordance with Sections 3-2-5 and 3-2-6. Laminates may be bi-directional or uni-directional. Bonding angles or tapes are to comply with Section 3-2-5. Laminates of webs, crowns and face bars of stiffeners, transverses and girders may be bi-directional, or multi-axial. Uni-axial caps may be used in the crowns and face bars of these members. In general, the tapes bonding the members, and their secondary bonds, are to develop the strength of the member being attached.

3.3 Fiber Reinforcement

The basic laminate given in Part 2, Chapter 6, or other approved laminates of glass, aramid, or carbon fiber, in mat, woven roving, cloth, knitted fabric, or non-woven uni-directional reinforcing plies may be used. The plies are in general to be laid-up parallel to the direction of the internal. The strength of the laminate in a direction perpendicular to the direction of the internal is in general not to be less than 25% of the warp strength except for the uni-directional caps of the flange or crown of the internal members. In way of continuous longitudinal members, the required section modulus, shear area and moment of inertia of transverse members are to be maintained by the shell or deck plating and that part of the transverse member that is continuous over the longitudinal member.

Where higher strength or higher modulus plies are used in the flange or crown of the internal, it may be advisable to provide similar higher strength, higher modulus local plies in the shell or deck plating, in the direction parallel to the internal to balance the strength and stiffness of the high strength and high modulus plies in the flange or crown of the internal.

3.5 Strength and Stiffness

3.5.1 Section Modulus

The section modulus of each longitudinal, stiffener, transverse web and girder including the plating to which it is attached is to be not less than given by the following equation:

\[
SM = \frac{83.3 \times \mu \ell^2}{\tau_a} \text{ cm}^3
\]

\[
SM = \frac{144 \times \mu \ell^2}{\tau_a} \text{ in}^3
\]
where \( p, s, \ell \) and \( \sigma_a \) are defined in 3-2-4/1.3.

Where the shell, deck or bulkhead plating, and the webs and flange and crown of the member are of different strength or elastic property plies, consideration is to be given to the effect of the different moduli plies in calculating the moment of inertia and section modulus; the required section modulus is to be considered for each different strength laminate of the member.

### 3.5.2 Moment of Inertia

The moment of inertia of each longitudinal, stiffener, transverse web, stringer or girder, including the plating to which it is attached, is to be not less than given by the following equation:

\[
I = \frac{260ps\ell^3}{K_4E} \text{ cm}^4
\]

\[
I = \frac{54ps\ell^3}{K_4E} \text{ in}^4
\]

where

\[
K_4 = 0.005 \quad \text{for shell and deep tank girders, stringers and transverse webs.}
\]

\[
= 0.004 \quad \text{for deck girders and transverses.}
\]

\[
= 0.010 \quad \text{for all other members.}
\]

\( E \) = tensile or compressive modulus, in N/mm² (kgf/mm², psi) representative of the basic value used in the moment of inertia calculation.

\( p, s \) and \( \ell \) are as given in 3-2-4/1.3.

### 3.5.3 Shear Area

The web area, \( A \), of the member is to be not less than given by the following equation:

\[
A = \frac{1000ps\ell}{2\tau} \text{ mm}^2
\]

\[
A = \frac{144ps\ell}{2\tau} \text{ in}^2
\]

where

\( A \) = net web area, in mm² (in²), at location being considered

\( \tau \) = design shear stress, in N/mm² (kgf/mm², psi), to be taken not greater than 0.4\( \tau_u \)

\( \tau_u \) = lesser of ultimate shear strength, in N/mm² (kgf/mm², psi), in either warp or fill of the web laminate

\( p, s \) and \( \ell \) are as given in 3-2-4/1.3.

Consideration will be given to determining the web area using more detailed methods of determining the shear stress in the web at the neutral axis of the member.

### 3.7 Proportions

The thickness of webs and flanges are to be in accordance with Section 3-2-6.
3.9 Buckling

3.9.1 Single Skin Laminate
Where single skin laminate members are subject to in-plane compressive loading likely to cause axial overall or local buckling, design calculations are to be submitted to show the margin against buckling failure.

3.9.2 Sandwich Laminates
Where sandwich laminate members are subject to in-plane compressive loading, likely to cause axial overall or local buckling of the sandwich, or of the sandwich skins, design calculations are to be submitted to show the margin against buckling failure.

5 Stanchions

5.1 General
The structure under stanchions is to be of sufficient strength to distribute the loads effectively. Stanchions above are to be arranged directly over stanchions below wherever possible; where this is not possible, effective means are to be provided for transmitting the loads to the structure below. Stanchions in double bottoms and under the tops of deep tanks are to be metal and solid in cross section. Stanchions are in general not to be used in the bottom or double bottom structures where subject to high impact loads in service.

5.3 Stanchion Analysis
The load, $W$, on a given stanchion is to be developed from the end reaction from the girders that the stanchion supports. These end reactions are to be developed considering the design pressure for the deck in which they are located plus any point loads from stanchions located on the girder. When cascading the stanchion loads through the structure, the analysis is to consider the load from the deck directly above the stanchion plus the loads from all complete decks and one-half the load from all partial or deckhouse decks. The requirement in 3-2-4/5.5 is given for a simple stanchion that will only need to support the deck directly above. In general, stanchions are to have sectional area not less than $1.015 W \text{ cm}^2$ ($0.16 W \text{ in}^2$) where the stanchions are subject to tension loads.

5.5 Stanchion Load
The load on a stanchion is to be obtained from the following equation:

$$W = pbs \text{ kN (tf)}$$
$$W = 0.064 pbs \text{ Ltf}$$

where

$W =$ load, in kN (tf, Ltf)

$b =$ mean breadth, in m (ft), of area supported

$s =$ mean length, in m (ft), of area supported

$p =$ design pressure, in kN/m$^2$ (tf/m$^2$, psi), given in Section 3-2-2

5.7 Permissible Load
The load a stanchion may carry is to be equal to or greater than the load on the stanchion obtained in 3-2-4/5.3. This permissible load is to be obtained from the following equations:

5.7.1 Ordinary Strength Steel Stanchions

$$W_a = (12.09 - 4.44\ell/r)A \text{ kN}$$
\[ W_a = (1.232 - 0.452 \ell/r)A \text{ tf} \]
\[ W_a = (7.83 - 0.345 \ell/r)A \text{ Ltf} \]

Refer to 3-2-8/3.1 of the *Rules for Building and Classing Marine Vessels* for high strength steel.

### 5.7.2 Aluminum-Alloy Stanchions (1 January 2004)

\[ W_a = (10.00 - 5.82 \ell/r)A \sigma_y/165 \text{ kN} \]
\[ W_a = (1.02 - 0.593 \ell/r)A \sigma_y/17 \text{ tf} \]
\[ W_a = (6.49 - 0.452 \ell/r)A \sigma_y/24000 \text{ Ltf} \]

where

- \( W_a \) = permissible load, in kN (tf, Ltf)
- \( r \) = least radius of gyration of stanchion, in cm (in.)
- \( A \) = area of stanchion, in cm\(^2\) (in\(^2\))
- \( \ell \) = unsupported length of stanchion, in m (ft)
- \( \sigma_y \) = minimum yield strength of welded aluminum under consideration, in N/mm\(^2\) (kgf/m\(^2\), psi)

The adoption of aluminum test values higher than given in Part 2, Chapter 5 will be subject to special consideration.

### 5.9 FRP Stanchions

FRP stanchions will be subject to special consideration.

### 5.11 Support by Bulkheads

Bulkheads supporting girders or bulkheads fitted in lieu of stanchions are to be stiffened to provide support not less effective than required for stanchions.

### 7 Internals Subject to Military Mission Loads

A first principles analysis is to be performed for all internals that are subject to a military mission load. The maximum stresses and deflections in these plates are not to exceed the stresses given in 3-2-4/7 TABLE 2.

#### TABLE 2
Maximum Stresses

<table>
<thead>
<tr>
<th></th>
<th>Steel</th>
<th>Aluminum</th>
<th>FRP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \sigma )</td>
<td>( \delta )</td>
<td>( \sigma )</td>
</tr>
<tr>
<td><strong>Own vessel</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>weapon weapon firing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>effects</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Weapon foundation</strong></td>
<td>( 0.5\sigma_y )</td>
<td>( 0.5\sigma_{yw} )</td>
<td>( 0.33\sigma_u )</td>
</tr>
<tr>
<td><strong>Gun Blast</strong></td>
<td>( \sigma_y )</td>
<td>( \sigma_{yw} )</td>
<td>( 0.33\sigma_u )</td>
</tr>
<tr>
<td><strong>Missile Blast</strong></td>
<td>( \sigma_y )</td>
<td>( \sigma_{yw} )</td>
<td>See Note 3</td>
</tr>
<tr>
<td><strong>Human Load</strong></td>
<td>---</td>
<td>---</td>
<td>( 0.33\sigma_u )</td>
</tr>
<tr>
<td>Part</td>
<td>Chapter</td>
<td>Section</td>
<td>3-2-4</td>
</tr>
<tr>
<td>------------------</td>
<td>---------------</td>
<td>---------------</td>
<td>-------</td>
</tr>
</tbody>
</table>

### Hull Construction and Equipment

#### Hull Structures and Arrangements

#### Internals

<table>
<thead>
<tr>
<th></th>
<th>Steel</th>
<th>Aluminum</th>
<th>FRP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \sigma )</td>
<td>( \sigma_{yw} )</td>
<td>See Note 3</td>
</tr>
<tr>
<td>Overall Dist. Loading</td>
<td>( 0.60\sigma_y )</td>
<td>( 0.6\sigma_{yw} )</td>
<td></td>
</tr>
<tr>
<td>Landing Impact Loading</td>
<td>( \sigma_y )</td>
<td>( \sigma_{yw} )</td>
<td>See Note 3</td>
</tr>
<tr>
<td>Girders, Stanchions, or Truss Supports (a)</td>
<td>( 0.9\sigma_y )</td>
<td>( 0.9\sigma_{yw} )</td>
<td>See Note 3</td>
</tr>
<tr>
<td>Loading Beams</td>
<td>( 0.9\sigma_y )</td>
<td>( 0.9\sigma_{yw} )</td>
<td>See Note 3</td>
</tr>
<tr>
<td>Loading Girders, Stanchions, or Truss Supports (a)</td>
<td>( 0.8\sigma_y )</td>
<td>( 0.8\sigma_{yw} )</td>
<td>See Note 3</td>
</tr>
<tr>
<td>Masts (1)</td>
<td>( 0.4\sigma_y ) (2)</td>
<td>( 0.4\sigma_{yw} ) (2)</td>
<td>See Note 3</td>
</tr>
</tbody>
</table>

\( \sigma_y \) = yield strength of steel, in N/mm\(^2\) (kgf/mm\(^2\), psi)

\( \sigma_{yw} \) = welded yield strength of aluminum, in N/mm\(^2\) (kgf/mm\(^2\), psi)

\( s \) = panel spacing

\( \sigma_u \) = ultimate tensile strength, in N/mm\(^2\) (kgf/mm\(^2\), psi)

**Notes:**

1. The pretension of stays are to be 0.20\( Bs \). The maximum tension in the stays is 0.40\( Bs \) or 0.35\( Bs \) for masts with two levels of stays.
2. Stayed masts are to be checked in the unstayed position with an allowable stress of 0.80\( \sigma_y \) for steel or 0.80\( \sigma_{yw} \) for aluminum.
3. Composites will be specially considered for use in this location.
4. For members subjected to axial compression, the factor of safety is to be based on the yield stress or critical buckling stress, whichever is less.
1 Structural Arrangement – All Materials

1.1 Framing, Webs, Girders, and Non-tight Structural Bulkheads

1.1.1 General

The shell, main deck, and the sides and tops of long superstructures are in general to be longitudinally framed; depending on vessel length, speed and structural stability, vessels may also be transversely framed. On transversely framed vessels, it is to be clearly indicated that the structure has a continuous load path that eliminates hard spots on unsupported structure.

Bulkheads, partial bulkheads or web frames are to be arranged in the main hull and in long superstructures or deckhouses to provide effective transverse rigidity. Bulkheads or deep web frames are to be provided in the main hull under the ends of superstructures or deckhouses.

Longitudinal frames are to be supported by transverse web frames, transverse bulkheads or other transverse structure. For vessels over 61 m (200 ft) in length, or on vessels where the longitudinal stiffeners need to be included in the offered longitudinal strength calculation to meet the requirements in 3-2-1/1, the longitudinals are to be continuous in way of transverse supporting members, including transverse bulkheads. All other vessels may have longitudinal members intercostal to the transverse bulkheads provided that continuity of strength and end fixity are maintained in accordance with 3-1-2/5.9 and 3-2-5/1.1.2. Vessels that are under 30.5 m (100 ft) in length, and where the longitudinal stiffeners do not need to be included in the offered longitudinal strength calculation to meet the requirements in 3-2-1/1, may have longitudinal stiffeners that are intercostal to the transverse supporting members and bulkheads providing that continuity of strength and end fixity are maintained in accordance with 3-1-2/5.9 and 3-2-5/1.1.2. With transverse framing, deck and bottom girders are to be provided. Girders may be intercostal at transverse bulkheads provided continuity of strength is maintained and end fixity is provided in accordance with 3-1-2/5.9 and 3-2-5/1.1.2.

Transverses are to be arranged as continuous web rings and girders are to be aligned with stiffeners at bulkheads. Alternative arrangements that provide fixity at the ends of transverses and girders will be specially considered.
1.1.2 Attachments and Stiffening
At supporting members, the attachment of all internal structural members is to provide end fixity and effective load transmission. Special consideration will be given to reduced end fixity where the alternative structure has equivalent strength.

The webs of all members are to be effectively attached to the shell, deck or bulkhead plating, to their supporting members and to face bars in accordance with the requirements in Section 3-2-13.

1.1.3 Engines, Machinery, Masts, Weapons, and other Foundations
The foundations of engines and associated machinery are to be installed to the manufacturer’s recommendations. These foundations are to be constructed to withstand the loads imparted by the equipment they support under the worst intended operating conditions. The rigidity of foundations and supporting structure is to be sufficient to prevent misalignment, deflection, or vibration, which would interfere with the operation of the equipment.

Where main engine girders are part of the longitudinal strength of the vessel, there is to be continuity of strength and transition to smaller longitudinal structure. The flanges of engine girders are to be tripped at each transverse frame. All changes of engine girder web depth are to be gradual. The angle of this transition is not to exceed 45°.

Foundations of auxiliary equipment are to be similar to that of engine foundations. They are to provide for secure attachment of the equipment and are to be effectively attached to the hull structure.

Weapon foundations are to be designed in accordance with Sections 3-2-2, 3-2-3, and 3-2-4 to withstand all impact and recoil loads in addition to any other specific requirements that are indicated by the Naval Administration.

Mast foundations are to be designed in accordance with Sections 3-2-2, 3-2-3, and 3-2-4 to stand with all constrains from the mast legs or stays.

Crane and davit foundations are to be capable of withstanding the axial load and the maximum overturning moments specified by the crane manufacturer.

The foundations for anchor winches or windlasses are to be designed in accordance with the requirements in 3-5-1/11.3.

Structural members of all foundations are not to be punched or drilled for the attachment of equipment or fittings. Brackets, margin plates, special framing, or weld studs are to be attached to the structure and the components mounted on them and not directly on the structure.

All connections that are constructed with the use of a bi-metallic connection are to be in accordance with 3-2-6/1.1.6 and 3-2-13/3.

1.3 Watertight Bulkheads
1.3.1 General (1 July 2022)
All vessels having lengths, L, equal to or exceeding 15 m (50 ft) are to be provided with watertight bulkheads in accordance with this section. The plans submitted are to clearly show the location and extent of each watertight bulkhead.

1.3.2 Openings and Penetration (1 July 2022)
The number of openings in watertight subdivisions is to be kept to a minimum, compatible with the design and proper working of the vessel. Where penetrations of watertight bulkheads and internal deck are necessary for access, piping, ventilation, electrical cables, etc., arrangements are to be made to maintain the watertight integrity. Relaxation in the watertightness of openings above
the freeboard deck may be considered, provided it is demonstrated that any progressive flooding
can be easily controlled and that the safety of the vessel is not impaired.

Ventilation penetrations through watertight subdivision bulkheads are to be avoided. Where
penetrations are unavoidable, the ventilation ducting is to satisfy watertight bulkhead
requirements or watertight closing appliances are to be installed at the bulkhead penetrations. For
ventilation penetrations below the bulkhead deck or below damage equilibrium waterlines, the
closing appliances are to be operable from the bridge. Otherwise, local, manual controls may be
provided.

1.3.3 Collision Bulkhead (2019)

Vessel having a length, as defined in Section 3-1-1, of or exceeding 15 m (50 ft) are to be provided
with a collision bulkhead fitted not less than 0.05\(L\) or 10 m (32.8 ft), whichever is less, abaft the
reference point. The bulkheads are to be intact except for approved pipe penetrations, and are to
extend to the main weather deck preferably in one plane. In vessels having long superstructures at
the forward end, the bulkheads are to be extended weathertight to the superstructure deck. Provided
the extensions are not less than 0.05\(L\) abaft the reference point, they need not be fitted
directly over the collision bulkhead. In such cases, the part of the deck forming the step is to be
weathertight. Alternative locations of the collision bulkhead may be considered if specified by
Naval Administration.

1.3.4 Reference Point (2019)

The reference point in determining the location of the collision bulkhead is the forward end of \(L\)
except that in the case of vessels having any part of the underwater body, such as the bulbous bow,
rectifying forward of the forward end of \(L\), the required distances are to be measured from a
reference point located a distance forward of the forward end of \(L\). This distance, \(x\), is the lesser of
the following (see 3-2-5/1.3.4 FIGURE 1):

\[ i) \quad \text{Half the distance between the forward end of } L \text{ and the extreme forward end of the} \]

\[ p/2 \]

\[ ii) \quad 0.015L \]

\[ iii) \quad 3 \text{ m (9.84 ft)} \]

where \(L\) is as defined in 3-1-1/3.

The forward end of \(L\) is to coincide with the fore side of the stem on the waterline at which \(L\) is
measured.
1.3.5 Engine Room
The engine room is to be enclosed by watertight bulkheads extending to the main weather deck.

1.3.6 Chain Locker (2012)
For vessels with length $L$ (as defined in 3-1-1/3) greater than 24 meters (79 feet), chain lockers and chain pipes are to be made watertight up to the weather deck. The arrangements are to be such that accidental flooding of the chain locker cannot result in damage to auxiliaries or equipment necessary for the proper operation of the vessel nor in successive flooding into other spaces. Bulkheads between separate chain lockers not forming a part of subdivision bulkhead (see 3-2-5/1.3.6 FIGURE 2A below), or bulkheads which form a common boundary of chain lockers (see 3-2-5/1.3.6 FIGURE 2B below), need not be watertight.

Where means of access into chain lockers are provided, they are to be closed by a substantial cover secured by closely spaced bolts. Doors are not permitted.

Where a means of access to chain lockers is located below the weather deck, the access cover and its securing arrangements are to be in accordance with recognized standards (such as ISO 5894-1999), or equivalent for watertight manhole covers. Butterfly nuts and/or hinged bolts are prohibited as the securing mechanism for the access cover.

For closure of chain pipes, see 3-2-9/21.7.

The arrangements on vessels that are not subject to the International Convention on Load Lines or its Protocol may be specially considered.
1.5 **Tanks**

The arrangements of all tanks, their intended service, and the heights of the overflow pipes are to be indicated clearly on the drawings submitted for approval.

Where potable water tanks are fitted, water closets are not to be installed on top of the tanks nor are soil lines to run over the tops of the tanks. Pipes containing non-potable liquids are not to be run through the tanks. Attention is directed to the requirements of the Naval Administration that might govern the location, construction or design of such tanks.

Baffle or swash plates are to be provided. Special consideration may be given for the omission of baffle or swash plates providing the effects of fluid slamming on the plate are considered.

Scantlings of pressurized tanks will be subject to special consideration.

All tanks and void spaces are to be accessible for inspection and repair.

1.7 **Decks**

Where a deck is stepped or has a break, suitable scarphing or brackets are to be provided at the side shell.

Decks passing into superstructures within the $0.5L$ amidships are to be increased in way of the break. See 3-2-1/1.7.4.

1.9 **Means of Escape**

Unless otherwise specified by the Naval Administration, all main hull spaces accessed by the passengers or military personnel, including accommodations, are to have two means of escape to the main weather deck. These escapes are to be located as far apart as practicable and are to be operable from both sides. All escape routes are to be readily accessible and unobstructed.

Size and materials for stairs, vertical ladders, hatches, doors, etc. that are used for escape measures are to be specified by the Naval Administration.
1.11 **Double Bottoms**

The length and extent of double bottoms are to be determined by the Naval Administration.

1.13 **Doors, Hatches, Scuttles, and Manhole Covers**

Unless otherwise specified by the Naval Administration, all doors, hatches, scuttles, and manhole covers, together with their frames and coamings, are to be in accordance with the same requirements as the structure in which they are installed.

1.15 **Helicopter Landing Areas**

1.15.1 **General**

Helicopter decks, where provided, are to meet the following safety requirements. The attention of owners, builders, and designers is directed to various Naval Administration regulations and guides regarding the operational and other design requirements for helicopter landing on vessels. See also 4-6-4/3.9.2, and 4-6-6/7.

Plans showing the arrangement of the helicopter deck are to be submitted. The arrangement plan is to show the overall size of the helicopter deck and the designated landing area.

1.15.2 **Safety Net**

The unprotected perimeter of the helicopter landing deck is to be provided with safety netting or equivalent.

1.15.3 **Material**

In general, the construction of helicopter decks is to be of steel or other material with equivalent ability to retain structural capacity in a fire. If the helicopter deck forms the deckhead of a deckhouse or superstructure, it is to be insulated to A-60 class standard.

Aluminum alloys may be used for helicopter decks integral if they form part of an aluminum deckhouse or superstructure. They may also be of aluminum alloy, fitted above a steel deckhouse or deck structure, provided the following conditions are complied with:

1. There are to be no openings in the exterior bulkheads directly below the helicopter deck.
2. All windows in the lower exterior bulkheads are to be fitted with steel shutters.

1.15.4 **Means of Escape and Access**

The helicopter deck is to be provided with both a main and an emergency means of escape and access for fire fighting and rescue personnel. These means are to be located as far apart from each other as is practicable and preferably on opposite sides of the helicopter deck.

1.17 **Ammunition Stowage Magazines**

1.17.1 **General**

The following requirements apply to stowage magazines for torpedoes, missiles, bombs, large-caliber gun ammunition, and all cargo ammunition, to minimize the threat of internal explosions from own-vessel sources such as sparks, fires, or accidental detonation of own-vessel weapons. The requirements in this section do not generally apply to ready-use magazines or other short-term stowage of munitions, nor to small-arms magazines.

1.17.2 **Magazine Location and Access**

Stowage magazines are not to be located adjacent to helicopter decks, either horizontally or vertically. There is to be at least one deck vertically separating internal magazines from a helicopter deck. Stowage magazines, except for cargo magazines, are not to have common boundaries with other stowage magazines. This requirement may be waived at the request of the Naval Administration for magazines within ballistic protection zones.
1.17.3 Magazine Requirements
No equipment is to be located within a magazine. Distributive systems are not to penetrate the boundaries of magazines except for those directly serving that magazine. Projectiles are not to be stowed in magazines containing powder cartridges or detonators, and vice-versa. Magazines are to have securing systems for all munitions adequate to prevent movement under all ship motions. Munitions are to have an air gap of at least 2 inches between the stowage stack and adjacent plating or sheathing. No cast iron or semi-steel is to be used for magazine equipment or stowage devices.

1.19 Arrangements for the Protection Against Own-Vessel Weapons-Firing Effects
1.19.1 General
Vessel structures, systems and personnel are to be protected against the effects of firing its own weapons, specifically guns and missiles (this does not include temporarily mounted small-caliber guns or portable missiles). The blast zones consist of two areas. Direct blast areas are those which lie in the direct line of impingement by the exhaust stream of the missile or near the muzzle of the gun. Reflected blast areas are those areas onto which the exhaust stream or muzzle blast is deflected after impinging on a deck or bulkhead in the direct blast areas.

1.19.2 Hull Fittings
The following items may be installed in the blast areas without shielding: flush-type including ramp low profile hatches and scuttles, portable lifelines and stanchions, bitts, chocks, fairleads, and rubber scuppers. Other items composed only of metallic materials may be installed in reflected blast areas without shielding.

Benchmarks in direct blast areas are to be equipped with steel covers. Recessed benchmarks are to be protected with flush deck covers and protruding benchmarks are to be protected with portable steel covers.

1.19.3 Requirements for Blast Shields
Shields are to be provided with adequate rigidity by edge stiffening or other stiffening where needed. In reflected blast areas shields are to enclose the protected item with the open side facing away from the launcher. Blast shields are to be steel with a minimum thickness of 3 mm, or an equivalent heat-resistant material. Steel shields are to be attached to the deck or bulkhead by welding.

Shields are to be configured to present an oblique impingement surface to deflect the exhaust stream and to preclude the deflection of blast onto other equipment.

Shields are not to interfere with weapons handling or be a hazard to personnel. Shields are to have rounded corners and edges.

1.19.4 Personal Protection
Red danger lights and labels are to be installed at doors and hatches which provide access into blast zones.

3 Structural Arrangements – Additional Requirements for Steel and Aluminum Alloys

3.1 Shell Plating
The bottom shell plating is to extend to the chine or upper turn of bilge. In general, the side shell is to be of the same thickness from its lower limit to the gunwale. Increases in thickness and additional stiffening are required in way of skegs, shaft struts, hawse pipes etc. Where a bow thruster tube is fitted to be in accordance with the requirements in 3-2-3/1.7.
5 Structural Arrangements – Additional Requirements for Fiber Reinforced Plastic Hulls

5.1 Tanks

In fiber reinforced plastic construction, non-integral tanks are to be used whenever possible. When integral tanks are used they are to be of single skin construction; the only exception is the tank top plating can be of sandwich construction. No stiffeners within integral tanks are to penetrate the tank boundaries. No gasoline tanks, or tanks containing petroleum products with flash points less than 60°C (150°F) are to be fitted integrally. The design and arrangements of oil fuel tanks is to be such that there is no exposed horizontal section at the bottom that could be exposed to a fire. Other fire protection arrangements for oil fuel tanks will be specially considered. For details of fire protection requirements see Section 3-4-1.

All internal surfaces of FRP tanks are to be covered with chopped strand mat weighing at least 600 g/m² (2 oz/ft²). This covering is to be in addition to the scantlings required by these Rules. A suitable coating is to be applied to this covering to prevent the contents of the tank from impregnating the surrounding laminates. The sides, tops, and baffles of integral tanks are to have all connections taped on both sides. Fresh water tanks are to be coated with a non-toxic and non-tainting coat of resin that is recommended by the resin manufacturer for potable water tanks. Where outfit items are to be laminated to the tank surface, the heavy coating of resin is to be applied afterwards and the laminated brackets sealed to prevent the ingress of moisture. The scantlings of integral oil fuel and water tanks are to be in accordance with Sections 3-2-3 and 3-2-4. Integral tanks are to be tested in accordance with 3-6-1/3.5.7 TABLE 1.
CHAPTER 2
Hull Structures and Arrangements

SECTION 6
Arrangement, Structural Details and Connections

1 Structural Details

1.1 Aluminum and Steel

1.1.1 General
Structural details are to be designed and constructed to minimize hard spots, notches and other structural discontinuities. Openings in webs, girders and other structural internal members are to be arranged clear of concentrated loads or areas of high stresses; slots in transverses and girders for longitudinals or beams in such locations are to be fitted with collars. Care is to be taken to verify structural continuity; sharp corners and abrupt changes in section are to be avoided; toes of brackets and ends of members are not to terminate on plating without attachment to an adjacent member, unless specially approved.

1.1.2 Longitudinals
Deck, bottom and inner bottom longitudinals are in general to be continuous unless specially approved otherwise, but in way of bulkheads they may be intercostal provided continuity of strength and end fixity are maintained by the end brackets. The ends of all internal structural members are to provide end-fixity and load transmission to the supporting member. Departures from this may be considered where the alternative structure has equivalent strength. See 3-2-5/1.

1.1.3 Girders and Transverses
Girders and transverses are to have depths not less than twice the depth of slots for longitudinals and beams or other openings. Transverses are to be arranged as continuous web rings, girders are to be aligned with stiffeners at bulkheads, alternative arrangements that provide fixity at the ends of transverses and girders will be specially considered.

1.1.4 Openings
Access and lightening holes with suitably radiused corners are to be arranged as necessary and clear of areas of load concentration or high stresses. Their depths and lengths are generally not to exceed respectively, 0.5 and 0.75 the depth of the members.

1.1.5 Limber Holes
Drains or limber holes are to be provided in non-tight structure to prevent the accumulation of liquids. Holes are to be located to provide complete drainage of all non-tight voids, bays, or pockets formed by structure. The holes are not to be located at points of high stress, such as the
intersection of members. Limber holes are to be half round at the edge, or round if not at the edge, of the structure that is to be drained. The diameter of drain or limber hole is not to be greater than 20% of the depth of the member.

1.1.6 Bi-metallic Connections
In aluminum construction, where bi-metallic connections are unavoidable, suitable insulation, such as gaskets, washers, sleeves, and bushings, are to be provided. The faying surfaces between mechanically fastened metal components, except machinery foundation shims, are to be protected by the use of a bedding compound. Stainless steel fasteners may be joined directly. See also 3-2-13/3.

1.3 Fiber Reinforced Plastic
1.3.1 General
Structural continuity is to be maintained and where changes in thickness or structural section occur, they are to be gradual to prevent notches, hard spots and other structural discontinuities. The requirements of 3-2-6/1.3.4 and 3-2-6/1.3.5, below, and of 3-2-6/3 and 3-2-6/5 are for the basic laminate given in Part 2, Chapter 6. Special consideration will be given where other laminates or resins are used. The ends of all internal structural members are to provide end-fixity and load transmission to the supporting member. Departures from this may be considered where the alternative structure has equivalent strength.

1.3.2 Changes in Laminate Thickness
A gradual taper is to be used for all changes in laminate thickness. Where the construction changes from sandwich laminate to a solid laminate, the thickness of the core material is in general, to be reduced by a gradual taper of not less than 2:1.

1.3.3 Openings, Holes and Raw Edges
Access and lightening holes with suitably radiused corners are to be arranged as necessary and clear of areas of load concentration or high stresses. Their depths and lengths are generally not to exceed, respectively, 0.5 and 0.75 times the depths of the members. Air and limber holes are to be in accordance with 3-2-6/1.1.5.

All exposed edges in way of cuts or holes in FRP single-skin laminates are to be sealed with resin. Edges of sandwich panels and edges of holes in sandwich panels are to be covered with one ply of glass cloth lapped no less than 25 mm (1 in.) onto each face of the laminate. The cloth is to be completely saturated with resin.

Ferrules installed in sandwich panels or stiffeners for drains or wire penetrations are to be set in bedding compound.

All hatch openings are to be supported by a system of transverse and longitudinal stiffeners.

1.3.4 Piping and Wiring in Foam
Piping or wiring passing through foam-filled spaces is to be installed in PVC tubing. The pipe is to be arranged such that water will not become trapped. The ends of the plastic tubing are to be joined to adjacent structure with resin impregnated mat. See 3-2-6/1.3.4 FIGURE 1.
1.3.5 Stiffeners

1.3.5(a) General. Stiffeners, frames, girders, deck beams, bulkhead stiffeners, etc. used to support FRP panels may be entirely of FRP, FRP laid over nonstructural cores or forms, or composites of FRP or other approved structural materials.

1.3.5(b) Stiffeners without effective Cores or with Nonstructural Cores. Stiffeners without cores or with cores not indicated in 2-6-1/5.5 TABLE 1 are to conform to 3-2-6/1.3.5(b) FIGURE 2, and the thickness of the crown and web of the stiffeners is to be not less than obtained from the following equations:

\[ t_1 = \frac{w}{20} \text{ mm (in.)} \]

\[ t = \frac{h}{30} \text{ mm (in.)} \]

where

- \( t_1 \) = thickness of stiffener crown, in mm (in.)
- \( t \) = thickness of stiffener webs, in mm (in.)
- \( w \) = width of stiffener crown, in mm (in.)
- \( h \) = height of stiffener webs, in mm (in.)

Where the stiffeners are of laminates with properties differing from the basic laminate, the thickness is to be modified by the factor:

\[ 7.7 \sqrt{\frac{C}{E}} \]

where

- \( E \) = compressive modulus of proposed laminate, in kg/cm\(^2\) (psi)
- \( C \) = ultimate compressive strength of proposed laminate, in kg/cm\(^2\) (psi)

Where polyvinylchloride, balsa, or other approved core material is used, thicknesses less than given above may be accepted provided the buckling stresses of the stiffener skins comply with the buckling stress criteria in 3-2-3/5.7.4.

Hat-section stiffeners constructed by laying FRP over premolded FRP forms (3-2-6/1.3.7 FIGURE 6) are to conform with 3-2-6/1.3.5(b) FIGURE 2 and the above equations; the premolded forms
may be considered structurally effective if their physical properties are at least equal to those of the overlay laminates.

**FIGURE 2**
Proportions of Stiffeners

Premolded stiffeners bonded to the laminates with FRP angles, flanges or tapes (3-2-6/1.3.5(b) FIGURE 4) are also to conform to 3-2-6/1.3.5(b) FIGURE 2 and the above equations. The thickness of each bonding angle flange or tape is to be not less than the thickness of the webs of the stiffener, and the legs of the bonding angle, flange or tape are to be of equal length in accordance with 3-2-6/5. Joints in premolded stiffeners are to be scarphed and spliced or otherwise reinforced to maintain the fill strength of the stiffeners.

The thickness may be less than obtained from the above equation if these members are suitably stiffened and provided with adequate lateral stability. The required minimum flange or tape laps onto such members, as shown in 3-2-6/1.3.5(b) FIGURE 2, if greater than 50 mm (2 in.), need not exceed 10t.
1.3.6 Girders and Longitudinal Frames

Girders and longitudinal frames are to be continuous through floors and web frames. Except in way of integral-tank end bulkheads, girders and longitudinal frames are also to be continuous through transverse bulkheads. Where such members are intercostal, attention is to be given to minimizing structural discontinuities. Where transverse structure is cut out in way of continuous members, the cut out is to be closed as to maintain the required tightness.

An acceptable type of continuous girder and longitudinal-frame FRP connection is shown in 3-2-6/1.3.6 FIGURE 5. The laps of the connections onto the supporting structure are to be not less than the overall widths of the structural members including flanges, and the thicknesses of the connections are to be not less than the thicknesses of the structural-member flanges or tapes.

1.3.7 Engine Foundations

Engine bed fittings are to be of thicknesses and widths appropriate to the holding down bolts such that there is a close and accurate fit between the fittings and the engine girder.
Where the engine girders are a non-molded surface, the fittings are to be set in filled resin or mat. On a molded surface where the contours on the girders match the contours on the fitting, the fittings are to be set in a structural adhesive of a filled resin.

The fittings are to be bolted through the webs of the girders. A compression sleeve constructed of stainless steel or FRP is to be fitted in way of the through bolts. The area of the girder that is connected to the fitting is to have a high density insert in way of the faying surfaces. The insert is to extend 25 mm (1 in.) in all directions beyond the connection. If the size of the insert is less than 150 cm² (24 in²) a compound consisting of three parts phenolic or glass microballons, two parts resin, and one part milled glass fibers, by volume, may be used. A doubler consisting of one ply of mat and two plies of structural laminates are to be added to each face of the cored laminate. The doubler is to extend no less than 75 mm (3 in.) beyond the high density foam insert.
1.3.8 Deck Fittings

Deck fittings, such as cleats and chocks, are to be bedded in sealing compound, structural adhesive, or gasketed, through-bolted, and supported by either oversize washers or metal, plywood or wood backing plates, as shown in 3-2-6/1.3.8 FIGURE 7. Where washers are used, the laminate in way of the fittings is to be increased at least 25% in thickness. In no case is the fitting to impair the strength or tightness of the structure.
1.3.9 Through Hull Penetrations

Generally all through hull penetrations below the deepest draft design waterline are to be formed by solid FRP laminates, as shown in 3-2-6/1.3.9 FIGURE 8. When sandwich construction is used for the hull, the core material is to be completely sealed off from the through hull penetration, as shown in 3-2-6/1.3.9 FIGURE 9. All through hull penetrations are to be taped on both sides of the penetration. The penetration is to be set in a bedding compound.

FIGURE 8
Through Hull Penetration – Solid Laminate
1.3.10 Boundary Angles, Flanges or Tapes

1.3.10(a) FRP to FRP.
Secondary bonding of FRP components by means of double boundary angles, flanges or tapes is to be in accordance with Part 2, Chapter 6. Typical boundary angles for FRP components are shown in 3-2-6/1.3.10(d) FIGURE 10. At the end connections of sandwich laminates, the core shear strength is to be effectively developed. The bulkheads are to be set into a foam insert, slow curing polyester putty, a microballoon mixture or other approved material. The thickness of each boundary angle, flange or tape having similar strength to the members being connected is to be not less than obtained from the following:

1.3.10(b) Single-skin to Single-skin.
One-half the thickness of the thinner of the two laminates being joined.

1.3.10(c) Sandwich to Sandwich.
The greater of the mean thicknesses of the skins of the sandwich panels being attached.

1.3.10(d) Sandwich to Single Skin.
Either one-half the thickness of the single-skin laminate or the mean thickness of the skins of the sandwich panel being attached, whichever is less.

The thickness of each FRP-to-FRP boundary angle also is to be not less than obtained from the following equation:

\[ t = 0.105L + 1.11 \text{ mm} \]

\[ t = 0.00133L + 0.044 \text{ in.} \]

where

\[ L = \text{length, in m (ft), as defined in 3-1-1/3, need not be taken as more than 46.6 m (153 ft).} \]

The width of each flange, not including end taper, is to be not less than 10 times the thickness given above, including the end taper, 13 times the thickness given above, and in general not less than 50 mm (2 in.).
3 Welded and Mechanical Connections

3.1 Steel and Aluminum

3.1.1 General
Components may be fastened by either welding or rivets. For welding, see 3-2-13 and Part 2, Chapters 4 and 5.

3.1.2 Expanding Rivets
Rivets of the expanding type (blind or “pop” rivets) may be used for lightly loaded connections where lack of accessibility prohibits the use of through fastenings. Such rivets are not to be used for joining components having a total thickness exceeding 12.5 mm (0.50 in.), and are not to be used for joining decks to hulls except as temporary or unstressed fastenings installed for the sake of convenience or speed during assembly.

3.1.3 Conventional Rivets
Conventional rivets, where used, are to be subject to special consideration, and are to be of the cold-driven type. Washers, essentially of the same material as the rivets, are to be installed under both the heads and the points.

3.3 Fiber Reinforced Plastic

3.3.1 General
Components may be fastened with bolts, machine screws, or self-tapping screws. Where machine screws or self-tapping screws are used, they are not to have countersunk heads. Shanks of all threaded fastenings are to be long enough to pass through the joints, by at least one thread beyond the top of the nut or plastic locking element. Excessive protrusion is to be avoided, and where the threaded end of the fastener is accessible, and the excess length can constitute a hazard, the excess
length is to be removed. Washers are not to be used for the sole purpose of lessening thread protrusion. When it is necessary to reduce the length of thread protrusion, excess length is to be removed without damaging the threads and the bolts dressed to remove rough edges. Where watertight joints are required, suitable sealants or bedding compounds are to be used in addition to the fastenings. All threaded fasteners are to be stainless steel unless alternatives are specifically allowed by the Naval Administration. Sizes and specifications are to be indicated on the submitted plans. The diameter of a fastening is not to be less than the thickness of the thinner component being fastened, with a minimum diameter of 8 mm (0.315 in.). Where hardware is predrilled for fastener sizes that are less than specified above, the size of the fastener used is to match the size of the predrilled holes.

3.3.2 Bolts and Machine Screws

Bolts or machine screws are to be used where accessibility permits. The diameter of each fastener is to be at least equal to the thickness of the thinner component being fastened. Bolts and machine screws less than 8 mm (0.315 in.) in diameter are not to be used. Where \( d \) is the fastener diameter, fastener centers are to be spaced at a minimum of 3\( d \) apart and are to be set in from edges of laminates a minimum of 3\( d \).

Generally in fiber reinforced plastic construction, all bolted connections are to be made through solid fiber reinforced plastic inserts. Where this is not possible, all low density core material is to be replaced with a structurally effective insert. Diameters of fastening holes are not to exceed fastening diameters by more than 0.5 mm (0.02 in.) for bolts less than or equal to 18 mm (0.71 in.) in diameter and 1 mm (0.39 in.) for bolts greater than 18 mm (0.71 in.) in diameter. Elongated and oversize holes are permitted where necessary for adjustment or alignment.

Washers or backing plates are to be installed under all fastening heads and nuts that otherwise would bear on laminates. Washers are to measure not less than 2.25\( d \) in outside diameter and 0.1\( d \) in thickness. Nuts are to be either of the self-locking type, or other effective means are to be provided to prevent backing off. Mechanical thread locking devices and methods such as lockwashers, either spring, tooth, or tab type, peening wiring, or thread upset after assembly are not to be used.

Bolted connections are, in general, to be bonded along all mating surfaces to insure the tightness of the structure using an accepted structural adhesive, applied in accordance with the manufacturer’s requirements.

In general, all structural, bolted connections are to use threads of bolts in accordance with the requirements in the following table:

<table>
<thead>
<tr>
<th>Location</th>
<th>Pitch ( (1) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watertight connections below design waterline</td>
<td>10( d )</td>
</tr>
<tr>
<td>Connections in hull above design waterline to deck</td>
<td>15( d )</td>
</tr>
<tr>
<td>Hull to deck connections, bonded with approved structural adhesive</td>
<td>15( d )</td>
</tr>
<tr>
<td>Connections in deckhouses</td>
<td>20( d )</td>
</tr>
<tr>
<td>Deckhouse to deck connection, bonded with approved structural adhesive</td>
<td>15( d )</td>
</tr>
<tr>
<td>Minimum distance between reeled lines of bolts</td>
<td>3( d )</td>
</tr>
</tbody>
</table>

*Notes:*

1. \( d \) is the diameter of the bolt.
2. Internal boundary sealing angle is to be provided for all locations.
All structural, single line, bolted connections without adhesive bonding are to be in accordance with the requirements in the following table:

<table>
<thead>
<tr>
<th>Location</th>
<th>Pitch $d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manhole covers to fuel tanks</td>
<td>6d</td>
</tr>
<tr>
<td>Manhole covers to water tanks</td>
<td>8d</td>
</tr>
<tr>
<td>Covers to void tanks/cofferdams</td>
<td>10d</td>
</tr>
<tr>
<td>Bolted access hatches in decks</td>
<td>10d</td>
</tr>
<tr>
<td>Bolted watertight door frames</td>
<td>8d</td>
</tr>
<tr>
<td>Window frames</td>
<td>8d</td>
</tr>
</tbody>
</table>

Note:

1. $d$ is the diameter of the bolt.

Bolt holes are to be drilled, without undue pressure at breakthrough, having a diametric tolerance of two percent of the bolt diameter. Where bolted connections are to be made watertight, the hole is to be sealed with resin and allowed to cure before the bolt is inserted. In areas of high stress or where unusual bolting configurations, on the basis of equivalence with the above requirements, are proposed, testing may be required.

3.3.3 Self-tapping Screws

In general, no self-tapping screws are to be used in fiber reinforced plastic construction. Self-tapping screws having straight shanks may be used for non-structural connections where lack of accessibility prohibits the use of through fastenings. Where used, self-tapping screws are to have coarse threads.

3.5 Backing Bars and Tapping Plates

The requirements for backing plates and bars will be individually considered, on the basis of the loading imposed, details of which are to be indicated on the submitted plans. Metal plates and bars are to be suitably protected against corrosion. Tapping plates may be encapsulated within the laminate, laminated to or bolted to the structure. Tapping plate edges or corners are to be suitably rounded.

5 Deck-to-Hull Joints

5.1 Weather Joints (1 January 2004)

The connection is to develop the strength of the deck and shell laminate, whichever is stronger, by either a bolted or bonded connection.

Where flanges are used, the hull flanges are to be equal in thickness and strength to the hull laminates and the deck flanges are to be equal in strength and thickness to the deck laminates. Where bolts are used to develop the required strength of the connection, the faying surfaces are to be set in bedding compound, polyester putty, or other approved material. Minimum widths of overlaps, minimum bolt diameters, and maximum bolt spacing are to be in accordance with 3-2-6/5.1 TABLE 1. Intermediate values may be obtained by interpolation.

FRP bonding angles, where used, are to have flanges of the same strength and of at least one-half the thickness of single skin hull or deck laminate. On sandwich laminates, they are to have the same strength and thickness as the skin of a sandwich laminate, based on the thicker of the two laminates being connected. The widths of the flanges are to be in accordance with the widths of overlaps in 3-2-6/5.1 TABLE 1.
Calculations supporting the geometry of the deck-to-hull joint are to be submitted for vessels over 60 m (200 ft) in length.

**TABLE 1**
Deck-to-Hull Joints (1 January 2004)

<table>
<thead>
<tr>
<th>Length of Vessel L, m</th>
<th>Minimum Width of Overlap, mm</th>
<th>Minimum Bolt Diameter, mm</th>
<th>Bolt Spacing, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>63.5</td>
<td>6.50</td>
<td>155</td>
</tr>
<tr>
<td>12</td>
<td>75.0</td>
<td>7.75</td>
<td>165</td>
</tr>
<tr>
<td>15</td>
<td>87.5</td>
<td>9.00</td>
<td>180</td>
</tr>
<tr>
<td>18</td>
<td>100.0</td>
<td>10.25</td>
<td>190</td>
</tr>
<tr>
<td>21</td>
<td>112.5</td>
<td>11.50</td>
<td>205</td>
</tr>
<tr>
<td>24</td>
<td>125.0</td>
<td>12.75</td>
<td>215</td>
</tr>
<tr>
<td>27</td>
<td>137.5</td>
<td>14.00</td>
<td>230</td>
</tr>
<tr>
<td>30</td>
<td>150.0</td>
<td>15.25</td>
<td>240</td>
</tr>
<tr>
<td>33</td>
<td>162.5</td>
<td>16.50</td>
<td>255</td>
</tr>
<tr>
<td>36</td>
<td>175.0</td>
<td>17.75</td>
<td>265</td>
</tr>
<tr>
<td>39</td>
<td>187.5</td>
<td>19.00</td>
<td>280</td>
</tr>
<tr>
<td>42</td>
<td>200.0</td>
<td>20.25</td>
<td>295</td>
</tr>
<tr>
<td>45</td>
<td>212.5</td>
<td>21.50</td>
<td>310</td>
</tr>
<tr>
<td>48</td>
<td>225.0</td>
<td>22.75</td>
<td>325</td>
</tr>
<tr>
<td>51</td>
<td>237.5</td>
<td>23.00</td>
<td>340</td>
</tr>
<tr>
<td>54</td>
<td>250.0</td>
<td>24.25</td>
<td>355</td>
</tr>
<tr>
<td>57</td>
<td>262.5</td>
<td>25.50</td>
<td>370</td>
</tr>
<tr>
<td>60</td>
<td>275.0</td>
<td>26.75</td>
<td>385</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>2.5</td>
<td>0.25</td>
<td>6.0</td>
</tr>
<tr>
<td>40</td>
<td>3.0</td>
<td>0.30</td>
<td>6.5</td>
</tr>
<tr>
<td>50</td>
<td>3.5</td>
<td>0.35</td>
<td>7.0</td>
</tr>
<tr>
<td>60</td>
<td>4.0</td>
<td>0.40</td>
<td>7.5</td>
</tr>
<tr>
<td>70</td>
<td>4.5</td>
<td>0.45</td>
<td>8.0</td>
</tr>
<tr>
<td>80</td>
<td>5.0</td>
<td>0.50</td>
<td>8.5</td>
</tr>
<tr>
<td>90</td>
<td>5.5</td>
<td>0.55</td>
<td>9.0</td>
</tr>
<tr>
<td>100</td>
<td>6.0</td>
<td>0.60</td>
<td>9.5</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-------------------------------</td>
<td>---------------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>110</td>
<td>6.5</td>
<td>0.65</td>
<td>10.0</td>
</tr>
<tr>
<td>120</td>
<td>7.0</td>
<td>0.70</td>
<td>10.5</td>
</tr>
<tr>
<td>130</td>
<td>7.5</td>
<td>0.75</td>
<td>11.0</td>
</tr>
<tr>
<td>140</td>
<td>8.0</td>
<td>0.80</td>
<td>11.5</td>
</tr>
<tr>
<td>150</td>
<td>8.5</td>
<td>0.85</td>
<td>12.0</td>
</tr>
<tr>
<td>160</td>
<td>9.0</td>
<td>0.90</td>
<td>12.5</td>
</tr>
<tr>
<td>170</td>
<td>9.5</td>
<td>0.95</td>
<td>13.0</td>
</tr>
<tr>
<td>180</td>
<td>10.0</td>
<td>1.00</td>
<td>13.5</td>
</tr>
<tr>
<td>190</td>
<td>10.5</td>
<td>1.05</td>
<td>14.0</td>
</tr>
<tr>
<td>200</td>
<td>11.0</td>
<td>1.10</td>
<td>14.5</td>
</tr>
</tbody>
</table>

Each joint is to be protected by a guard, molding, fender, or rail cap of metal, wood, rubber, plastic, or other approved material. The size and ruggedness of this protective strip are to be consistent with the severity of the service for which the vessel is intended. The strip is to be installed in such a manner that it may be removed for repair or replacement without endangering the integrity of the deck-to-hull joint.

5.3 Interior Joints

Interior decks are to be connected to the hull by shelves, stringers, or other structural members on both sides by FRP tapes. The connection is to effectively develop the strength of the interior deck. The fit-up between the parts are typically not to exceed 5 mm (0.2 in.). The interior deck is to be bedded in syntactic foam or filled resin during assembly and prior to tabbing.

7 Shell Details

7.1 Keels

Plate keels are to be not less than shown in 3-2-6/7.1 FIGURE 11a and 3-2-6/7.1 FIGURE 11b, and vertical keels or skegs are to be not less than shown in 3-2-6/7.1 FIGURE 12. Keels or skegs are to be adequate for docking loads, which are to be provided by the designer.
7.3 **Chines and Transoms**

Chines and transoms are to be not less than shown in 3-2-6/Figures 13a through 13d.
FIGURE 13b
Chine or Transom – Sandwich Construction

Overlap laminates in way of chine for minimum of B/20

FIGURE 13c
Stepped Chine – Foam Wedge Option

Core wedge of same density as topside core

Overlap laminates in way of chine for minimum of B/20
FIGURE 13d
Stepped Chine – Putty Radius

Overlap laminates in way of chine for minimum of B/20
1 Materials

1.1 Ordinary Strength Steels
The requirements in the following subsections are based upon ordinary strength steel. For higher strength steels and aluminum alloys see 3-2-7/1.3.

1.3 High Strength Steels and Aluminum Alloys
Unless otherwise specified, the required section modulus and inertia for high strength steels and aluminum alloys are as follows:

$$ SM = S_M S $$
$$ I = I_s E_s / E_o $$

where

$$ SM, I $$ = required section modulus and inertia. Unless specifically stated otherwise, the properties about the minor axis (axis perpendicular to $h$ or $w$) are to be used.

$$ S_M s, I_s $$ = section modulus and inertia obtained from the dimensions given for ordinary strength steel.

$$ Q $$ = as defined in 3-2-1/1.1.1

$$ E_s $$ = $2.06 \times 10^5$ N/mm$^2$ ($21 \times 10^3$ kgf/mm$^2$, $30 \times 10^6$ psi)

$$ E_o $$ = modulus of the material being considered in N/mm$^2$ (kgf/mm$^2$, psi)

Use of materials other than steel or aluminum will be specially considered.

1.5 Fiber Reinforced Plastic
For fiber reinforced plastic hulls, keels and skegs are to have proportions as indicated in 3-2-6/Figure 11 and 3-2-6/7.1 FIGURE 12.
3 **Keels**

3.1 **Bar Keels**

Where bar keels are fitted the thickness and depth is not to be less than obtained from the following equations:

\[
t = 0.625L + 12.5 \text{ mm}
\]

\[
t = 0.0075L + 0.50 \text{ in.}
\]

\[
h = 1.46L + 100 \text{ mm}
\]

\[
h = 0.0175L + 4 \text{ in.}
\]

where

\[
t = \text{ thickness, in mm (in.)}
\]

\[
h = \text{ depth, in mm (in.)}
\]

\[
L = \text{ length of vessel, in m (ft), as defined in 3-1-1}
\]

Thicknesses and depths other than given above are acceptable provided the section moduli and moments of inertia about the transverse horizontal axis are not less than given above.

3.3 **Plate Keels**

The thickness of the steel plate keel throughout the length of the vessel is to be not less than the bottom shell required in 3-2-3.

5 **Stems**

5.1 **Bar Stems**

Where bar stems are fitted the thickness and depth is not to be less than obtained from the following equations:

\[
t = 0.625L + 6.35 \text{ mm}
\]

\[
t = 0.0075L + 0.25 \text{ in.}
\]

\[
w = 1.25L + 90 \text{ mm}
\]

\[
w = 0.015L + 3.5 \text{ in.}
\]

where

\[
t = \text{ thickness, in mm (in.)}
\]

\[
w = \text{ width, in mm (in.)}
\]

\[
L = \text{ length of vessel, in m (ft), as defined in 3-1-1}
\]

This thickness and width is to be maintained between the keel and design load waterline. Above the designed load waterline they may be gradually reduced until the area at the head is 70% of that obtained from the equations.
Thicknesses and widths other than given above are acceptable provided the section moduli and moments of inertia about the longitudinal axis are not less than above. The thickness of the bar stem in general is also to not be less than twice the shell thickness.

5.3 Plate Stems
Where plate stems are used, they are not to be less in thickness than the bottom shell plating required in 3-2-3/1 and 3-2-3/3, where \( s \) is the frame spacing, or 610 mm (24 in.) if greater. Plate stems are to be suitably stiffened.

7 Stern Frames
Vessels that are fitted with stern frames, shoe pieces, rudder horns, and rudder gudgeons are to meet the applicable requirements in 3-2-13 of the *Rules for Building and Classing Marine Vessels*.

9 Shaft Struts

9.1 General
Tail-shaft (propeller-shaft) struts where provided may be of the V or I type. The following equations are for solid struts having streamline cross-sectional shapes. For struts other than ordinary strength steel see 3-2-7/1. For hollow section and non-streamlined struts, the equivalent cross sectional area, inertia, and section modulus (major axis) are to be maintained. For a streamlined cross-section strut, the inertia about the longitudinal axis is \( \frac{wt^3}{25} \) and the section modulus about the same axis is \( \frac{wt^2}{12.5} \). Generally each leg of a “V” strut are to have similar cross section. Alternative methods for the determination of “V” strut requirements can be found in 3-2-A3.

9.3 V Strut

9.3.1 Width
The width of each strut arm is not to be less than obtained from the following equation:

\[
w = 2.27D
\]

where

\[
w = \text{width of strut (major axis), in mm (in.)}
\]

\[
D = \text{required diameter of ABS Grade 2 tail shaft, in mm (in.). (see Section 4-3-2)}
\]

9.3.2 Thickness
The thickness of the strut is not to be less than obtained from the following equation:

\[
t = 0.365D
\]

where

\[
t = \text{thickness of strut (minor axis), in mm (in.)}
\]

\[
D = \text{required diameter of ABS Grade 2 tail shaft, in mm (in.)}
\]

Where the included angle is less than 45 degrees, the foregoing scantlings are to be specially considered.
9.5 I Strut

9.5.1 Width

The width of the strut arm is not to be less than obtained from the following equation:

\[ w_1 = 3.22D \]

where

\[ w_1 = \text{width of strut (major axis) in mm (in.)} \]
\[ D = \text{diameter of tail shaft in mm (in.)} \]

9.5.2 Thickness

Thickness The thickness of the strut is not to be less than obtained from the following equation:

\[ t_1 = 0.515D \]

where

\[ t_1 = \text{thickness of strut (minor axis), in mm (in.)} \]
\[ D = \text{diameter of tail shaft, in mm (in.)} \]

9.7 Strut Length

The length of the longer leg of a V strut or the leg of an I strut, measured from the outside perimeter of the strut barrel or boss to the outside of the shell plating, is not to exceed 10.6 times the diameter of the tail shaft. Where this length is exceeded, the width and thickness of the strut are to be increased, and the strut design will be given special consideration. Where strut length is less than 10.6 times required tailshaft diameter, the section modulus of the strut may be reduced in proportion to the reduced length, provided the section modulus is not less than 0.85 times Rule required section modulus.

9.9 Strut Barrel

The thickness of the strut barrel or boss is to be at least one-fifth the diameter of the tail shaft. The length of the strut barrel or boss is to be adequate to accommodate the required length of propeller-end bearings. Strut barrels constructed of aluminum are not subject to the corrections required by 3-2-7/1.3.

10 Skegs and Other Hull Appendages (2015)

Vessels fitted with skegs and other permanent hull appendages are to comply with the following:

i) The anticipated operational loadings under all vessels operations (docking loads, hydrodynamic forces, and etc., as applicable) are to be submitted for ABS review.

ii) All skegs and other permanent hull appendages are to be attached to the shell plate by means of double continuous fillet welds in accordance with 3-2-13/1.5 using a weld factor \( C = 0.5 \) DC. Appendage structure is to be aligned or reinforced with internal hull structural members.

iii) Thickness of shell plating in way of an appendage is to be increased in accordance with 3-2-3/1.1.

iv) Where a closing plate prohibits the inspection of a void space or joint that is integral to the shell plating, access ports and drain plugs are to be provided in way of this space.

v) In the case of large continuous skegs or other similar hull appendages, direct analysis may be requested by ABS in order to validate stress interaction effects with the hull girder.

vi) Where the appendages designed to shear off in the event of impact, calculations for the appendage are to be submitted and subject to special consideration.
11 Propeller Nozzles (2009)

11.1 Application
The requirements in this section are applicable for propeller nozzles with inner diameter \( d \) of 5 meters (16.4 feet) or less. Nozzles of larger inner diameter are subject to special consideration with all supporting documents and calculations submitted for review.

11.3 Design Pressure
The design pressure of the nozzle is to be obtained from the following:

\[
p_d = 10^{-6} \cdot c \cdot \varepsilon \cdot \left(\frac{N}{A_p}\right) \quad \text{N/mm}^2(\text{kgf/mm}^2, \text{psi})
\]

where

\[
c = \text{coefficient as indicated in 3-2-7/11.3 TABLE 1}
\]

\[
\varepsilon = \text{coefficient as indicated in 3-2-7/11.3 TABLE 2, but not to be taken less than 10}
\]

\[
N = \text{maximum shaft power, in kW (hp)}
\]

\[
A_p = \text{propeller disc area} = D^2\frac{\pi}{4} \quad \text{in}^2(\text{ft}^2)
\]

\[
D = \text{propeller diameter, in m (ft)}
\]

11.5 Nozzle Cylinder
11.5.1 Shell Plate Thickness
The thickness of the nozzle shell plating, in mm (in.), is not to be less than:

\[
t = t_o + t_c
\]

but not to be taken less than 7.5 (0.3) mm (in.)

where

\[
t_o = \text{thickness of nozzle shell plating}
\]

\[
t_c = \text{thickness of nozzle shell plating}
\]


\[ t_o = \text{thickness obtained from the following formula:} \]
\[ = c_n \cdot S_p \cdot \sqrt{p_d K_n} \text{ mm (in.)} \]

- \( c_n \) = coefficient as indicated in 3-2-7/11.5.1 TABLE 3
- \( S_p \) = spacing of ring webs, in mm (in.)
- \( p_d \) = nozzle design pressure, in N/mm\(^2\) (kgf/mm\(^2\), psi), as defined in 3-2-7/11.3
- \( t_c \) = corrosion allowance determined by 3-2-7/11.5.1 TABLE 4
- \( K_n \) = nozzle material factor as defined in 3-2-8/1.3

**TABLE 3**

<table>
<thead>
<tr>
<th>( p_d \text{ in N/mm}^2 )</th>
<th>( p_d \text{ in kgf/mm}^2 )</th>
<th>( p_d \text{ in psi} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( c_n )</td>
<td>( 1.58 \times 10^{-1} )</td>
<td>( 4.95 \times 10^{-1} )</td>
</tr>
<tr>
<td></td>
<td>( 1.32 \times 10^{-2} )</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 4**

<table>
<thead>
<tr>
<th>Value of ( t_o )</th>
<th>( t_c \text{ mm (in.)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>If ( t_o \leq 10.0 \text{ (0.4)} )</td>
<td>1.5 \text{ (0.06)}</td>
</tr>
<tr>
<td>If ( t_o &gt; 10.0 \text{ (0.4)} )</td>
<td>the lesser of ( b_1, b_2 )</td>
</tr>
</tbody>
</table>

where

- \( b_1 = 3.0 \text{(0.12)} \text{ mm (in.)} \)
- \( b_2 = \left( \frac{t_o}{\sqrt{K_n}} + 5 \right) \times 10^{-1} \text{ mm or } b_2 = \left( \frac{t_o}{\sqrt{K_n}} + 0.2 \right) \times 10^{-1} \text{ in.} \)

11.5.2 Internal Diaphragm Thickness

Thickness of nozzle internal ring web is not to be less than the required nozzle shell plating for Zone 3.

11.7 Nozzle Section Modulus

The minimum requirement for nozzle section modulus is obtained from the following formula:

\[ SM = d^2 b V_d^2 Q n \text{ cm}^3 \text{ (in}’\)\]

where

- \( d \) = nozzle inner diameter, in m (ft)
- \( b \) = nozzle length, in m (ft)
- \( V_d \) = design speed in ahead condition, in knots, as defined in 3-2-8/3.1
- \( Q \) = reduction factor conditional on material type
  - = 1.0 for ordinary strength steel
  - = 0.78 for H32 strength steel
  - = 0.72 for H36 strength steel
\[ Q = 0.68 \] for H40 strength steel

\[ n = \text{nozzle type coefficient taken equal to 0.7 (0.0012) for fixed nozzles} \]

**FIGURE 1(a)**

*Propeller Nozzle Section View (2014)*
\[ b = \text{nozzle length} \]
\[ d = \text{nozzle inner diameter} \]

**Zone 1**  
zone of nozzle inner skin from nozzle leading edge to the fore end of Zone 2

**Zone 2**  
zone of nozzle inner skin in way of propeller tips with two ring webs within the zone

\[ z_{1/2\text{min}} = \begin{cases} 
\frac{b}{8} & \text{where Zone 2 center plane and propeller disc center plane coincide as shown in 3-2-7/11.7 FIGURE 1(a)}; \\
\frac{b}{8} \cos \alpha + \frac{d}{2} \tan \alpha & \text{where } \alpha \text{ is the tilt angle between the Zone 2 and propeller disc center planes, as shown in 3-2-7/11.7 FIGURE 1(b)};
\end{cases} \]

**Zone 3**  
zone of nozzle inner and outer skin covering the tail vicinity, from aft end of Zones 2 to the aft end of Zone 4

**Zone 4**  
zone of nozzle outer skin from the leading edge to the fore end of Zone 3
11.9 Welding Requirement
The inner and outer nozzle shell plating is to be welded to the internal stiffening ring webs with double continuous welds as far as practicable. Plug/slot welding is prohibited for the inner shell, but may be accepted for the outer shell plating, provided that the nozzle ring web spacing is not greater than 350 mm (13.8 in.).

13 Propulsion Improvement Devices (PID) as Hull Appendages (2017)

13.1 Application Scope
The requirements in this Subsection are applicable for Propulsion Improvement Devices (PID) hull appendages including wake equalizing and flow separation alleviating devices (such as spoilers, wake equalizer, stern tunnels, pre-swirl fins, stators, and pre-swirl ducts) and post swirl devices (such as rudder thrust fins, post swirl stators, and rudder bulbs) that are permanently affixed to the hull structure.

13.3 Plans and Documentation (2019)
The following plans and details are to be submitted for approval, while the calculations are to be submitted for reference:

i) Drawings and plans covering the detailed design of the structural components, including the end connections and attachment to the hull structure;

ii) Information on material properties and welding details, such as scantlings of the welded connection and welding detail and size;

iii) Calculations to validate the design of the PID and the supporting foundations interior to the vessel. The calculations are to consider strength, fatigue and vibration, due to hydrodynamic lift and drag loads, in both the ahead and astern conditions. However, depending on the type of PID (such as rudder bulbs, etc.) the calculation may consider the strength only.

13.5 Design and Arrangement
The following requirements are to be complied with for the propulsion improvement devices as outlined in 3-2-7/13.1. Devices of novel concept are to be specially considered with all the related drawings and documents submitted:

i) The structural materials are to be compatible with the mechanical and chemical properties of the hull strake to which it is attached. Examples of such design considerations are to have adequate structural strength for load bearing/transferring and acceptable galvanic potential between materials to reduce the risk of galvanic corrosion.

ii) PID end connections are to have a suitable transition for the particular application and to be effectively terminated in way of internal stiffening members.

13.7 Structural End Connection
Welded end connections of device structural component to the hull are to be designed and constructed in accordance with the following:

i) Welding at the connection is to be full penetration and is to be in accordance with 2-4-1 of the ABS Rules for Materials and Welding (Part 2) and 3-2-13, as applicable.

ii) Nondestructive volumetric and surface examinations are to be performed on the welds of the connection plates and the shell penetration. 100% Magnetic Testing (MT) and at least 10% Ultrasonic Testing (UT) is to be carried out on the welds of the connection plates and the shell penetration.
15 **Ride Control Systems (RCS) (1 July 2022)**

15.1 **Application Scope**

The requirements in this Subsection are applicable for externally-installed Ride Control Systems (RCS) connected to hull structures, such as canards, stabilizers, T-foils, stern flaps, or interceptors. Permanently welded structures are covered in 3-2-7/10.

15.3 **General**

A Ride Control System (RCS) is a system designed to reduce the vessel’s motion due to waves, primarily roll, pitch or heave motions. Although any devices designed to reduce motion is a RCS, only externally-installed RCSs in foil or thin plate type will be addressed in this section. RCS may consist of three parts: the structural part (plates, connection to hull, supporting structures), the mechanical parts (actuators), and the control parts (system).

15.5 **Types of RCS**

RCS can be categorized by its mechanism to generate forces. There are foil type RCSs, which generate hydrodynamic lift and drag. This type may include canards, stabilizers, or T-foils. Another type has a mechanism to cause the stagnation of the flow, and to generate forces to control vessel’s motion. This type may include stern flaps, and interceptors.

15.5.1 **Fins - Canards and Stabilizers**

Fins can be categorized into two types: anti-pitch fins and anti-roll fins. Anti-pitch fins, or canards, are fixed or movable control surfaces in the forward part of vessel to control the heave or pitch motion. Anti-roll fins, or stabilizers, are fixed or movable control surfaces in the aft part of the vessel to control the roll motion of the vessel.

Fins are most effective at high speeds as the lift force is proportional to the square of the flow speed. For the lift and drag calculations for the fin type RCS, refer to 3-1-3/7.3.3. If large vertical motions are expected in low draft condition, which may induce fins to exit from the water surface, the fins are to be designed to consider the slamming loads due to the re-entry into waters.

3-2-7/15.5 FIGURE 2 illustrates canards and stabilizers.

**FIGURE 2**

Fins - Canards and Stabilizers

15.5.2 **T-Foils**

T-Foils, in the shape of inverted “T”, consist of a vertical strut and a foil attached at the bottom. T-foils are usually installed in the bow bottom area to maximize their effectiveness in control of heave and pitch. Some T-foils are designed to be retractable in order to reduce the resistance when they are not effective.
3-2-7/15.5 FIGURE 3 illustrates T-foils.

**FIGURE 3**

*T-Foils*

15.5.3 **Stern Flaps, Interceptors**

Stern flaps and interceptors are typically installed at the transom stern area of planing hulls to control the trim by modifying the flow. Lift force is generated by the flow in stagnation due to the existence of the plates. With an independent control of port and starboard side flaps or interceptors, it is possible to control roll or even yaw motions.

3-2-7/15.5 FIGURE 4 illustrates stern flaps and interceptors.

**FIGURE 4**

*Stern Flaps, Interceptors*

15.7 **Design Review**

The structural design of RCS is to be proved by direct calculations for vessels that the effects of RCS is used to reduce the vessel motion and loads.

*Commentary:*

For example, some high-speed catamarans may experience large heave and pitch motions, which then may significantly increase the slamming loads on the wet deck, if it operates without a forward T-foil. Therefore the T-foil is required to be reviewed unless the vessel structure is reviewed for the higher slamming loads.
15.7.1 RCS-to-Hull Interface

The interface between RCS to the hull structures is to be designed to have adequate structural strength under the design loads on the RCS, including impact loads. The following plans and details are to be submitted for review:

- Detail design of structural components and arrangement of the RCS compartments, including the connection of RCS to the hull structure.
- Calculations to validate the design of the connection of the RCS to the hull structure and the supporting foundations interior to the vessel.
- Material properties and welding details.
- Design loads on RCS including impact loads.

The following requirements are to be complied with for the RCS to hull interface:

- The arrangement of the RCS compartment is to comply with the vendor recommendation.
- The structural material of the connection is to comply with the requirements of Chapter 1 of the ABS Rules for Materials and Welding (Part 2) and 3-1-2/1.1 TABLE 2.
- The connections of RCS to the hull structure are to have adequate structural strength for load bearing/transferring.
- A FE-based structural analysis of the local hull structure is required to verify the structural adequacy.

The acceptance criteria for the FE-based structural analysis are as follows:

- For normal operating loads (combined with hull girder and local loads), the allowables are according to 3-1-3/11.3
- For impact loads, the allowables are the yield stress of the material properties of steel, and the yield stress of the welded properties of aluminum.

15.7.2 Structure of RCS

If the RCS reduces a Dominant Load Parameter (DLP) or is used as a primary steering device, it is required to review the structure of the RCS. The review is to be based on a FE analysis with the same allowables as 3-2-7/15.7.1. In case such review is required, the following plans and details are to be submitted:

- Detail design of structural components and arrangement of the RCS.
- Material properties and welding details, if applicable.
- Design loads on RCS including impact loads.
- A FE-based structural analysis to validate the structural design of the RCSs.

15.7.3 Control System

The control system of RCS is not usually reviewed by ABS. However, it is required that the RCS return to its neutral position when the control system fails. This requirement of neutral position needs to be witnessed during sea trials by ABS Surveyors. The designer may prepare a second operational profile for ABS review in case of the control failure. In addition, a detection method, which may involve sensors, or notification system, to identify such failure are to be submitted for ABS review.
15.7.4 Operations Manual

If the RCS reduces a DLP(s), the operations manual is to consider the conditions when the RCS is damaged or broken off from the hull.
CHAPTER 2
Hull Structures and Arrangements

SECTION 8
Rudders and Steering Equipment (2009)

1 General

1.1 Application (1 July 2016)
Requirements specified in this Section are applicable to:

i) Ordinary profile rudders described in 3-2-8/3 TABLE 1A with rudder operating angle range from
   $-35^\circ$ to $+35^\circ$.

ii) High-lift rudders described in 3-2-8/3 TABLE 1B, the rudder operating angle of which might be
    exceeding $35^\circ$ on each side at maximum design speed.

iii) Other steering equipment other than rudders identified in Section 3-2-8.

Rudders not covered in 3-2-8/3 TABLE 1A nor in 3-2-8/3 TABLE 1B are subject to special consideration,
provided that all the required calculations are prepared and submitted for review in full compliance with
the requirements in this Section. Where direct analyses adopted to justify an alternative design are to take
into consideration all relevant modes of failure, on a case by case basis. These failure modes may include,
amongst others: yielding, fatigue, buckling and fracture. Possible damages caused by cavitation are also to
be considered. Validation by laboratory tests or full scale tests may be required for alternative design
approaches.

Special consideration will be given to aluminum rudder stocks and fiber reinforced plastic rudders and
rudder stocks. Material specifications are to be listed on the plans.

1.3 Materials for Rudder, Rudder Stock and Steering Equipment (1 July 2015)
Rudder stocks, pintles, coupling bolts, keys and other steering equipment components described in this
Section are to be made from material in accordance with the requirements of Chapter 1 of the ABS Rules
for Materials and Welding (Part 2), 3-1-2/1.1 TABLE 2, and particularly:

i) The Surveyor need not witness material tests for coupling bolts and keys.

ii) The surfaces of rudder stocks in way of exposed bearings are to be of noncorrosive material.

iii) Material properties of dissimilar parts and components in direct contact with each other are to be
    submitted for review of compatibilities, such as galvanic potential.
Material factors of castings and forgings used for the shoe piece \((K_g)\), horn \((K_h)\), stock \((K_s)\), bolts \((K_b)\), coupling flange \((K_f)\), pintles \((K_p)\), and nozzles \((K_n)\) are to be obtained for their respective material from the following equation:

\[
K = \left(\frac{n_y}{Y}\right)^e
\]

where

\[
n_y = 235 \text{ N/mm}^2 (24 \text{ kgf/mm}^2, 34000 \text{ psi})
\]

\[
Y = \text{specified minimum yield strength of the material, in N/mm}^2 (\text{kgf/mm}^2, \text{psi}), \text{but is not to be taken as greater than } 0.7U \text{ or } 450 \text{ N/mm}^2 (46 \text{ kgf/mm}^2, 65000 \text{ psi}), \text{ whichever is less}
\]

\[
U = \text{minimum tensile strength of material used, in N/mm}^2 (\text{kgf/mm}^2, \text{psi})
\]

\[
e = 1.0 \text{ for } Y \leq 235 \text{ N/mm}^2 (24 \text{ kgf/mm}^2, 34000 \text{ psi})
\]

\[
e = 0.75 \text{ for } Y > 235 \text{ N/mm}^2 (24 \text{ kgf/mm}^2, 34000 \text{ psi})
\]

### 1.5 Expected Torque

The torque considered necessary to operate the rudder in accordance with 4-3-4/21.7.ii is to be indicated on the submitted rudder or steering gear plan. See 4-3-4/1.11 and 3-2-8/5.7.

Note that this expected torque is not the design torque for rudder scantlings.

### 1.7 Rudder Stops

Strong and effective structural rudder stops are to be fitted. Where adequate positive mechanical stops are provided within the steering gear in accordance with 4-3-4/5.11, structural stops will not be required.

### 3 Rudder Design Force

Rudder force, \(C_R\), upon which rudder scantlings are to be based, is to be obtained from equation described either in 3-2-8/3.1 or 3-2-8/3.3 as applicable. Where for the ordinary rudders the rudder angle, \(\phi\), exceeds 35°, the rudder force, \(C_R\), is to be increased by a factor of 1.74 \(\sin(\phi)\).

#### 3.1 Rudder Blades without Cutouts (2014)

Where the rudder profile can be defined by a single quadrilateral, the rudder force is to be obtained from the following equation.

\[
C_R = n \ k_R k_c k_e \ AV_R^2 \quad \text{kN (tf, Ltf)}
\]

where

\[
n = 0.132 (0.0135, 0.00123)
\]

\[
k_R = \left(\frac{b^2}{A_t} + 2\right)/3 \text{ but not taken more than 1.33}
\]

\[
b = \text{mean height of rudder area, in m (ft}, \text{ as determined from 3-2-8/3 FIGURE 1A}
\]

\[
A_t = \text{sum of rudder blade area, } A, \text{ and the area of rudder post or rudder horn within the extension of rudder profile, in m}^2 (\text{ft}^2)
\]

\[
A = \text{total projected area of rudder as illustrated in 3-2-8/3 FIGURE 1A, in m}^2 (\text{ft}^2)
\]

For steering nozzles, \(A\) is not to be taken less than 1.35 times the projected area of the nozzle.
$k_c = \text{coefficient depending on rudder cross section (profile type) as indicated in 3-2-8/Table 1A and 1B. For profile types differing from those in 3-2-8/Table 1A and 1B, } k_c \text{ is subject to special consideration.}$

$k_f = \text{coefficient as specified in 3-2-8/5.3 TABLE 2}$

$V_R = \text{vessel speed, in knots}$

$V_R = V_d \text{ or } V_{min}, \text{ whichever is greater}$

$V_R = V_a \text{ or } 0.5V_d, \text{ or } 0.5V_{min}, \text{ whichever is greater}$

$V_d = \text{design speed in knots with the vessel running ahead at the maximum continuous rated shaft rpm and at the summer load waterline}$

$V_a = \text{maximum astern speed in knots}$

$V_{min} = (V_d + 20)/3$

Where there are any appendages such as rudder bulb fitted on the rudder, its effective areas are to be included in the area of the rudder blade if significant.

### 3.3 Rudder Blades with Cutouts

This paragraph applies to rudders with cutouts (semi-spade rudders), such that the whole blade area cannot be adequately defined by a single quadrilateral. See 3-2-8/3 FIGURE 1B. Equations derived in this paragraph are based on a cutout blade with two quadrilaterals. Where more quadrilaterals are needed to define the rudder shape, similar rules apply.

The total rudder force described in 3-2-8/3.1 is applicable for rudders with cutout(s), with $A$ being the summation of sub-quadrilaterals that make up the whole area of the rudder blade. Rudder force distribution over each quadrilateral is to be obtained from the following equations:

$$C_{R1} = C_R A_1 / A \text{ kN(tf, Ltf)}$$

$$C_{R2} = C_R A_2 / A \text{ kN(tf, Ltf)}$$

where

$C_R$ and $A$ are as defined in 3-2-8/3.1

$A_1$ and $A_2$ are as described in 3-2-8/3 FIGURE 1B.

### 3.5 Rudders Blades with Twisted Leading-Edge (2014)

This kind of rudder has the leading edge twisted horizontally on the top and bottom of the section that is an extension of the center of the propeller shaft. For the purpose of calculating design force, twisted rudders may be distinguished in four categories:

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The projected leading edge of twisted upper and lower blades not lineup to each other</td>
</tr>
<tr>
<td>2</td>
<td>The projected leading edge of twisted upper and lower blades form a straight line</td>
</tr>
<tr>
<td>3</td>
<td>Rudder with twisted leading-edge combined with tail edge flap or fins</td>
</tr>
<tr>
<td>4</td>
<td>The twisted leading edge has a smooth continuous wavy contour (no deflector) or the rudder has multiple section profile types</td>
</tr>
</tbody>
</table>

Design force for rudder with twisted leading edge is obtained according to the following criteria:
For Category 1 rudders as indicated in the above table, design force over upper and lower rudder blades are obtained from the following equations respectively:

\[
C_{R1} = n k_R k_c A_1 V_R^2 \quad \text{kN(tf, Ltf)} \quad \text{for twisted upper rudder blade;}
\]

\[
C_{R2} = n k_R k_c A_2 V_R^2 \quad \text{kN(tf, Ltf)} \quad \text{for twisted upper rudder blade;}
\]

\[
C_R = C_{R1} + C_{R2} \quad \text{kN(tf, Ltf)} \quad \text{overall design force;}
\]

For Categories 2, 3, and 4, rudder design force indicated in 3-2-8/3.1 is applicable, that is:

\[
C_R = n k_R k_c k_k A V_R^2 \quad \text{kN(tf, Ltf)}
\]

where

\[n, k_R, k_c, k_k, A, V_R\] are as defined in 3-2-8/3.1, (for rudder has multiple section profile types, \(A\) is the whole projected areas).

\(A_1\) and \(A_2\) are the projected areas of upper and lower blades separated at the deflector cross section, respectively. Where the effective projected area of rudder bulb (if present) forward of rudder leading edge is significant and needs to be counted, the proportioned bulb effective areas are added to \(A_1\) and \(A_2\) accordingly

Values of \(k_c\) for ahead and astern conditions are determined from one of the methods below as applicable, if the type of basic rudder profile is not provided:

\(a)\) \(k_c\) is taken from 3-2-8/3 TABLE 1A for twisted rudders of Categories 1 & 2;

\(b)\) \(k_c\) is taken from 3-2-8/3 TABLE 1B for twisted rudders of Category 3;

\(c)\) \(k_c\) is subjected to special considerations for twisted rudders of Category 4;

\(d)\) Shipyard/rudder manufacturers’ submitted \(k_c\) obtained from testing data or calculations may be accepted subject to ABS review of all the supporting documents;

**TABLE 1A**

**Coefficient \(k_c\) for Ordinary Rudders (2014)**

<table>
<thead>
<tr>
<th>Profile Type</th>
<th>(k_c)</th>
<th>Ahead Condition</th>
<th>Astern Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Single plate</td>
<td>1.0</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>2 NACA-00 Göttingen</td>
<td>1.1</td>
<td>0.80</td>
<td></td>
</tr>
<tr>
<td>3 Flat side</td>
<td>1.1</td>
<td>0.90</td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 1B

**Coefficient $k_c$ for High-Lift/Performance Rudders (2021)**

<table>
<thead>
<tr>
<th>Profile Type</th>
<th>$k_c$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Ahead Condition</strong></td>
</tr>
<tr>
<td><strong>Profile Type</strong></td>
<td></td>
</tr>
<tr>
<td>Mixed (e.g., HSV)</td>
<td>1.21</td>
</tr>
<tr>
<td>Hollow</td>
<td>1.35</td>
</tr>
<tr>
<td>Twisted rudder of Cat. 1 &amp; 2</td>
<td>1.21 (if not provided)</td>
</tr>
</tbody>
</table>

**Profile Type**

<table>
<thead>
<tr>
<th>$k_c$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ahead Condition</strong></td>
</tr>
<tr>
<td>Fish tail (e.g., Schilling high-lift rudder)</td>
</tr>
<tr>
<td>Flap rudder (or Twisted rudder of Cat. 3)</td>
</tr>
<tr>
<td>Rudder with steering nozzle</td>
</tr>
</tbody>
</table>
**FIGURE 1A**  
Rudder Blade without Cutouts (2009)

$$b = \frac{z_3 + z_4 - z_2 - z_1}{2}$$  
$$c = \frac{x_3 + x_4 - x_1 - x_2}{2}$$

- $A$ (see 3-2-8/3.1)  
- $A_f$ (see 3-2-8/5.3)
5 Rudder Design Torque

5.1 General
The rudder design torque, $Q_R$, for rudder scantling calculations is to be in accordance with 3-2-8/5.3 or 3-2-8/5.5 as applicable.

5.3 Rudder Blades without Cutouts (2014)

Rudder torque, $Q_R$, is to be determined from the following equation for both ahead and astern conditions.

$$Q_R = C_R r \text{ kN-m (tf-m, Ltf-ft)}$$

where
C_R = rudder force as calculated in 3-2-8/3.1
r = c(a − k) (but not less than 0.1c for ahead condition)
c = mean breadth of rudder area, as shown in 3-2-8/3 FIGURE 1A, in m (ft)
a = coefficient as indicated in 3-2-8/5.3 TABLE 3
k = A_f / A
A_f = area of rudder blade situated forward of the centerline of the rudder stock, in m² (ft²), as shown in 3-2-8/3 FIGURE 1A
A = whole rudder area as described in 3-2-8/3.1

Where there are any appendages such as rudder bulb fitted on the rudder, effective areas are to be included in the area of the rudder blade if significant.

### TABLE 2
**Coefficient k_ℓ (2009)**

<table>
<thead>
<tr>
<th>Rudder/Propeller Layout</th>
<th>k_ℓ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rudders outside propeller jet</td>
<td>0.8</td>
</tr>
<tr>
<td>Rudders behind a fixed propeller nozzle</td>
<td>1.15</td>
</tr>
<tr>
<td>All others</td>
<td>1.0</td>
</tr>
</tbody>
</table>

### TABLE 3
**Coefficient α (2014)**

<table>
<thead>
<tr>
<th>Rudder Position or High-lift</th>
<th>Ahead Condition</th>
<th>Astern Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Located behind a fixed structure, such as a rudder horn</td>
<td>0.25</td>
<td>0.55</td>
</tr>
<tr>
<td>Located where no fixed structure forward of it</td>
<td>0.33</td>
<td>0.75 (hollow profile)</td>
</tr>
<tr>
<td>High-Lift Rudders (see 3-2-8/3 TABLE 1B)</td>
<td>Special consideration (0.40 if unknown)</td>
<td>Special consideration</td>
</tr>
</tbody>
</table>

5.5 **Rudders Blades with Cutouts**

This paragraph refers to rudder blades with cutouts (semi-spade rudders) as defined in 3-2-8/3.3. Equations derived in this paragraph are based on a cutout blade with two quadrilaterals. Where more quadrilaterals are needed to define the rudder shape, similar rules apply.

Total rudder torque, Q_R, in ahead and astern conditions is to be obtained from the following equation:

\[ Q_R = C_{R_1}r_1 + C_{R_2}r_2 \text{ kN-m (tf-m, Ltf-ft)} \]

but not to be taken less than Q_{R_{mm}} in the ahead condition

where
\[ Q_{Rmn} = 0.1 C_R (A_1 c_1 + A_2 c_2) / A \]
\[ r_1 = c_1 (a - k_1) \text{ m (ft)} \]
\[ r_2 = c_2 (a - k_2) \text{ m (ft)} \]
\[ c_1, c_2 = \text{mean breadth of partial area } A_1, A_2, \text{ from 3-2-8/3 FIGURE 1B} \]
\[ a = \text{coefficient as indicated in 3-2-8/5.3 TABLE 3} \]
\[ k_1, k_2 = A_{1f}/A_1, A_{2f}/A_2 \text{ where } A_{1f}, A_{2f} = \text{area of rudder blade situated forward of the centerline of the rudder stock for each part of the rudder, as shown in 3-2-8/3 FIGURE 1B} \]

\[ C_R, C_{R1}, C_{R2}, A_1, A_2 \text{ are as defined in 3-2-8/3.3.} \]

### 5.7 Rudders with Twisted Leading Edge (2014)

In general, rudder torque, \( Q_R \), indicated in 3-2-8/5.3 is applicable for rudders with twisted leading edge, where \( C_R \) is obtained from 3-2-8/3.5.

### 5.9 Trial Conditions

The above equations for \( Q_R \) are intended for the design of rudders and should not be directly compared with the torques expected during the trial (see 3-2-8/1.5) or the rated torque of steering gear (see 4-3-4/1.11).

### 7 Rudder Stocks

#### 7.1 Upper Rudder Stocks (2012)

The upper stock is that part of the rudder stock above the neck bearing or above the top pintle, as applicable.

\[ S = N_u \sqrt[3]{Q_R K_s} \text{ mm (in.)} \]

where

\[ N_u = 42.0 (89.9, 2.39) \]
\[ Q_R = \text{rudder torque, as defined in 3-2-8/5, in kN-m (tf-m, Ltf-m)} \]
\[ K_s = \text{material factor for upper rudder stock, as defined in 3-2-8/1.3} \]

#### 7.3 Lower Rudder Stocks (2018)

In determining lower rudder stock scantlings, values of rudder design force and torque calculated in 3-2-8/3 and 3-2-8/5 are to be used. Bending moments, shear forces, as well as the reaction forces are to be determined from 3-2-8/7.5 and 3-2-8/13.5, and are to be submitted for review. For rudders supported by shoe pieces or rudder horns, these structures are to be included in the calculation model to account for support of the rudder body. Guidance for calculation of these values is given in Appendix 3-2-A1.

The lower rudder stock diameter is not to be less than obtained from the following equation:

\[ S_\ell = S^3 / 1 + (4/3)(M/Q_R)^2 \text{ mm (in.)} \]

where
$S = \text{upper stock required diameter from 3-2-8/7.1, in mm (in.)}$

$S_L = \text{lower stock required diameter.}$

$M = \text{bending moment at the section of the rudder stock considered, in kN-m (tf-m, Ltf-ft)}$

$Q_R = \text{rudder torque from 3-2-8/5, in kN-m (tf-m, Ltf-ft)}$

Above the neck bearing a gradual transition is to be provided where there is a change in the diameter of the rudder stock.

The equivalent stress of bending and torsion, $\sigma_c$, to be assessed from the aforementioned direct calculation in the transition is not to exceed $118/K N/mm^2 \quad (12.0/K kgf/mm^2, 17100/K \text{ lbs/in}^2)$.

$$\sigma_c = \sqrt{\sigma_b^2 + 3\tau^2} \quad \text{N/mm}^2 \quad \text{(kgf/mm}^2, \text{lbs/in}^2)$$

where

$K = \text{material factor as defined in 3-2-8/1.3}.$

$\sigma_b = 10.2 \times 10^6 M / S_L^3 \quad \text{for SI and MKS units}$

$= 270 \times 10^3 M / S_L^3 \quad \text{for US units}$

$\tau = 5.1 \times 10^6 Q_R / S_L^3 \quad \text{for SI and MKS units}$

$= 135 \times 10^3 Q_R / S_L^3 \quad \text{for US units}$

### 7.4 Rudder Trunk and Rudder Stock Sealing (1 July 2021)

The requirements in 3-2-8/7.5 iii), iv) and v) apply to trunk configurations which are extended below the stern frame and arranged in such a way that the trunk is stressed by forces due to rudder action.

i) In rudder trunks which are open to the sea, a seal or stuffing box is to be fitted above the deepest load waterline, to prevent water from entering the steering gear compartment and the lubricant from being washed away from the rudder carrier.

ii) Where the top of the rudder trunk is below the deepest waterline two separate stuffing boxes are to be provided.

iii) **Materials.** The steel used for the rudder trunk is to be of weldable quality, with a carbon content not exceeding 0.23% on ladle analysis or a carbon equivalent (Ceq) not exceeding 0.41%. Plating materials for rudder trunks are in general not to be of lower grades than corresponding to class II as defined in 3-1-2/1.1 TABLE 1. Rudder trunks comprising of materials other than steel are to be specially considered.

iv) **Scantlings.** The scantlings of the trunk are to be such that the equivalent stress due to bending and shear does not exceed $0.35\sigma_F$, and the bending stress on welded rudder trunk is to be in compliance with the following formula:

$$\sigma \leq 80/k \text{ N/mm}^2$$

$$\sigma \leq 8.17/k \text{ kgf/mm}^2$$

$$\sigma \leq 11.600/k \text{ psi}$$

where
\[ \sigma = \text{bending stress in the rudder trunk} \]

\[ k = K \text{ as defined in 3-2-8/1.3 for castings} \]

\[ = 1.0 \text{ for ordinary strength hull steel plate} \]

\[ = Q \text{ as defined in 3-2-1/1.1.1 for higher strength steel plate} \]

\[ k \text{ is not to be taken less than 0.7} \]

\[ \sigma_F = \text{specified minimum yield strength of the material used, in } N/mm^2 \text{ (kgf/mm}^2, \text{ psi}) \]

For calculation of bending stress, the span to be considered is the distance between the mid-height of the lower rudder stock bearing and the point where the trunk is clamped into the shell or the bottom of the skeg.

**v) Welding at the Connection to the Hull.** The weld at the connection between the rudder trunk and the shell or the bottom of the skeg is to be full penetration and fillet shoulder is to be applied in way of the weld. The fillet shoulder radius \( r \), in mm (in.) (see 3-2-8/7.4 FIGURE 2) is to be as large as practicable and to comply with the following formulae:

\[ r = 0.1S_\ell \]

without being less than:

\[ r = 60 \text{ mm when } \sigma \geq 40/k \text{ N/mm}^2 \]

\[ = 60 \text{ mm when } \sigma \geq 4.09/k \text{ kgf/mm}^2 \]

\[ = 2.4 \text{ in. when } \sigma \geq 5800/k \text{ psi} \]

\[ r = 30 \text{ mm when } \sigma < 40/k \text{ N/mm}^2 \]

\[ = 30 \text{ mm when } \sigma < 4.09/k \text{ kgf/mm}^2 \]

\[ = 1.2 \text{ in. when } \sigma < 5800/k \text{ psi} \]

where

\[ S_\ell = \text{rudder stock diameter axis defined in 3-2-8/7.3} \]

\[ \sigma = \text{bending stress in the rudder trunk in } N/mm^2 \text{ (kgf/mm}^2, \text{ psi}) \]

\[ k = \text{material factor as defined in 3-2-8/7.4.iv} \]

The radius may be obtained by grinding. If disk grinding is carried out, score marks are to be avoided in the direction of the weld. The radius is to be checked with a template for accuracy. Four profiles at least are to be checked. A report is to be submitted to the Surveyor.
7.5 Bending Moments

The bending moment on the rudder and rudder stock may be determined in accordance with Appendix 3-2-A1 or in accordance with the following equations:

7.5.1 Spade Rudders

\[ M_n = C_R \ell_n \text{ kN} \cdot \text{m(Ltf ft)} \]
\[ M_s = C_R \frac{A_1}{A} \ell_c \text{ kN} \cdot \text{m(Ltf ft)} \]

where

- \( M_n \) = bending moment at neck bearing.
- \( M_s \) = bending moment at section under consideration.
- \( \ell_n \) = distance from center of neck bearing to the centroid of rudder area, m (ft)
- \( \ell_c \) = distance from section under consideration to the centroid of rudder area, \( A_1 \), m (ft)
- \( A \) = area below section under consideration, \( m^2 \) (ft²)

\( C_R \) and \( A \) are defined in 3-2-8/3.

7.5.2 Balanced Rudders with Shoepiece Support

The bending moment at the neck bearing may be taken as indicated below. Bending moments at other locations are to be determined by direct calculation and are to be submitted. See Appendix 3-2-A1 for guidance in calculating bending moments.

\[ M_n = NC_R \ell_b \text{ kN} \cdot \text{m(Ltf ft)} \]

where
\[ M_n = \text{bending moment at neck bearing} \]
\[ \ell_b = \text{distance between center of neck bearing and center of shoepiece pintle bearing, m (ft)} \]
\[ N = \frac{0.5 + a_1^{1/3}}{1 + a_1^{1/3} + \ell_u l_b / \ell_b l_u} \]
\[ a_1 = \frac{\ell_b l_d}{\ell_s l_b} \]
\[ I_d = \text{mean moment of inertia of shoepiece about the vertical axis, cm}^4 \text{ (in}^4) \]
\[ \ell_s = \text{distance between center of shoepiece pintle bearing and the effective support point of the shoepiece in the hull, m (ft)} \]
\[ \ell_u = \text{distance between center of the neck bearing and the center of the rudder carrier bearing, m (ft)} \]
\[ I_u = \text{mean moment of inertia of rudder stock, between neck bearing and rudder carrier bearing, cm}^4 \text{, (in}^4) \]

9 \text{ Flange Couplings}

9.1 \text{ General}
Rudder flange couplings are to comply with the following requirements:

\text{i)} Couplings are to be supported by an ample body of metal worked out from the rudder stock.
\text{ii)} The smallest distance from the edge of the bolt holes to the edge of the flange is not to be less than two-thirds of the bolt diameter.
\text{iii)} Coupling bolts are to be fitted bolts.
\text{iv)} Suitable means are to be provided for locking the nuts in place.

In addition to the above, rudder flange couplings are to meet the type-specific requirements in 3-2-8/9.3 (horizontal couplings) or 3-2-8/9.5 (vertical couplings) as applicable.

9.3 \text{ Horizontal Couplings}
9.3.1 \text{ Coupling Bolts}
There are to be at least six coupling bolts in horizontal couplings, and the diameter, \(d_b\), of each bolt is not to be less than obtained by the following equation:

\[ d_b = 0.62 \sqrt{\frac{d_s^2 K_b}{(n r K_s)}} \text{ mm (in.)} \]

where

\[ d_s = \text{required rudder stock diameter, } S \text{ (3-2-8/7.1) or } S_k \text{ (3-2-8/7.3) as applicable, in way of the coupling} \]
\[ n = \text{total number of bolts in the horizontal coupling} \]
\[ r = \text{mean distance, in mm (in.), of the bolt axes from the center of the bolt system} \]
9.3.2 Coupling Flange

Coupling flange thickness is not to be less than the greater of the following equations:

\[
t_f = d_{bt} \sqrt{\frac{K_f}{K_b}} \quad \text{mm (in.)}
\]

\[
t_f = 0.9 d_{bt} \quad \text{mm (in.)}
\]

where

\[d_{bt} = \text{calculated bolt diameter as per 3-2-8/9.3.1 based on a number of bolts not exceeding 8}\]

\[K_f = \text{material factor for flange, as defined in 3-2-8/1.3}\]

\[K_b = \text{material factor of bolts, as defined in 3-2-8/1.3}\]

9.3.3 Joint between Rudder Stock and Coupling Flange (1 July 2016)

The welded joint between the rudder stock and the flange is to be made in accordance with 3-2-8/9.3.3 FIGURE 3 or equivalent.

**FIGURE 3**

Welded Joint Between Rudder Stock and Coupling Flange (1 July 2016)

9.5 Vertical Couplings

9.5.1 Coupling Bolts (1 July 2016)

There are to be at least eight coupling bolts in vertical couplings and the diameter, \(d_b\), of each bolt is not to be less than obtained from the following equation:

\[
d_b = 0.81 d_{sv} \sqrt{\frac{K_b}{n K_s}} \quad \text{mm (in.)}
\]
where

\[ n = \text{total number of bolts in the vertical coupling, which is not to be less than 8} \]

\[ d_s, K_b, K_s \text{ are as defined in 3-2-8/9.3.} \]

In addition, the first moment of area, \( m \), of the bolts about the center of the coupling is not to be less than given by the following equation:

\[ m = 0.00043d_s^3 \text{ mm}^3(\text{in}^3) \]

where

\[ d_s = \text{diameter as defined in 3-2-8/9.3} \]

### 9.5.2 Coupling Flange

Coupling flange thickness, \( t_f \), is not to be less than \( d_b \), as defined in 3-2-8/9.5.1.

### 9.5.3 Joint between Rudder Stock and Coupling Flange (1 July 2016)

The welded joint between the rudder stock and the flange is to be made in accordance with 3-2-8/9.3.3 FIGURE 3 or equivalent.

### 11 Tapered Stock Couplings

#### 11.1 Coupling Taper (1 July 2021)

Tapered stock couplings are to comply with the following general requirements in addition to type-specific requirements given in 3-2-8/11.3 or 3-2-8/11.5 as applicable:

**i)** Tapered stocks, as shown in 3-2-8/11 FIGURE 4, are to be effectively secured to the rudder casting by a nut on the end.

**ii)** The cone shapes are to fit exactly.

**iii)** The coupling length (\( \ell \)) in the casting as shown in 3-2-8/11 FIGURE 4A is generally not to be less than 1.5 times the stock diameter (\( d_o \)) as shown in 3-2-8/11 FIGURE 4.

**iv)** The taper on diameter (\( c \)) is to be 1/12 to 1/8 for keyed taper couplings and 1/20 to 1/12 for couplings with hydraulic mounting/dismounting arrangements, as shown in the following table. The cone length (\( \ell_c \)) is defined in 3-2-8/11 FIGURE 4A.

**v)** Where mounting with an oil injection and hydraulic nut, the push-up oil pressure and the push-up length are to be specially considered upon submission of calculations.

**vi)** Means of effective sealing are to be provided to protect against sea water ingress.

<table>
<thead>
<tr>
<th>Type of Coupling Assembly</th>
<th>( c = \frac{d_o - d_u}{\ell_c} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without hydraulic mounting/dismounting</td>
<td>( 1/12 \leq c \leq 1/8 )</td>
</tr>
<tr>
<td>With hydraulic mounting/dismounting</td>
<td>( 1/20 \leq c \leq 1/12 )</td>
</tr>
</tbody>
</table>
Part 3 Hull Construction and Equipment
Chapter 2 Hull Structures and Arrangements
Section 8 Rudders and Steering Equipment (2009)

11.3 Keyed Fitting (1 July 2021)

Where the stock, it is to be fitted in accordance with the following:

i) The top of the keyway is to be located well below the top of the rudder.

ii) Torsional strength of the key equivalent to that of the required upper stock is to be provided.

iii) For the couplings between stock and rudder the shear area* of the key is not to be less than:
\[ a_s = \frac{17.55 Q_F}{d_k \sigma_F^1} \text{ cm}^2 \]
\[ a_s = \frac{21.06 Q_F}{d_k \sigma_F^1} \text{ in}^2 \]

where

\[ Q_F = \text{design yield moment of rudder stock, in N-m (kgf-m, lbf-ft)} \]
\[ = 0.02664 \frac{d_t^3}{k} \text{ N-m} \]
\[ = 0.002717 \frac{d_t^3}{k} \text{ kgf-m} \]
\[ = 321.9838 \frac{d_t^3}{k} \text{ lbf-ft} \]

Where the actual rudder stock diameter \( d_{ta} \) is greater than the calculated diameter \( d_t \), the diameter \( d_{ta} \) is to be used. However, \( d_{ta} \) applied to the above formula need not be taken greater than 1.145 \( d_t \).

\[ d_t = \text{stock diameter, in mm (in.), according to 3-2-8/7.1} \]
\[ k = \text{material factor for stock as given in 3-2-8/1.3} \]
\[ d_k = \text{mean diameter of the conical part of the rudder stock, in mm (in.), at the key} \]
\[ \sigma_F^1 = \text{minimum yield stress of the key material, in N/mm}^2 \text{ (kgf/mm}^2, \text{ psi)} \]

The effective surface area of the key (without rounded edges) between key and rudder stock or cone coupling is not to be less than:

\[ a_k = \frac{5Q_F}{d_k \sigma_F^2} \text{ cm}^2 \]
\[ a_k = \frac{6Q_F}{d_k \sigma_F^2} \text{ in}^2 \]

where

\[ \sigma_F^2 = \text{minimum yield stress of the key, stock or coupling material, in N/mm}^2 \text{ (kgf/mm}^2, \text{ psi)}, \text{ whichever is less.} \]

**iv)** In general, the key material is to be at least of equal strength to the keyway material. For keys of higher strength materials, shear and bearing areas of keys and keyways may be based on the respective material properties of the keys and the keyways, provided that compatibilities in mechanical properties of both components are fully considered. In no case, is the bearing stress of the key on the keyway to exceed 90% of the specified minimum yield strength of the keyway material.

**v)** Push up. It is to be proved that 50% of the design yield moment is solely transmitted by friction in the cone couplings. This can be done by calculating the required push-up pressure and push-up length according to 3-2-8/11.5.iv) and 3-2-8/11.5.v) for a torsional moment \( Q_F' = 0.5Q_F \).

**vi)** Where a key is fitted to the coupling between stock and rudder and it is considered that the entire rudder torque is transmitted by the key at the couplings, the requirement of 3-2-8/11.3v) need not be applied provided that the actual shear area and the effective surface area of the key are more than twice of that required by 3-2-8/11.3iii).
Note: * The effective area is to be the gross area reduced by any area removed by saw cuts, set screw holes, chamfer, etc., and is to exclude the portion of the key in way of spooning of the key way.

11.5 **Keyless Fitting (1 July 2021)**

Hydraulic and shrink fit keyless couplings are to be fitted in accordance with the following:

1. Detailed preloading stress calculations and fitting instructions are to be submitted;
2. Prior to applying hydraulic pressure, at least 75% of theoretical contact area of rudder stock and rudder bore is to be achieved in an evenly distributed manner;
3. The upper edge of the upper main piece bore is to have a slight radius;
4. **Push-up Pressure.** The push-up pressure is not to be less than the greater of the two following values:

\[ P_{req1} = \frac{2Q_F}{d_m^2 \pi \mu_0} \times 10^3 \text{ N/mm}^2 \text{(kgf/mm}^2 \text{)} \]

\[ P_{req1} = \frac{24Q_F}{d_m^2 \pi \mu_0} \text{ psi} \]

\[ P_{req2} = \frac{6M_b}{d_m^2 \ell} \times 10^3 \text{ N/mm}^2 \text{(kgf/mm}^2 \text{)} \]

\[ P_{req2} = \frac{72M_b}{d_m^2 \ell} \text{ psi} \]

where

- \( Q_F \) = design yield moment of rudder stock, as defined in 3-2-8/11.3.iii)
- \( d_m \) = mean cone diameter, in mm (in.)
- \( \ell \) = coupling length, in mm (in.)
- \( \mu_0 \) = frictional coefficient, equal to 0.15
- \( M_b \) = bending moment in the cone coupling (e.g., in case of spade rudders), in N-m (kgf-m, lbf-ft)

It has to be proved by the designer that the push-up pressure does not exceed the permissible surface pressure in the cone. The permissible surface pressure is to be determined by the following formula:

\[ p_{perm} = \frac{0.95 Y_G (1 - a^2)}{\sqrt{3} + a} p_b \text{ N/mm}^2 \text{(kgf/mm}^2 \text{, psi)} \]

where

\[ p_b = \frac{3.5M_b}{d_m^2 \ell} \times 10^3 \text{ N/mm}^2 \text{ (kgf/mm}^2 \text{)} \]

\[ p_b = \frac{42M_b}{d_m^2 \ell} \text{ psi} \]

\[ Y_G = \text{specified minimum yield strength of the material of the gudgeon or stock, whichever is smaller, in N/mm}^2 \text{ (kgf/mm}^2 \text{, psi)} \]

\[ a = \frac{d_m}{d_a} \]
\[ d_m = \text{mean cone diameter, in mm (in.)} \]
\[ d_a = \text{outer diameter of the gudgeon, in mm (in.) as shown in 3-2-8/FIGURE 4B (The least diameter is to be considered)} \]

The outer diameter of the gudgeon in mm (in.) shall not be less than \( 1.25d_0 \), with \( d_0 \) defined in 3-2-8/11 FIGURE 4.

**FIGURE 4B**

**Gudgeon Outer Diameter \( (d_a) \) Measurement (1 July 2021)**

v) Push-up Length. The push-up length \( \Delta \ell \), in mm (in.), \( \Delta \ell \) is to comply with the following formula:

\[ \Delta \ell_1 \leq \Delta \ell \leq \Delta \ell_2 \]

where

\[ \Delta \ell_1 = \frac{p_{req}d_m}{\ell(1-a^2)/2} + 0.8R_{tm} \text{mm (in.)} \]
\[ \Delta \ell_2 = \frac{p_{perm}d_m}{\ell(1-a^2)/2} + 0.8R_{tm} \text{mm (in.)} \]

\( R_{tm} = \text{mean roughness, in mm (in.) taken equal to 0.01} \)
\( c = \text{taper on diameter according to 3-2-8/11.1.iv)} \)
\( Y_G = \text{specified minimum yield strength of the material of the gudgeon, in N/mm}^2 \) (kgf/mm\(^2\), psi)
\( E = \text{Young’s modulus of the material of the gudgeon, in N/mm}^2 \) (kgf/mm\(^2\), psi)

\( Y_G, a, \) and \( d_m \) are as defined in 3-2-8/11.5.iv).

**Note:** In case of hydraulic pressure connections the required push-up force \( P_e \) for the cone may be determined by the following formula:

\[ P_e = p_{req}d_m \pi \ell \left( \frac{1}{2} + 0.02 \right) \text{ N (kgf, lbf)} \]

The value 0.02 is a reference for the friction coefficient using oil pressure. It varies and depends on the mechanical treatment and roughness of the details to be fixed. Where due to the fitting procedure a partial push-up effect caused by the rudder weight is given, this may be taken into account when fixing the required push-up length, subject to approval.

vi) **Couplings with Special Arrangements for Mounting and Dismounting the Couplings.** Where the stock diameter exceeds 200 mm (8 in.), the press fit is recommended to be effected by a hydraulic pressure connection. In such cases the cone is to be more slender, \( c \approx 1:12 \) to \( =1:20 \). In case of hydraulic pressure connections the nut is to be effectively secured against the rudder stock or the pintle. For the safe transmission of the torsional moment by the coupling between rudder stock and rudder body the push-up pressure and the push-up length are to be determined according to 3-2-8/11.5.iv) and 3-2-8/11.5.v), respectively.

vii) The locking nut is to be fitted in accordance with 3-2-8/11.7.
11.7 **Locking Nut (2022)**

Dimensions of the securing nut, as shown in 3-2-8/9.3.3 FIGURE 3, are to be proportioned in accordance with the following and the nut is to be fitted with an effective locking device.

- **Height** \( h_n \geq 0.6d_g \)
- **Outer diameter of nut** \( d_n \geq 1.2d_u \) or \( 1.5d_g \), whichever is greater
- **External thread diameter** \( d_g \geq 0.65d_o \)

In the case of a hydraulic pressure secured nut, a securing device such as a securing flat bar is to be provided. Calculations proving the effectiveness of the securing device are to be submitted.

A securing flat bar will be regarded as an effective securing device for the nut, if its shear area, in \( \text{mm}^2 \) (in\(^2\)), is not less than:

\[
A_S = \frac{P_S \sqrt{B}}{\sigma_F} \quad \text{(in}^2\text{)}
\]

where:

- \( P_S \) = shear force, in N (kgf, lbf)
  \[ P_S = \frac{P_e}{2} \mu_1 \left( \frac{d_1}{d_g} - 0.6 \right) \]
- \( P_e \) = push-up force, in N (kgf, lbf), as defined in 3-2-8/11.5.v
- \( \mu_1 \) = frictional coefficient between nut and rudder body, normally \( \mu_1 = 0.3 \)
- \( d_1 \) = mean diameter of the frictional area between nut and rudder body, in mm (in.)
- \( d_g \) = external thread diameter of the nut, in mm (in.)
- \( \sigma_F \) = specified minimum yield stress of the securing flat bar material, in N/mm\(^2\) (kgf/mm\(^2\), psi)

13 **Pintles**

13.1 **General (1 July 2016)**

Pintles are to have a conical attachment to the gudgeons with a taper on diameter of:

- 1/12 to 1/8 for keyed and other manually assembled pintles with locking nut.
- 1/20 to 1/12 for pintle mounted with oil injection and hydraulic nut.

13.3 **Diameter (1 July 2019)**

The diameter of the pintles is not to be less than obtained from the following equation.

\[
d_p = k_1 \sqrt{\frac{B}{K_p}} \quad \text{mm(in.)}
\]

where

- \( k_1 \) = 11.1 (34.7, 1.38)
- \( B \) = bearing force, in kN (tf, Ltf), from 3-2-8/13.5 but not to be taken less than \( B_{min} \) as specified in 3-2-8/13.3
- \( K_p \) = material factor for the pintle, as defined in 3-2-8/1.3
TABLE 4
Minimum Bearing Force $B_{\text{min}}$ (2009)

<table>
<thead>
<tr>
<th>Pintle Type</th>
<th>$B_{\text{min}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional two pintle rudder</td>
<td>0.5 $C_R$</td>
</tr>
<tr>
<td>3-2-A1/7.1 FIGURE 3</td>
<td>lower pintle</td>
</tr>
<tr>
<td>3-2-A1/7.1 FIGURE 3</td>
<td>main pintle</td>
</tr>
<tr>
<td>3-2-13/5 FIGURE 3 of the Marine Vessel Rules</td>
<td>main pintle</td>
</tr>
<tr>
<td></td>
<td>upper pintle</td>
</tr>
</tbody>
</table>

$B_{\text{min}} = C_R$ where $\ell_a / \ell_p \geq 1$

$\ell_a, \ell_p$ as described in 3-2-13/5 FIGURE 3 of the Marine Vessel Rules

For rudders on horns with two pintles, as shown in 3-2-8/3 FIGURE 1B, calculations are to include pintle bearing forces with the vessel running ahead at the maximum continuous rated shaft rpm and at the lightest operating draft.

Threads and nuts are to be in accordance with 3-2-8/11.7.

i) The depth of the pintle boss is not to be less than $d_p$.

ii) The bearing length of the pintle is to be between 1.0 and 1.2 times the pintle diameter, where $d_p$ is measured on the outside of the liner.

iii) The bearing pressure is to be in accordance with 3-2-8/15.1.

iv) The thickness of the pintle housing is not to be less than 25% of the pintle diameter.

Renewal limits are based upon pintle diameter without exceeding the following limits:

i) Spade type rudders: 6 mm.

ii) Other rudders: 7.5 mm.

Special consideration is to be given to metal bearings and unique rudder types.

13.4 Push-up Pressure and Push-up Length (1 July 2019)

The required push-up pressure for pintles, in N/mm$^2$ (kgf/mm$^2$, psi), is to be determined by the following formula:

$$p_{\text{req}} = \frac{0.4 B_1 d_o}{d_m^2 \ell} \text{ N/mm}^2 \text{ (kgf/mm}^2, \text{ psi)}$$

where

- $B_1$ = supporting force in the pintle, in N (kgf, lbf)
- $d_o$ = actual pintle diameter excluding the liner, in mm (in.)
- $d_m$ = mean cone diameter, in mm (in.)
- $\ell$ = cone length, in mm (in.)
The push up length is to be calculated similarly as in 3-2-8/11.5.v), using required push-up pressure and properties for the pintle.

### 13.5 Shear and Bearing Forces

The shear and bearing forces may be determined in accordance with Appendix 3-2-A1, or by the equations given below.

#### 13.5.1 Spade Rudder

- **Bearing force at rudder carrier:**
  \[ P_u = \frac{M_n}{\ell_u} \text{ kN (tf, Ltf)} \]

- **Bearing force at neck bearing:**
  \[ P_n = C_R + P_u \text{ kN (tf, Ltf)} \]

- **Shear force at neck bearing:**
  \[ F_n = C_R \text{ kN (tf, Ltf)} \]

where \( C_R \) is as defined in 3-2-8/3 and \( \ell_u \) is as defined in 3-2-8/7.5.2.

#### 13.5.2 Balanced Rudder with Shoepiece Support

- **Bearing force at rudder carrier:**
  \[ P_u = \frac{M_n}{\ell_u} \text{ kN (tf, Ltf)} \]

- **Bearing force at neck bearing:**
  \[ P_n = P_u \left(1 + \frac{\ell_u}{\ell_b}\right) + C_R \left(\frac{\ell_R}{2} + \ell_p\right) \text{ kN (tf, Ltf)} \]

where

\[
\ell_b = \text{distance between the center of neck bearing support and the center of shoepiece support, as shown in 3-2-A1/5.1 FIGURE 2}
\]

\[
\ell_p = \text{distance between bottom of rudder blade and center of support of neck bearing}
\]

\[
\ell = \text{distance between top of rudder blade and center of support of neck bearing}
\]

- **Bearing force at shoepiece:**
  \[ P_p = C_R + P_u - P_n \text{ kN (tf, Ltf)} \text{ but not less than } 0.5C_R \]

- **Shear force at neck bearing:**
  \[ F_n = P_n - P_u \text{ kN (tf, Ltf)} \]

where \( C_R \) is as defined in 3-2-8/3.

### 15 Supporting and Anti-Lifting Arrangements

#### 15.1 Bearings (2012)

##### 15.1.1 Bearing Surfaces

Bearing surfaces for rudder stocks, shafts and pintles are to meet the following requirements:

- **i)** The length/diameter ratio \( \ell_b / d_e \) of the bearing surface is not to be greater than 1.2*

- **ii)** The projected area of the bearing surface \( A_b = d_e \ell_b \) is not to be less than \( A_{\text{min,proj}} \)

where
\( d_L \) = outer diameter of the liner, in mm (in.)

\( \ell_b \) = bearing length, in mm (in.)

\( A_{b\text{min}} = k_1 \frac{P}{q_a} \text{ mm}^2 \left( \text{in}^2 \right) \)

\( k_1 = 1000 \ (2240) \)

\( P \) = bearing reaction force, in kN (tf, Ltf), as determined from 3-2-8/15.1.5 TABLE 5

\( P_a \) = allowable surface pressure, as indicated in 3-2-8/15.1.5 TABLE 6, depending on bearing material, in N/mm\(^2\) (kgf/mm\(^2\), psi)

* Request for bearing arrangement of length/diameter ratio greater than 1.2 is subject to special consideration provided that calculations are submitted to show acceptable clearance at both ends of the bearing.

15.1.2 Bearing Clearance

\textit{i)} The clearance for metal bearings is not to be less than \( d_L /1000 + 1.0 \text{ mm (} d_L /1000 + 0.04 \text{ in.) on the diameter, where } d_L \text{ is the inner diameter of the bushing, in mm (in.)}. \)

\textit{ii)} The clearance for non-metallic bearings is to be specially determined considering the material’s swelling and thermal expansion properties. This clearance in general is not to be taken less than 1.5 mm (0.06 in.) on diameter*.

\textbf{Note:} * Request of clearance less than 1.5 mm (0.06 in.) for non-metallic bearings is subject to special considerations provided that documented evidence, such as manufacturer's recommendation on acceptable clearance, expansion allowance and satisfactory service history with reduced clearances, are submitted for review.

For spade rudders with a rudder stock diameter of 400 mm (15.75 in.) or less, the clearances on the diameter are not to be less than given below:

<table>
<thead>
<tr>
<th>Stock Diameter, mm (in.)</th>
<th>Metallic Bushing, mm (in.)</th>
<th>Synthetic Bushing(^{(1)}), mm (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 (15.75)</td>
<td>1.15 (0.045)</td>
<td>1.15 (0.045) + ( E )^{(2)}</td>
</tr>
<tr>
<td>300 (11.81)</td>
<td>0.85 (0.033)</td>
<td>0.85 (0.033) + ( E )</td>
</tr>
<tr>
<td>200 (7.87)</td>
<td>0.78 (0.031)</td>
<td>0.78 (0.031) + ( E )</td>
</tr>
<tr>
<td>100 (3.94)</td>
<td>0.75 (0.030)</td>
<td>0.75 (0.030) + ( E )</td>
</tr>
</tbody>
</table>

\textbf{Notes:}

1 The bushing manufacturer’s recommended running clearance may be used as an alternative to these clearances.

2 \( E \) = expansion allowance provided by bushing manufacturer, mm (in.).

15.1.3 Bearing Pressure

Bearing pressure is to be accordance with 3-2-8/15.1.5 TABLE 6.

15.1.4 Bearing Material

Where stainless steel or wear-resistant steel is used for liners or bearings, the material properties including chemical composition of both components are to be submitted for review for an approved combination.

15.1.5 Liners and Bushes (1 July 2016)

\textit{i)} \textit{Rudder Stock Bearings}. Liners and bushes are to be fitted in way of bearings. The minimum thickness of liners and bushes is to be equal to:
The thickness of any liner or bush is neither to be less than:

\[ t = k_1 \sqrt{B} \text{ mm (in.)} \]

where

\[ B = \text{bearing force, in N (kgf, lbf)} \]
\[ k_1 = 0.01 \text{ (0.0313, 0.000830)} \]

nor than the minimum thickness defined in 3-2-8/15.1.5.i).

- The bearing length \( L_p \) of the pintle is to be in accordance with 3-2-8/13.1.

### TABLE 5

<table>
<thead>
<tr>
<th>Bearing Type</th>
<th>( P ), Bearing Reaction Force Bearing Type kN (tf, Ltf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pintle bearings</td>
<td>( P = B ) as defined in 3-2-8/13</td>
</tr>
<tr>
<td>Other bearings</td>
<td>Calculation of ( P ) is to be submitted. Guidelines for calculation can be found in Appendix 3-2-A1</td>
</tr>
</tbody>
</table>

### TABLE 6

<table>
<thead>
<tr>
<th>Bearing Material</th>
<th>( p_a )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N/mm²</td>
</tr>
<tr>
<td>lignum vitae</td>
<td>2.5</td>
</tr>
<tr>
<td>white metal, oil lubricated</td>
<td>4.5</td>
</tr>
<tr>
<td>steel[3] and bronze and hot-pressed bronze-graphite materials</td>
<td>7.0</td>
</tr>
</tbody>
</table>

Notes:

1. Indentation hardness test at 23°C (73.4°F) and with 50% moisture, according to a recognized standard. Synthetic bearing materials to be of approved type.
2. Higher values than given in the table may be taken if they are verified by tests, but in no case more than 10 N/mm² (1.02 kgf/mm², 1450 psi).

15.3 Rudder Carrier (1 July 2016)

- The weight of the rudder assembly is to be supported by a rudder carrier mounted on the hull structure designed for that purpose.

- At least half of the rudder carrier’s holding-down bolts are to be fitted bolts. Alternative means of preventing horizontal movement of the rudder carrier may be considered.
iii) The bearing part is to be well lubricated by dripping oil, automatic grease feeding, or a similar method.

iv) Hull structures in way of the rudder carrier are to be suitably strengthened.

15.5 Anti Lifting Devices

Means are to be provided to prevent accidental unshipping or undue movement of the rudder which may cause damage to the steering gear. There are to be at least two bolts in the joint of the anti-lifting ring.

17 Double Plate Rudder

17.1 Strength (1 July 2021)

The section modulus and web area of the rudder mainpiece are to be such that the stresses indicated in the following Subparagraphs are not exceeded.

In calculating the section modulus of the rudder, the effective width of side plating is to be taken as not greater than twice the athwartship dimension of the rudder. Bolted cover plates on access openings to pintles are not to be considered effective in determining the section modulus of the rudder. In order for a cover plate to be considered effective, it is to be closed using a full penetration weld and confirmed suitable by non-destructive testing method. Generous radii are to be provided at abrupt changes in section where there are stress concentrations, including in way of openings and cover plates. When inspection windows are located in the panel below the rudder hub, the stress is to be as permitted in way of cutouts.

Moments, shear forces and reaction forces are to be as given in 3-2-8/7.5 and 3-2-8/13.5.

For spade rudders and rudders with horns, the section modulus at the bottom of the rudder is not to be less than one-third the required section modulus of the rudder at the top of the rudder or at the center of the lowest pintle.

Special attention is to be paid in design and construction of rudders with slender foil sections in the vicinity of their trailing edge (e.g., hollow foil sections, fishtail foil sections). Where the width of the rudder blade at the aftermost vertical diaphragm, \( w \), is equal or less than \( \frac{1}{6} L \) of the trailing edge length measured between the diaphragm and the trailing edge, \( \ell \), finite element vibration analysis and trailing edge vortex shedding analysis of the rudder blade are also to be submitted for review. See 3-2-8/17.1 FIGURE 5.

**FIGURE 5**

(1 July 2017)

Spade rudders with an embedded rudder trunk are to have a trailing edge with dimensions that satisfy the following requirements:

i) For a rudder trailing edge having a monotonous transition to an end with a finite thickness or diameter (see 3-2-8/15.1.5 TABLE 6), the thickness or diameter of the rounded end, \( t_e \), is to satisfy the following requirements:
For \( b \times (c_r + c_t)/2 \geq 70 \text{ m}^2 \) (753 ft\(^2\)), \( t_e \) is not to exceed:

\[
t_e = 43\alpha^{-0.36}c_t^{0.5} - 3.5c_t \quad \text{mm}
\]

\[
t_e = 0.93\alpha^{-0.36}c_t^{0.5} - 0.042c_t \quad \text{in.}
\]

For \( b \times (c_r + c_t)/2 < 70 \text{ m}^2 \) (753 ft\(^2\)), the minimum value of \( t_e \) is to satisfy:

\[
t_e = 15.2\alpha^{-0.36}V_d - 3.5c_t \quad \text{mm}
\]

\[
t_e = 0.6\alpha^{-0.36}V_d - 0.042c_t \quad \text{in.}
\]

where

- \( b \) = mean height of rudder area, as determined from 3-2-8/17.1.i FIGURE 6, in m (ft)
- \( c_r \) = root chord length, as determined from 3-2-8/17.1.i FIGURE 6, in m (ft)
- \( c_t \) = tip chord length, as determined from 3-2-8/17.1.i FIGURE 6, in m (ft)
- \( t_e \) = rudder trailing edge thickness or diameter of rounded end, as determined from 3-2-8/17.1.i FIGURE 6, in mm (in.)
- \( \alpha \) = rudder trailing edge angle, as determined from 3-2-8/17.1.i FIGURE 6, in degrees
- \( V_d \) = as defined in 3-2-8/3.1, in knots
For a rudder trailing edge with a flat splitter plate (see 3-2-8/17.1.ii FIGURE 7), the extension of the splitter plate beyond the weld to rudder, $\ell_0$, is to be the same as the trailing edge thickness, as determined from 3-2-8/17.1.ii FIGURE 7. The thickness of splitter plate, $t_0$, is to satisfy:

$$t_0 \leq \frac{t_e}{3}, \text{ and not to be less than } 20 \text{ mm (0.8 in.)}$$

where

$$t_0 = \text{thickness of splitter plate, as determined from 3-2-8/17.1.ii FIGURE 7, in mm (in.)}$$
$$t_e = \text{rudder trailing edge thickness or diameter of rounded end, as determined from 3-2-8/17.1.ii FIGURE 7, in mm (in.)}$$

Edge serrations (i.e., a sawtooth shaped edge) may be added to the splitter plate as an extension beyond the required length, $\ell_0$, to mitigate the effect of trailing edge vortex shedding.
iii) For a vessel with a rudder trailing edge different from 3-2-8/17.1 i) and ii), a vibration analysis is to be carried out to verify that the natural frequencies of the rudder vibration modes that are susceptible to the adverse effect of rudder trailing edge vortex shedding are at least ±20% away from the rudder trailing edge vortex shedding frequency at the vessel speed range between 0.6\(V_d\) and \(V_d\), where \(V_d\) is the design speed as defined in 3-2-8/3.1.

For a rudder trailing edge as described in 3-2-8/17.1 i), the trailing edge vortex shedding frequency, \(f_s\), in Hz at a given vessel speed, \(V\), in knots can be calculated using the following equation:

\[
f_s = \frac{109 - 0.088\alpha^2}{1 + 0.0034/\left(t_e / c_t\right) - 0.14/\left(t_e / c_t\right)^{0.2}} \times \frac{V}{\Gamma_e} \text{ in SI units}
\]

\[
f_s = \frac{4.29 - 0.0035\alpha^2}{1 + 0.0034/\left(t_e / c_t\right) - 0.14/\left(t_e / c_t\right)^{0.2}} \times \frac{V}{\Gamma_e} \text{ in US customary units}
\]

where \(t_e\), \(c_t\), and \(\alpha\) are defined in 3-2-8/17.1 i).

Alternatively, the rudder trailing edge vortex shedding frequency can be determined through a detailed numerical analysis or a sea trial.

### 17.1.1 Clear of Rudder Recess Sections (1 July 2019)

Allowable stresses for determining the rudder strength clear of rudder recess sections (cutouts) where 3-2-8/17.1.2 applies are as follows:

- **Bending stress**
  \[
  \sigma_b = K_\sigma / Q \text{ N/mm}^2 \text{ (kgf/mm}^2, \text{ psi)}
  \]

- **Shear stress**
  \[
  t = K_t / Q \text{ N/mm}^2 \text{ (kgf/mm}^2, \text{ psi)}
  \]

- **Equivalent stress**
  \[
  \sigma_e = \sqrt{\sigma_b^2 + 3\tau^2} = K_e / Q \text{ N/mm}^2 \text{ (kgf/mm}^2, \text{ psi)}
  \]

where

<table>
<thead>
<tr>
<th></th>
<th>SI units</th>
<th>MKS units</th>
<th>US units</th>
</tr>
</thead>
<tbody>
<tr>
<td>(K_\sigma)</td>
<td>110</td>
<td>11.2</td>
<td>15,900</td>
</tr>
<tr>
<td>(K_t)</td>
<td>50</td>
<td>5.1</td>
<td>7,300</td>
</tr>
<tr>
<td>(K_e)</td>
<td>120</td>
<td>12.2</td>
<td>17,400</td>
</tr>
</tbody>
</table>
$Q = \text{as defined in 3-2-1/1.1.1}$

### 17.1.2 In Way of Rudder Recess Sections (1 July 2019)

Allowable stresses for determining the rudder strength in way of the recess sections (cutouts) for the rudder horn pintle on semi-spade rudders (see 3-2-8/17.1.2 FIGURE 8) are as follows:

- **Bending stress**  
  \[ \sigma_b = K_\sigma \]
  \( \text{N/mm}^2 \) (kgf/mm\(^2\), psi)

- **Shear stress**  
  \[ t = K_\tau \]
  \( \text{N/mm}^2 \) (kgf/mm\(^2\), psi)

- **Equivalent stress**  
  \[ \sigma_e = \sqrt{\sigma_b^2 + 3\tau^2} = K_e \]
  \( \text{N/mm}^2 \) (kgf/mm\(^2\), psi)

where

<table>
<thead>
<tr>
<th></th>
<th>SI units</th>
<th>MKS units</th>
<th>US units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_\sigma$</td>
<td>75</td>
<td>7.65</td>
<td>10,900</td>
</tr>
<tr>
<td>$K_\tau$</td>
<td>50</td>
<td>5.1</td>
<td>7,300</td>
</tr>
<tr>
<td>$K_e$</td>
<td>100</td>
<td>10.2</td>
<td>14,500</td>
</tr>
</tbody>
</table>

Note: The stresses in 3-2-8/17.1.2 apply equally to high tensile and ordinary steels.

**FIGURE 8 (2009)**

The mainpiece of the rudder is to be formed by the rudder side plating (but not more than the effective width indicated above) and vertical diaphragms extending the length of the rudder or the extension of the rudder stock or a combination of both.

### 17.3 Side, Top and Bottom Plating (1 July 2016)

The plating thickness is not to be less than obtained from the following equation:

\[ t = 0.0055s\beta\sqrt{k_1d + k_2cR/A} \times \sqrt{Q + k_3} \text{ mm (in.)} \]
where

\[ k_1 = 1.0 \ (1.0, 0.305) \]
\[ k_2 = 0.1 \ (0.981, 10.7) \]
\[ k_3 = 2.5 \ (2.5, 0.1) \]
\[ d = \text{summer loadline draft of the vessel, in m (ft)} \]
\[ C_R = \text{rudder force according to 3-2-8/3, in kN (tf, Ltf)} \]
\[ A = \text{rudder area, in m}^2 \ (\text{ft}^2) \]
\[ s = \text{smaller unsupported dimension of plating, in mm (in.)} \]
\[ b = \text{greater unsupported dimension of plating, in mm (in.)} \]
\[ \beta = \sqrt{1.1 - 0.5(s/b)^2}; \text{ maximum 1.0 for } b/s \geq 2.5 \]
\[ Q = \text{material factor for rudder plating, as defined in 3-2-1/1.1.1} \]

The thickness of the rudder side or bottom plating is to be at least 2 mm (0.08 in.) greater than that required by 3-2-3/1.3 with \( p \) obtained from 3-2-2/9.1, for which \( h \) is measured from the lower edge of the plate to the design load waterline in displacement mode.

The rudder side plating in way of the solid part is to be of increased thickness per 3-2-8/17.7.

### 17.5 Diaphragm Plates (2018)

Vertical and horizontal diaphragms are to be fitted within the rudder, effectively attached to each other and to the side plating. Vertical diaphragms are to be spaced approximately 1.5 times the spacing of horizontal diaphragms. Openings are in general not to be more than 0.5 times the depth of the web.

The thickness of diaphragm plates is not to be less than 70% of the required rudder side plate thickness or 8 mm (0.31 in.) whichever is greater. Openings in diaphragms are to have generous radii and the effects of openings are to be considered in the strength assessment as required in 3-2-8/17.1.

The diaphragm plating in way of the solid part is to be of increased thickness for vertical and horizontal diaphragm plates per 3-2-8/17.7.

### 17.7 Connections of Rudder Blade Structure with Solid Parts (1 July 2019)

Solid parts in forged or cast steel, which house the rudder stock or the pintle, are to be provided with protrusions, except where not required as indicated below.

These protrusions are not required when the diaphragm plate thickness is less than:

- 10 mm (0.375 in.) for diaphragm plates welded to the solid part on which the lower pintle of a semispade rudder is housed and for vertical diaphragm plates welded to the solid part of the rudder stock coupling of spade rudders.
- 20 mm (0.75 in.) for other diaphragm plates.

The solid parts are in general to be connected to the rudder structure by means of two horizontal diaphragm plates and two vertical diaphragm plates.

Minimum section modulus of the connection with the rudder stock housing.
The section modulus of the cross-section of the structure of the rudder blade formed by vertical diaphragm plates and rudder plating, which is connected with the solid part where the rudder stock is housed is to be not less than:

\[ w_s = c_s S_e^3 \left( \frac{H_E - H_X}{H_E} \right)^2 \frac{Q}{K_s} 10^{-4} \text{ cm}^3 \]

\[ w_s = c_s S_e^3 \left( \frac{H_E - H_X}{H_E} \right)^2 \frac{Q}{K_s} 10^{-1} \text{ in}^3 \]

where

- \( c_s \) = coefficient, to be taken equal to:
  - 1.0 if there is no opening in the rudder plating or if such openings are closed by a full penetration welded plate
  - 1.5 if there is an opening in the considered cross-section of the rudder
- \( S_e \) = rudder stock diameter, in mm (in.)
- \( H_E \) = vertical distance between the lower edge of the rudder blade and the upper edge of the solid part, in m (ft)
- \( H_X \) = vertical distance between the considered cross-section and the upper edge of the solid part as indicated in 3-2-8/17.7 FIGURE 9, in m (ft)
- \( Q \) = material factor for the rudder blade plating as given in 3-2-8/17.1
- \( K_s \) = material factor for the rudder stock as given in 3-2-8/1.3

The actual section modulus of the cross-section of the structure of the rudder blade is to be calculated with respect to the symmetrical axis of the rudder.

The breadth of the rudder plating to be considered for the calculation of section modulus is to be not greater than:

\[ b = s_v + 2H_x/3 \text{ m(ft)} \]

where

- \( s_v \) = spacing between the two vertical diaphragm, in m (ft) (see 3-2-8/17.7 FIGURE 9)

Where openings for access to the rudder stock nut are not closed by a full penetration welded plate, they are to be deducted.
The thickness of the horizontal diaphragm plates connected to the solid parts, in mm (in.), as well as that of the rudder blade plating between these diaphragms, is to be not less than the greater of the following values:

\[
t_H = 1.2t \quad \text{mm (in.)}
\]

\[
t_H = 0.045d_S^2/S_H \quad \text{mm (in.)}
\]

where

- \( t \) = defined in 3-2-8/17.3
- \( d_S \) = diameter, in mm (in.), to be taken equal to:
  - \( S \ell \) as per 3-2-8/7.3, for the solid part housing the rudder stock
  - \( d_p \) as per 3-2-8/13.1, for the solid part housing the pintle
- \( S_H \) = spacing between the two horizontal diaphragm plates, in mm (in.)
The increased thickness of the horizontal diaphragms is to extend fore and aft of the solid part at least to the next vertical diaphragm.

The thickness of the vertical diaphragm plates welded to the solid part where the rudder stock is housed as well as the thickness of the rudder side plating under this solid part is to be not less than the values obtained, in mm (in.), from 3-2-8/17.7 TABLE 7.

The increased thickness of vertical diaphragm plates is to extend below the solid piece at least to the next horizontal diaphragm.

### TABLE 7

**Thickness of Side Plating and Vertical Diaphragm Plates (1 July 2016)**

<table>
<thead>
<tr>
<th>Type of Rudder</th>
<th>Thickness of Vertical Diaphragm Plates, in mm (in.)</th>
<th>Thickness of Rudder Plating, in mm (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rudder Blade without Opening</td>
<td>Rudder Blade with Opening</td>
</tr>
<tr>
<td>Rudder supported by sole piece</td>
<td>1.2t</td>
<td>1.6t</td>
</tr>
<tr>
<td>Semi-spade and spade rudders</td>
<td>1.4t</td>
<td>2.0t</td>
</tr>
</tbody>
</table>

$t =$ thickness of the rudder plating, in mm (in.), as defined in 3-2-8/17.3

17.9 **Welding and Design Details (1 July 2021)**

1. Slot-welding is to be limited as far as possible. Slot welding is not to be used in areas with large in-plane stresses transversely to the slots or in way of cut-out areas of semi-spade rudders.

2. When slot welding is applied, the length of slots is to be minimum 75 mm (3 in.) with breadth of 2 $t$, where $t$ is the rudder plate thickness, in mm (in.). The distance between ends of slots is not to be more than 125 mm (5 in.). The slots are to be fillet welded around the edges and filled with a suitable compound (e.g., epoxy putty). Slots are not to be filled with weld.

3. Grove welds with structural backing/backing bar (continuous type slot weld) may be used for double-plate rudder welding. In that case, the root gap is to be between 6 to 10 mm (0.25 to 0.375 in.) and the bevel angle is to be at least 15°.

4. In way of the rudder horn recess of semi-spade rudders the radii in the rudder plating except in way of solid part in cast steel are not to be less than 5 times the plate thickness, but in no case less than 100 mm (4 in.). Welding in side plate are to be avoided in or at the end of the radii. Edges of side plate and weld adjacent to radii are to be ground smooth.

5. Welds between plates and heavy pieces (solid parts in forged or cast steel or very thick plating) are to be made as full penetration welds. In way of highly stressed areas (e.g., cut-out of semispade rudder and upper part of spade rudder), cast or welding on ribs is to be arranged. Two sided full penetration welding is normally to be arranged. Where back welding is impossible welding is to be performed against ceramic backing bars or equivalent. Steel backing bars may be used and are to be continuously welded on one side to the heavy piece.

17.11 **Watertightness (1 July 2016)**

The rudder is to be watertight and is to be tested in accordance with Section 3-6-1.
19 Single Plate Rudders

19.1 Mainpiece Diameter
The mainpiece diameter is calculated according to 3-2-8/7.3. For spade rudders, the lower third may be tapered down to 0.75 times stock diameter at the bottom of the rudder.

19.3 Blade Thickness
The blade thickness is not to be less than obtained from the following equation:

\[ t_b = 0.0015sV_R + 2.5 \text{ mm} \]
\[ t_b = 0.0015sV_R + 0.1 \text{ in.} \]

where

\[ s = \text{spacing of stiffening arms, in mm (in.), not to exceed 1000 mm (39 in.)} \]
\[ V_R = \text{speed, as defined in 3-2-8/3.1} \]

19.5 Arms
The thickness of the arms is not to be less than the blade thickness obtained in 3-2-8/19.3. The section modulus of each set of arms about the axis of the rudder stock is not to be less than obtained from the following equation:

\[ SM = 0.0005sC_1^2V^2 \text{ cm}^3 \]
\[ SM = 0.0000719sC_1^2V^2 \text{ in}^3 \]

where

\[ C_1 = \text{horizontal distance from the aft edge of the rudder to the centerline of the rudder stock, in m (ft)} \]
\[ Q = \text{as defined in 3-2-1/1.1.1} \]

\[ s, V_R \text{ are defined in 3-2-8/19.3.} \]

21 Shelled Rudder Blades
Rudder blades that are constructed out of cast resilient polymers or filled FRP shells are to have a solid metallic core that complies with the requirements for single plate rudders, see 3-2-8/19.
CHAPTER 2
Hull Structures and Arrangements

SECTION 9
Protection of Deck Openings

1 General

All openings in decks are to be framed to provide efficient support and attachment for the ends of the deck beams. The proposed arrangement and details for all hatchways are to be submitted for approval.

3 Position of Deck Openings

Position 1
Upon exposed main and raised quarter decks, and upon exposed superstructure decks situated forward of a point located a quarter of the vessel length from the forward perpendicular.

Position 2
Upon exposed superstructure decks situated abaft a quarter of the vessel length from the forward perpendicular.

5 Hatchway Coamings, Companionway Sills and Access Sills

5.1 Coaming and Sill Heights

The heights above deck of the coamings, the sills of companionways and access openings, are to be not less than given in 3-2-9/5.1 TABLE 1. Where the coaming or sill height will interfere with the mission of the vessel, as indicated by the Naval Administration, a lesser sill height will be considered. Where hatch covers are substantially constructed and made tight by means of gaskets and clamping devices, these heights may be reduced, or the coamings omitted entirely, provided that the safety of the vessel is not thereby impaired in any sea conditions. Sealing arrangements are to be weathertight if coaming is fitted, and watertight for flush covers.

| TABLE 1 |
| Coamings and Sill Heights |

<table>
<thead>
<tr>
<th></th>
<th>Position 1</th>
<th>Position 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hatch Coamings</td>
<td>600 mm (23.5 in.)</td>
<td>450 mm (17.5 in.)</td>
</tr>
<tr>
<td>Companionway Sills</td>
<td>600 mm (23.5 in.)</td>
<td>380 mm (15 in.)</td>
</tr>
<tr>
<td>Access Sills</td>
<td>380 mm (15 in.)</td>
<td>380 mm (15 in.)</td>
</tr>
</tbody>
</table>

L equal to or over 24 meters (79 feet) in length

L under 24 meters (79 feet) in length
Enclosed Superstructures

To be considered enclosed, superstructures are to meet the following requirements. Superstructures with openings which do not fully comply with these requirements are to be considered as open superstructures. See also 3-2-11/3.7.

7.1 Closing Appliances

All openings in the bulkheads of enclosed superstructures are to be provided with efficient means of closing, so that in any sea conditions water will not penetrate the vessel. Opening and closing appliances are to be framed and stiffened so that the whole structure, when closed, is equivalent to the unpierced bulkhead.

Doors for access openings into enclosed superstructures are to be of steel or other approved material, permanently and strongly attached to the bulkhead. The doors are to be provided with gaskets and clamping devices, or other equivalent arrangements, permanently attached to the bulkhead or to the doors themselves, and the doors are to be so arranged that they can be operated from both sides of the bulkhead. The construction of the doors is to be as required in 3-2-5/1.13.

Portlights and windows in the end bulkheads of enclosed superstructures are to be of substantial construction and provided with efficient inside deadlights, as required in 3-2-11/5.

The location and means of the closing appliances for windows are to be in accordance with 3-2-11/7.

7.3 Sills of Access Openings (2022)

Except as otherwise provided in these Rules, the height of the sills of access openings in bulkheads at the ends of enclosed superstructures located on and below Position 2 is to be at least 380 mm (15 in.) above the deck. See 3-2-9/5.1 TABLE 1 for required sill heights.

7.5 Means of Access

Superstructures are not to be regarded as enclosed unless access is provided for the crew to reach machinery and other working spaces inside these superstructures by alternate means which are available at all times when bulkhead openings are closed.

9 Hatchways Closed by Covers of Steel and Fitted with Gaskets and Clamping Devices

9.1 Strength of Covers

The maximum allowable stress and deflection under design load, w, and the minimum top plate thickness are as follows:

- Maximum allowable stress: $0.235\sigma_u$
- Maximum allowable deflection: $0.0028s$
- Top plate thickness: $0.01s$, but not less than 6.0 mm (0.24 in.)
\[ w = 0.097L + 7.45 \quad \text{kN/m}^2 \]
\[ w = 0.0099L + 0.76 \quad \text{tf/m}^2 \]
\[ w = 0.61L + 158.0 \quad \text{lbf/ft}^2 \]

\text{Position 2}

\[ w = 0.0709L + 5.65 \quad \text{kN/m}^2 \]
\[ w = 0.00725L + 0.576 \quad \text{tf/m}^2 \]
\[ w = 0.450L + 118.5 \quad \text{lbf/ft}^2 \]

where

\[ w = \text{design load, in kN/m}^2 \text{ (tf/m}^2, \text{lbf/ft}^2) \]
\[ L = \text{length of vessel, in m (ft), as defined in Section 3-1-1, but is not to be taken less than 24 m (79 ft).} \]
\[ s = \text{stiffener spacing, in mm (in.)} \]
\[ \sigma_u = \text{minimum ultimate tensile strength, in N/mm}^2 \text{ (kgf/mm}^2, \text{ psi)} \]

\section*{9.3 Means for Securing Weathertightness}

The means for securing and maintaining weathertightness is to be such that the tightness can be maintained in any sea condition. The covers are to be hose tested in position under a water pressure of at least 2.1 bar (2.1 kgf/cm$^2$, 30 psi) at the time of installation.

\section*{9.5 Flush Hatch Covers}

Where flush hatch covers are fitted on the freeboard deck within the forward one-fourth length, and the vessel is operating with low freeboard (e.g., assigned a freeboard less than Type-B under the International Convention on Load Lines 1966), the assumed loads on flush hatch covers are to be increased 15% over that indicated in 3-2-9/9.1.

\section*{11 Hatchways Closed by Portable Covers in Lower Decks or within Fully Enclosed Superstructures}

\subsection*{11.1 General}

The following scantlings are intended for conventional type covers. Those for covers of special types are to be specially considered.

\subsection*{11.3 Steel Covers}

The thickness of the plating for steel covers is not to be less than required for lower decks as obtained from 3-2-3/1. A stiffening bar is to be fitted around the edges as required to provide the necessary rigidity to permit the covers being handled without deformation. The effective depth of the framework is normally to be not less than 4% of its unsupported length. The stiffeners, in association with the plating to which they are attached, are to have section modulus, $SM$, as determined by the following equation:

\[ SM = 7.8hsL^2 \text{ cm}^3 \]
$SM = 0.0041hs\ell^2 \text{ in}^3$

where

$h = \text{ tween-deck height, in m (ft)}$

$s = \text{ spacing of the stiffeners, in m (ft)}$

$\ell = \text{ length of the stiffener, in m (ft)}$

11.5 **Wheel Loading**

Where provision is to be made for the operation and stowage of vehicles having rubber tires, the thickness of the hatch cover plating is to be in accordance with 3-2-3/1.9.

13 **Hatchways Closed by Covers of Materials Other Than Steel**

Hatch covers constructed of materials other than steel will be specially considered.

14 **Small Hatches on the Exposed Fore Deck (1 January 2004)**

14.1 **Application**

This subsection is applicable to vessels with length $L$ (as defined in 3-1-1/3) not less than 80 meters (263 feet).

The requirements of this subsection apply to all small hatches [opening normally 2.5 square meters (27 ft$^2$) or less] located on the exposed fore deck within the forward 0.25$L$, where the deck in way of the hatch is less than 0.1$L$ or 22 m (72.2 ft) above the summer load line, whichever is less.

Hatches designed for emergency escape need not comply with 3-2-9/14.5.i, 3-2-9/14.5.ii, the third paragraph of 3-2-9/14.7 and 3-2-9/14.9.

14.3 **Strength**

For small rectangular steel hatch covers, the plate thickness, stiffener arrangement and scantlings are to be in accordance with 3-2-9/14.9 TABLE 2 and 3-2-9/14.9 FIGURE 1. Stiffeners, where fitted, are to be aligned with the metal-to-metal contact points required in 3-2-9/14.7. See also 3-2-9/14.9 FIGURE 1. Primary stiffeners are to be continuous. All stiffeners are to be welded to the inner edge stiffener, see 3-2-9/14.9 FIGURE 2.

The upper edge of the hatchway coaming is to be suitably reinforced by a horizontal section, normally not more than 170 to 190 mm (6.9 to 7.5 in.) from the upper edge of the coaming.

For small hatch covers of circular or similar shape, the cover plate thickness and reinforcement is to provide strength and stiffness equivalent to the requirements for small rectangular hatches.

For small hatch covers constructed of materials other than steel, the required scantlings are to provide strength and stiffness equivalent to 235 N/mm$^2$ (24 kgf/mm$^2$, 34 psi) yield strength steel.

14.5 **Primary Securing Devices**

The primary securing devices are to be such that their hatch covers can be secured in place and made weather-tight by means of a mechanism employing any one of the following methods:

i) Butterfly nuts tightening onto forks (clamps), or

ii) Quick acting cleats, or

iii) A central locking device.
Dogs (twist tightening handles) with wedges are not acceptable.

14.7 Requirements for Primary Securing

The hatch cover is to be fitted with a gasket of elastic material. This is to be designed to allow a metal-to-metal contact at a designed compression and to prevent over compression of the gasket by green sea forces that may cause the securing devices to be loosened or dislodged. The metal-to-metal contacts are to be arranged close to each securing device in accordance with 3-2-9/14.9 FIGURE 1, and of sufficient capacity to withstand the bearing force.

The primary securing method is to be designed and manufactured such that the designed compression pressure is achieved by one person without the need of any tools.

For a primary securing method using butterfly nuts, the forks (clamps) are to be of robust design. They are to be designed to minimize the risk of butterfly nuts being dislodged while in use; by means of curving the forks upward and a raised surface on the free end, or a similar method. The plate thickness of unstiffened steel forks is not to be less than 16 mm. An example arrangement is shown in 3-2-9/14.9 FIGURE 2.

For small hatch covers located on the exposed deck forward of the fore-most cargo hatch, the hinges are to be fitted such that the predominant direction of green sea will cause the cover to close, which means that the hinges are normally to be located on the fore edge.

On small hatches located between the main hatches, for example between Nos. 1 and 2, the hinges are to be placed on the fore edge or outboard edge, whichever is practicable for protection from green water in beam sea and bow quartering conditions.

14.9 Secondary Devices

Small hatches on the fore deck are to be fitted with an independent secondary securing device e.g., by means of a sliding bolt, a hasp or a backing bar of slack fit, which is capable of keeping the hatch cover in place, even in the event that the primary securing device became loosened or dislodged. It is to be fitted on the side opposite to the hatch cover hinges.

### TABLE 2
Scantlings for Small Steel Hatch Covers on the Fore Deck

<table>
<thead>
<tr>
<th>Nominal Size (mm × mm)</th>
<th>Cover Plate Thickness (mm)</th>
<th>Primary Stiffeners</th>
<th>Secondary Stiffeners</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Flat Bar (mm × mm); number</td>
<td></td>
</tr>
<tr>
<td>630 × 630</td>
<td>8</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>630 × 830</td>
<td>8</td>
<td>100 × 8; 1</td>
<td>---</td>
</tr>
<tr>
<td>830 × 630</td>
<td>8</td>
<td>100 × 8; 1</td>
<td>---</td>
</tr>
<tr>
<td>830 × 830</td>
<td>8</td>
<td>100 × 10; 1</td>
<td>---</td>
</tr>
<tr>
<td>1030 × 1030</td>
<td>8</td>
<td>120 × 12; 1</td>
<td>80 × 8; 2</td>
</tr>
<tr>
<td>1330 × 1330</td>
<td>8</td>
<td>150 × 12; 2</td>
<td>100 × 10; 2</td>
</tr>
</tbody>
</table>
FIGURE 1
Arrangement of Stiffeners

Nominal size 630 × 630

Nominal size 630 × 830

Nominal size 830 × 830

Nominal size 830 × 630

Nominal size 1030 × 1030

Nominal size 1330 × 1330

---

Hinge

• Securing device/metal to metal contact

---

Primary stiffener

Secondary stiffener
15 **Hatchways within Open Superstructures**

Hatchways within open superstructures are to be considered as exposed.

17 **Hatchways within Deckhouses**

Hatchways within deckhouses are to have coamings and closing arrangements as required in relation to the protection afforded by the deckhouse from the standpoint of its construction and the means provided for the closing of all openings into the house.

19 **Machinery Casings**

19.1 **Arrangement**

Machinery-space openings in Position 1 or 2 are to be framed and efficiently enclosed by casings of ample strength, and wherever practicable, those in main decks are to be within superstructures or deckhouses.
Casings are to be of material similar to that of the surrounding structure. Openings in exposed casings are to be fitted with doors complying with the requirements of 3-2-9/7.1; the sills are to be in accordance with 3-2-9/5.1 for companionways. Other openings in such casings are to be fitted with equivalent covers, permanently attached. Stiffeners are to be spaced at not more than 760 mm (30 in.)

19.3 Scantlings
The scantlings of exposed casings are to be similar to those obtained for superstructures and deckhouses in accordance with the applicable requirements of Sections 3-2-2, 3-2-3 and 3-2-4.

The scantlings of casings within enclosed superstructures or deckhouses will be specially considered.

21 Miscellaneous Openings in Freeboard and Superstructure Decks

21.1 Manholes and Scuttles
Manholes and flush scuttles in Position 1 or 2 within superstructures other than enclosed superstructures are to be closed by substantial covers capable of being made watertight. Unless secured by closely spaced bolts, the covers are to be permanently attached.

21.3 Other Openings
Openings in freeboard decks other than hatchways, machinery-space openings, manholes and flush scuttles are to be protected by an enclosed superstructure, or by a deckhouse or companionway of equivalent strength and weathertightness. Any such opening in an exposed superstructure deck or in the top of a deckhouse on the main deck which gives access to a space below the main deck or a space within an enclosed superstructure is to be protected by an efficient deckhouse or companionway. Doorways in such deckhouses or companionways are to be fitted with doors complying with the requirements given in 3-2-9/7.1.

21.5 Escape Openings (1 July 2012)
   i) The closing appliances of escape openings are to be of a type that is operable from each side.
   ii) The maximum force needed to open the hatch cover is not to exceed 150 N (15.3 kgf, 33.7 lbf).
   iii) The use of a spring equalizing, counterbalance or other suitable device on the hinge side to reduce the force needed for opening is acceptable.

21.7 Chain Pipe Opening (1 July 2012)
For vessels with length \( L \) (as defined in 3-1-1/3) greater than 24 meters (79 feet), chain pipes through which anchor cables are led are to be provided with permanently attached closing appliances to minimize ingress of water. A canvas cover with appropriate lashing arrangement will be acceptable* for this purpose. Cement and wire mesh arrangement is not permitted.

The arrangement on vessels that are not subject to the International Convention on Load Lines or its Protocol may be specially considered.

Notes:
*Examples of acceptable arrangements are such as:
   i Steel plates with cutouts to accommodate chain links or
   ii Canvas hoods with a lashing arrangement that maintains the cover in the secured position.
CHAPTER 2
Hull Structures and Arrangements
SECTION 10
Protection of Shell Openings

1 Cargo, Gangway, or Fueling Ports

1.1 Construction
Cargo, gangway, or fueling ports in the sides of vessels are to be strongly constructed and capable of being made thoroughly watertight. Where frames are cut in way of such ports, web frames are to be fitted on the sides of the openings, and suitable arrangements are to be provided for the support of the beams over the openings. Thick shell plates or doublers are to be fitted as required to compensate for the openings. The corners of the openings are to be well rounded. Waterway angles and scuppers are to be provided on the decks in way of ports in cargo spaces below the freeboard deck or in cargo spaces within enclosed superstructures to prevent the spread of any leakage water over the decks.

Indicators showing whether the ports in the side shell below the freeboard or superstructure deck are secured closed or open are to be provided on the navigation bridge.

1.3 Location
The lower edges of cargo, gangway, or fueling-port openings are not to be below a line parallel to the main deck at side having as its lowest point the designed load waterline or upper edge of the uppermost load line.

3 Bow Doors, Inner Doors, Side Shell Doors and Stern Doors

3.1 General
Where steel bow doors of the visor or side-opening type are fitted leading to complete or long forward enclosed superstructure, bow doors and inner doors are to meet the requirements of this section. Hull supporting structure in way of the bow doors is to be able to withstand the loads imposed by the bow doors securing and supporting devices without exceeding the allowable stresses for those devices, both given in this section. Special consideration will be given to bow doors constructed of materials other than steel.

3.3 Arrangement
3.3.1 General
As far as practicable, bow doors and inner doors are to be arranged so as to preclude the possibility of the bow door causing structural damage to the inner door or to the collision bulkhead in the case of damage to or detachment of the bow door.
3.3.2 Bow Doors
Bow doors are to be situated above the main deck except that where a watertight recess fitted for arrangement of ramps or other related mechanical devices is located forward of the collision bulkhead and above the deepest waterline, the bow doors may be situated above the recess.

3.3.3 Inner Doors
An inner door is to be fitted in the extension of the collision bulkhead required by 3-2-5/1.3.3. A vehicle ramp made watertight and conforming to 3-2-5/1.3.3 in the closed position may be accepted for this purpose.

3.3.4 Side Shell and Stern Doors
Stern doors for passenger vessels are to be situated above the freeboard deck. Stern doors for ro-ro cargo vessels and all side shell doors need not be situated above the freeboard deck.

5 Securing, Locking and Supporting of Doors

5.1 Definitions
5.1.1 Securing Device
A device used to keep the door closed by preventing it from rotating about its hinges or its pivoted attachments to the vessel.

5.1.2 Supporting Device
A device used to transmit external or internal loads from the door to a securing device and from the securing device to the vessel’s structure, or a device other than a securing device, such as a hinge, stopper or other fixed device, that transmits loads from the door to the vessel’s structure.

5.1.3 Locking Device
A device that locks a securing device in the closed position.

7 Securing and Supporting Devices

7.1 General
Securing and supporting devices are to be arranged in accordance with this subsection, and are to have scantlings as required by 3-2-10/13.9, 3-2-10/15.5 or 3-2-10/17.9, as appropriate.

7.3 Bow Doors
Means are to be provided to prevent lateral or vertical movement of the bow doors when closed. Means are also to be provided for mechanically fixing the door in the open position.

Means of securing and supporting the door are to maintain equivalent strength and stiffness of the adjacent structure.

7.3.1 Clearance and Packing
The maximum design clearance between the door and securing/supporting devices is not to exceed 3 mm (0.12 in.). Where packing is fitted, it is to be of a comparatively soft type and the supporting forces are to be carried by the steel structure only.

7.3.2 Visor Door Arrangement.
The pivot arrangement is to be such that the visor is self-closing under external loads. The closing moment, \( M_y \), as defined in 3-2-10/19.5.1 is not to be less than \( M_{yo} \) as given by the following equation:
\[ M_{\text{y0}} = Wc + 0.1 a^2 + b^2 \sqrt{F_x^2 + F_z^2} \]

where \( W, a, b, c, F_x \) and \( F_z \) are as defined in 3-2-10/19.

In addition, the arrangement of the door is to be such that the reaction forces of pin or wedge supports at the base of the door does not act in the forward direction when the door is loaded in accordance with 3-2-10/19.5.4.

7.5 Side Shell and Stern Doors
Means are to be provided to prevent lateral or vertical movement of the side shell or stern doors when closed. Means are also to be provided for mechanically fixing the doors in the open position.

The means of securing and supporting the doors are to have strength and stiffness equivalent to the adjacent structure.

Clearance and packing for side shell and stern doors are to be in accordance with 3-2-10/7.3.1.

9 Securing and Locking Arrangement

9.1 General
Securing devices are to be provided with a mechanical locking arrangement (self-locking or separate arrangement), or are to be of the gravity type.

9.3 Operation
Securing devices are to be simple to operate and readily accessible. The opening and closing systems as well as the securing and locking devices are to be interlocked in such a way that they can only operate in the proper sequence.

9.3.1 Hydraulic Securing Devices
Where hydraulic securing devices are applied, the system is to be mechanically lockable in the closed position. In the event of a loss of hydraulic fluid, the securing devices are to remain locked.

The hydraulic system for securing and locking devices is to be isolated from other hydraulic circuits when in the closed position.

9.3.2 Remote Control
Where bow doors and inner doors give access to a vehicle deck, an arrangement for remote control from a position above the freeboard deck is to be provided allowing closing and opening of the doors and associated securing and locking of the securing and locking devices for every door. The operating panels for operation of doors are to be accessible to authorized persons only. A notice plate giving instructions to the effect that all securing devices are to be closed and locked before leaving harbor is to be placed at each operating panel and is to be supplemented by warning indicator lights as indicated in 3-2-10/9.5.1.

9.5 Indication/Monitoring
9.5.1 Indicators
The indicator system is to be designed on the fail safe principle and in accordance with the following:

9.5.1(a) Location and Type.
Separate indicator lights are to be provided on the navigation bridge to show that the bow door and inner door are closed and that their locking devices are properly positioned.
The indication panel on the navigation bridge is to be equipped with a mode selection function “harbor/sea voyage”, arranged so that an audible and visible alarm is given if in the sea voyage condition, the bow door or inner door is not closed, or any of the securing devices is not in the correct position.

Indication of the open/closed position of every door and every securing and locking device is to be provided at the operating panels.

9.5.1(b) Indicator lights.
Indicator lights are to be designed so that they cannot be manually turned off. The indication panel is to be provided with a lamp test function.

9.5.1(c) Power Supply.
The power supply for the indicator system is to be independent of the power supply for operating and closing the doors.

9.5.1(d) Protection of Sensors.
Sensors are to be protected from water, ice formation and mechanical damage.

9.5.2 Water Leakage Protection
A drainage system is to be arranged in the area between the bow door and ramp and in the area between the ramp and inner door where fitted. The system is to be equipped with an audible alarm function to the navigation bridge for water level in these areas exceeding 0.5 m (1.6 ft) above the car deck level.

A water leakage detection system with audible alarm and television surveillance are to be arranged to provide an indication to the navigation bridge and to the engine control room of leakage through the inner door.

9.5.3 Door Surveillance
Between the bow door and the inner door a television surveillance system is to be fitted with a monitor on the navigation bridge and in the engine control room. The system is to monitor the position of doors and a sufficient number of their securing devices.

11 Tightness

11.1 Bow Doors
Bow doors are to be so fitted as to provide tightness consistent with operational conditions and to give effective protection to the inner doors.

11.3 Inner Doors
Inner doors forming part of the extension of the collision bulkhead are to be weathertight over the full height of the cargo space and arranged with fixed sealing supports on the aft side of the doors.

11.5 Side Shell and Stern Doors
Side shell doors and stern doors are to be so fitted as to provide watertightness.

13 Bow Door Scantlings

13.1 General
Bow doors are to be framed and stiffened so that the whole structure is equivalent to the unpierced bulkhead when closed.
13.3 Primary Structure
Scantlings of primary members are to be designed so that the allowable stresses indicated in 3-2-10/25.1 are not exceeded when the structure is subjected to the design loads indicated in 3-2-10/19.1. Unless the ends of the primary members are effectively fixed-ended, the member is to be considered simply supported.

13.5 Secondary Stiffeners
Secondary stiffeners are to be supported by primary members constituting the main stiffening of the door. The section modulus, \( SM \), of secondary stiffeners is to be as required by 3-2-4/1.3. In addition, stiffener webs are to have a net sectional area not less than that obtained from the following equation:

\[
A = \frac{VQ}{10 \text{ cm}^2} \quad (A = \frac{VQ}{6.5 \text{ in}^2})
\]

where

\[
V = \text{shear force, in kN (tf, Ltf), in the stiffener calculated using the uniformly distributed external pressure } P_{eb} \text{ given in 3-2-10/19.1}
\]

\[
Q = \text{as defined in 3-2-2/1.3.1(a)}
\]

13.7 Plating
The thickness of bow door plating is to be not less than that required for side shell plating at the same location.

13.9 Securing and Supporting Devices
Scantlings of securing and supporting devices are to be designed so that the allowable stresses indicated in 3-2-10/25.1 are not exceeded when the structure is subjected to the design loads indicated in 3-2-10/19.3. All load transmitting elements in the design load path from the door through securing and supporting devices into the vessel structure, including welded connections, are to meet the strength standards required for securing and supporting devices. Where fitted, threaded bolts are not to carry support forces, and the maximum tensile stress in way of the threads is not to exceed the allowable stress given in 3-2-10/25.5.

In determining the required scantlings, the door is to be assumed to be a rigid body. Only those active supporting and securing devices having an effective stiffness in the relevant direction are to be included and considered when calculating the reaction forces on the devices. Small or flexible devices such as cleats intended to provide load compression of the packing material are not to be included in the calculations.

13.9.1 Bearing Pressure
The bearing pressure on steel to steel bearings is to be calculated by dividing the design force by the projected bearing area, and is not to exceed the allowable stress given in 3-2-10/25.3.

13.9.2 Redundancy
In addition to the above requirements, the arrangement of the securing and supporting devices is to be designed with redundancy such that in the event of failure of any single securing or supporting device, the stresses in the remaining devices do not exceed the allowable stresses indicated in 3-2-10/25.1 by more than 20% under the above loads.

13.9.3 Visor Door Securing and Supporting Devices
Securing and supporting devices, excluding the hinges, are to be capable of resisting the vertical design force given in 3-2-10/19.5.3 without stresses exceeding the allowable stresses in 3-2-10/25.1.

Two securing devices are to be provided at the lower part of the door, each capable of providing the full reaction force required to prevent opening of the door without stresses exceeding the
allowable stresses indicated in 3-2-10/25.1. The opening moment, $M_o$, to be balanced by this force is as given in 3-2-10/19.5.2.

13.9.4 Side-opening Door Thrust Bearing
A thrust bearing is to be provided in way of girder ends at the closing of the two doors, and is to prevent one door from shifting towards the other one under the effect of unsymmetrical pressure. Securing devices are to be fitted to secure sections thrust bearing to one another.

13.11 Visor Door Lifting Arms and Supports
Where visor type bow doors are fitted, calculations are to be submitted verifying that lifting arms and their connections to the door and vessel structure are adequate to withstand the static and dynamic forces applied during the lifting and lowering operations under a wind pressure of at least $1.5 \text{ kN/m}^2$ (0.15 tf/m², 0.014 Ltf/ft²)

15 Inner Door Scantlings

15.1 General
Scantlings of inner doors are to meet the requirements of this Subsection. In addition, where inner doors are used as vehicle ramps, scantlings are not to be less than required for vehicle decks.

15.3 Primary Structure
Scantlings of primary members are to be designed so that the allowable stresses indicated in 3-2-10/25.1 are not exceeded when the structure is subjected to the design loads indicated in 3-2-10/21.1.

15.5 Securing and Supporting Devices
Scantlings of securing and supporting devices are to be designed so that the allowable stresses indicated in 3-2-10/25.1 are not exceeded when the structure is subjected to the design loads indicated in 3-2-10/21. Where fitted, threaded bolts are not to carry support forces, and the maximum tensile stress in way of the threads is not to exceed the allowable stress given in 3-2-10/25.5.

The bearing pressure on steel to steel bearings is to be calculated by dividing the design force by the projected bearing area, and is not to exceed the allowable stress given in 3-2-10/25.3.

17 Side Shell Door and Stern Door Scantlings

17.1 General
Scantlings of side shell doors or stern doors are to meet the requirements of this subsection. The doors are to be framed and stiffened so that the whole structure is equivalent to the intact side or stern structure when closed. In addition, where the doors are used as vehicle ramps, scantlings are not to be less than required for vehicle decks in 3-2-3 and 3-2-4.

17.3 Primary Structure
Scantlings of primary members are to be designed so that the allowable stresses indicated in 3-2-10/25.1 are not exceeded when the structure is subjected to the design loads indicated in 3-2-10/23. The primary members are to be considered simply supported at their support points unless the end connections are effectively restrained.

17.5 Secondary Stiffeners
Secondary stiffeners are to be supported by primary members constituting the main stiffening of the door. The section modulus, $SM$, of secondary stiffeners is to be not less than required by 3-2-4 for frames in the
same location. In addition, the net sectional area of stiffener webs is to be in accordance with 3-2-10/13.5, using the external pressure, \( p_e \), given in 3-2-10/23.

### 17.7 Plating
The thickness of side or stern door plating is to be not less than that required for side shell plating at the same location.

### 17.9 Securing and Supporting Devices
Scantlings of securing and supporting devices are to be designed so that the allowable stresses indicated in 3-2-10/25.1 are not exceeded when the structure is subjected to the design loads indicated in 3-2-10/23. All load-transmitting elements in the design load path from the door through securing and supporting devices into the vessel structure, including welded connections, are to meet the strength standards required for securing and supporting devices. Where fitted, threaded bolts are not to carry support forces, and the maximum tensile stress in way of the threads is not to exceed the allowable stress given in 3-2-10/25.5.

In determining the required scantlings, the door is to be assumed to be a rigid body. Only those active supporting and securing devices having an effective stiffness in the relevant direction are to be included and considered when calculating the reaction forces on the devices. Small or flexible devices such as cleats intended to provide compression load on the packing material are not to be included in the calculations.

#### 17.9.1 Bearing Pressure
The bearing pressure on steel to steel bearings is to be calculated by dividing the design force by the projected bearing area, and is not to exceed the allowable stress given in 3-2-10/25.3.

#### 17.9.2 Redundancy
In addition to the above requirements, the arrangement of the securing and supporting devices is to be designed with redundancy such that in the event of a failure of any single securing or supporting device, the stresses in the remaining devices do not exceed the allowable stresses indicated in 3-2-10/25.1 by more than 20% under the above loads.

### 19 Bow Door Design Loads

#### 19.1 External Pressure
The design external pressure, \( P_{eb} \), is to be taken as indicated by the following equation.

\[
P_{eb} = nc(0.22 + 0.15\tan\beta)(0.4V_d\sin\alpha + 0.6\sqrt{Ltf})^2 \text{kN/m}^2 \left(\text{tf/m}^2, \text{Ltf/ft}^2\right)
\]

where

- \( n = 2.75 \) (0.280, 0.0256)
- \( c = 0.0125L \) for vessels having \( L < 80 \text{ m (260 ft)} \)
- \( c = 1.0 \) for other vessels
- \( L = \) length of vessel as defined in 3-1-1/3, in m (ft)
- \( \beta = \) flare angle at the point to be considered, defined as the angle between a vertical line and the tangent to the side shell plating measured in a vertical plane normal to the horizontal tangent to the shell plating. See 3-2-10/19.1 FIGURE 1.
- \( \alpha = \) entry angle at the point to be considered, defined as the angle between a longitudinal line parallel to the centerline and the tangent to the shell plating in a horizontal plane. See 3-2-10/19.1 FIGURE 1.
![Image](https://via.placeholder.com/150)

**FIGURE 1**

**Entry and Flare Angles**

---

### 19.3 External Forces

The design external forces considered in determining scantlings of securing and supporting devices of bow doors are not to be taken less than those given by the following equations:

\[
F_x = P_{em} A_x \\
F_y = P_{em} A_y \\
F_z = P_{em} A_z
\]

where

- \( F_x \) = design external force in the longitudinal direction, in kN (tf, Ltf)
- \( F_y \) = design external force in the horizontal direction, in kN (tf, Ltf)
- \( F_z \) = design external force in the vertical direction, in kN (tf, Ltf)
- \( A_x \) = area, in \( m^2 \) (ft\(^2\)), of the transverse vertical projection of the door between the levels of the bottom of the door and the upper deck or between the bottom of the door and the top of the door, whichever is less.
\[ A_y = \text{area, in m}^2 (\text{ft}^2), \text{of the longitudinal vertical projection of the door between the levels of the bottom of the door and the upper deck or between the bottom of the door and the top of the door, whichever is less.} \]

\[ A_z = \text{area, in m}^2 (\text{ft}^2), \text{of the horizontal projection of the door between the levels of the bottom of the door and the upper deck or between the bottom of the door and the top of the door, whichever is less.} \]

\[ P_{em} = \text{bow door pressure, } P_{eb}, \text{ determined using } a_m \text{ and } \beta_m \text{ in place of } a \text{ and } \beta. \]

\[ \beta_m = \text{flare angle measured at a point on the bow door } \frac{\ell}{2} \text{ aft of the stem line on a plane } \frac{h}{2} \text{ above the bottom of the door, as shown in 3-2-10/19.3 FIGURE 2.} \]

\[ a_m = \text{entry angle measured at the same point as } \beta_m. \text{ See 3-2-10/19.3 FIGURE 2.} \]

\[ h = \text{height, in m (ft), of the door between the levels of the bottom of the door and the upper deck or between the bottom of the door and the top of the door, whichever is less.} \]

\[ \ell = \text{length, in m (ft), of the door at a height of } \frac{h}{2} \text{ above the bottom of the door.} \]

**FIGURE 2**

Definition of \(a_m\) and \(\beta_m\)

---

19.5 Visor Door Forces, Moments and Load Cases

19.5.1 Closing Moment

For visor doors, the closing moment, \(M_y\), is to be taken as indicated by the following equation:

\[ M_y = F_z a + W_c - F_a b \quad \text{kN} - \text{m (tf} - \text{m, Ltf} - \text{ft)} \]
where

\[ W = \text{weight of the visor door, in kN (tf, Ltf)} \]
\[ a = \text{vertical distance, in m (ft), from the visor pivot to the centroid of the transverse vertical projected area of the visor door. See 3-2-10/19.5.1 FIGURE 3.} \]
\[ b = \text{horizontal distance, in m (ft), from visor pivot to the centroid of the horizontal projected area of the visor door. See 3-2-10/19.5.1 FIGURE 3.} \]
\[ c = \text{horizontal distance, in m (ft), from the visor pivot to the center of gravity of the visor. See 3-2-10/19.5.1 FIGURE 3.} \]

\( F_x \) and \( F_z \) are as defined in 3-2-10/19.3.

**FIGURE 3**

Visor Type Bow Door
19.5.2 Opening Moment

The opening moment, \( M_0 \), is to be taken as indicated by the following equation:

\[
M_0 = Wd + 5A_xa \quad \text{kN} \cdot \text{m} = (Wd + 0.5A_xa \quad \text{tf} = m, Wd + 0.047A_xa \quad \text{Ltf} = \text{ft})
\]

where

\( d = \) vertical distance, in m (ft), from the hinge axis to the center of gravity of the door

\( W, A_x \) and \( a \) are as indicated above.

19.5.3 Vertical Design Force

The vertical design force is to be taken as \( F_z - W \), where \( F_z \) is as defined in 3-2-10/19.3 and \( W \) as defined in 3-2-10/19.5.1.

19.5.4 Combined Load Case 1

The visor doors are to be evaluated under a load of \( F_x, F_y, F_z \) and \( W \) acting simultaneously with \( F_x \) and \( F_z \) acting at the centroid of their respective projected areas.

19.5.5 Combined Load Case 2

The visor doors are to be evaluated under a load of 0.7 \( F_y \) acting on each side separately together with 0.7 \( F_x \) and \( F_z \) acting at the centroid of their respective projected areas.

19.7 Side-Opening Door Load Cases

19.7.1 Combined Load Case 1

Side opening doors are to be evaluated under a load of \( F_x, F_y, F_z \) and \( W \) acting simultaneously with \( F_x, F_y, \) and \( F_z \) acting at the centroid of their respective projected areas.

19.7.2 Combined Load Case 2

Side opening doors are to be evaluated under a load of 0.7 \( F_x, 0.7 F_y \) and \( W \) acting on both doors simultaneously and 0.7 \( F_y \) acting on each door separately.

21 Inner Door Design Loads

21.1 External Pressure

The design external pressure is to be taken as the greater of \( P_{ei} \) or \( P_h \) as given by the following equations:

\[
P_{ei} = 0.45L_1 \quad \text{kN/m}^2 (0.046L_1 \quad \text{tf/m}^2, 0.00128L_1 \quad \text{Ltf/ft}^2)
\]

\[
P_h = 10h \quad \text{kN/m}^2 (1.0htf/m^2, 0.029hLtf/ft^2)
\]

where

\( L_1 = \) as defined in 3-1-1/3.

\( h = \) the distance, in m (ft), from the load point to the top of the cargo space.

21.3 Internal Pressure

The design internal pressure, \( P_i \), is to be taken as not less than 25 kN/m\(^2\) (2.5 tf/m\(^2\), 0.23 Ltf/ft\(^2\)).
23 Side Shell and Stern Doors

23.1 Design Forces for Primary Members

The design force, in kN (tf, Ltf), for primary members is to be the greater of the following:

External force: \( F_e = A P_e \)

Internal force: \( F_i = F_o + W \)

23.3 Design Forces for Securing or Supporting Devices of Doors Opening Inwards

The design force, in kN (tf, Ltf), for securing or supporting devices of doors opening inwards is to be the greater of the following:

External force: \( F_e = A P_e + F_p \)

Internal force: \( F_i = F_o + W \)

23.5 Design Forces for Securing or Supporting Devices of Doors Opening Outwards

The design force, in kN (tf, Ltf), for securing or supporting devices of doors opening outwards is to be the greater of the following:

External force: \( F_e = A P_e \)

Internal force: \( F_i = F_o + W + F_p \)

where

\[ A = \text{area, in } \text{m}^2 (\text{ft}^2), \text{ of the door opening} \]

\[ W = \text{weight of the door, in kN (tf, Ltf)} \]

\[ F_p = \text{total packing force, in kN (tf, Ltf). Packing line pressure is normally not to be taken less than } 5.0 \text{ N/mm (0.51 kg/mm, 28.6 lbf/in).} \]

\[ F_o = \text{the greater of } F_c \text{ and } k A, \text{ in kN (tf, Ltf)} \]

\[ k = 5 (0.51, 0.047) \]

\[ F_c = \text{accidental force, in kN (tf, Ltf), due to loose cargo, etc., to be uniformly distributed over the area } A \text{ and not to be taken less than } 300 \text{ kN (30.6 tf, 30.1 Ltf). For small doors such as bunker doors and pilot doors, the value of } F_c \text{ may be appropriately reduced. However, the value of } F_c \text{ may be taken as zero provided an additional structure such as an inner ramp is fitted which is capable of protecting the door from accidental forces due to loose cargoes.} \]

\[ P_e = \text{external design pressure, in kN/m}^2 \text{ (tf/ft}^2, \text{ Ltf/ft}^2) \text{, determined at the center of gravity of the door opening and not taken less than:} \]

\[ p_e = k_1 \text{ for } Z_G \geq d \]

\[ p_e = k_1(d - Z_G) + k_1 \text{ for } Z_G < d \]

Moreover, for vessels fitted with bow doors, \( p_e \) for stern doors is not to be taken less than:

\[ p_e = nc(0.8 + 0.6(k_2 L)^{0.5})^2 \]
For vessels fitted with bow doors and operating in restricted service, the value of \( p_e \) for stern doors will be specially considered.

\[
k_1 = 25.0 \quad (2.55, 0.233)
\]

\[
k_2 = 10.0 \quad (1.02, 0.0284)
\]

\[d = \text{draft, in m (ft), as defined in 3-1-1/9}\]

\[Z_G = \text{height of the center of area of the door, in m (ft), above the baseline.}\]

\[
n = 0.605 \quad (0.0616, 0.00563)
\]

\[
k_3 = 1.0 \quad (1.0, 0.305)
\]

\[
c = 0.0125L \quad \text{for } L < 80 \text{ m (262 ft)}
\]

\[
c = 1 \quad \text{for } L < 80 \text{ m (262 ft)}
\]

\[L = \text{length of vessel, in m (ft), as defined in 3-1-1/3, but need not be taken as greater than 200 m (656 ft).}\]

25 **Allowable Stresses**

25.1 **Primary Structure and Securing and Supporting Devices**

The following stresses are not to be exceeded under the loads indicated above:

- **Shear Stress:**
  \[
  \tau = \frac{80}{Q} \quad \text{N/mm}^2 \quad (8.2/Q \text{kgf/mm}^2, 11600/Q \text{psi})
  \]

- **Bending Stress:**
  \[
  \sigma = \frac{120}{Q} \quad \text{N/mm}^2 \quad (12.2/Q \text{kgf/mm}^2, 17400/Q \text{psi})
  \]

- **Equivalent Stress:**
  \[
  \sigma_e = \frac{150}{Q} \quad \text{N/mm}^2 \quad (15.3/Q \text{kgf/mm}^2, 21770/Q \text{psi})
  \]

where \( Q \) is defined in 3-2-1/1.1.1.

25.3 **Steel Securing and Supporting Devices Bearing Stress**

For steel to steel bearings in securing and supporting devices, the nominal bearing pressure is not to exceed 0.8\( \sigma_f \), where \( \sigma_f \) is the yield stress of the bearing material.

25.5 **Tensile Stress on Threaded Bolts**

The tensile stress in threaded bolts is not to exceed 125/Q N/mm² (12.7/Q kgf/mm², 18,000/Q psi).

27 **Operating and Maintenance Manual**

The following information is to be submitted for review:

27.1 **Manual**

An operating and maintenance manual for the bow door and inner door is to be provided on board and is to contain at least the following:

- Main particulars and design drawings
- Service conditions (e.g., service area)
- Restrictions, acceptable clearances for supports
- Maintenance and function testing
- Register of inspections and repairs
27.3 Operating Procedures

Documented operating procedures for closing and securing the bow door and inner door are to be kept on board and posted at an appropriate location.
1 Bulwarks and Guard Rails

Bulwarks or guard rails or a combination of both, are in general to be provided on exposed decks, and on exposed tops of superstructures and deckhouses.

Additional bulwark and guardrail requirements may be specified by the Naval Administration due to specific military mission requirements.

1.1 Location and Heights (2017)

Bulwarks or guardrails are also to be provided on the exposed side of any platform surface that is greater than 600 mm (24 in.) or higher above the adjacent surface.

The height of bulwarks and guard rails on exposed freeboard and superstructure decks, at the boundary of first tier deckhouses and at the ends of superstructures is to be at least 1 m (39.5 in.). Where this height would interfere with the normal service or operation of a vessel, a lesser height may be approved if adequate protection is provided. Where approval of a lesser height is requested, justifying information is to be submitted, such as arrangements provided to prevent personnel going over the guard rails or bulwarks.

In exposed areas not traversed in the normal operation of the vessel, where it is not practical to fit bulwarks or guard rails, hand or grab rails may be considered.

1.3 Strength of Bulwarks

Bulwarks are to be of ample strength for their height and location, suitably stiffened at the top, and if necessary at the bottom, and supported by efficient stays or brackets.

Stays or brackets on the main weather deck are to be spaced not more than 1.83 m (6.0 ft).

Openings in bulwarks are to be smooth-edged, with well-rounded corners.

1.5 Guard Rails

1.5.1

Fixed, removable or hinged stanchions are to be fitted at approximately 1.5 m (5 ft) apart.
1.5.2 (1 July 2022)
At least every third stanchion is to be supported by a bracket or stay. Dimensions and arrangement of stanchion and stays are to be as shown in 3-2-11/1.5.2 FIGURE 1. Where the arrangements would interfere with the safe traffic of persons on board, the following alternative arrangements of stanchions may be acceptable:

i) At least every third stanchion is to be of increased breadth, $k b_s = 2.9 b_s$ at the attachment of stanchion to the deck, or,

ii) At least every second stanchion is to be of increased breadth, $k b_s = 2.4 b_s$ at the attachment of stanchion to the deck, or,

iii) Every stanchion is to be of increased breadth, $k b_s = 1.9 b_s$ at the attachment of stanchion to the deck.

where, $b_s$ is the breadth of normal stanchion according to the recognized design standard. (see 3-2-11/1.5.2 FIGURE 2)

In any arrangement of i), ii) or iii) above, the following details are to be complied with:

iv) Flat steel stanchion required by i), ii) or iii) above is to be aligned with supporting member below the deck unless the deck plating thickness exceeds 20 mm (0.79 in.) and welded to deck with double continuous fillet weld with minimum leg size of 7.0 mm (0.28 in.) or as specified by the design standard.

v) The underdeck supporting member of the stanchion is to be a minimum of $100 \times 12$ mm (4.0 x 0.5 in.) flat bar welded to deck by double continuous fillet weld.
** Top Rail = 34 mm outside diameter pipe with 2.6 mm minimum wall thickness (or pipes having an equivalent section modulus)

* = 19 mm solid round bar or 26.9 mm outside diameter pipe with 2.3 mm minimum wall thickness (or pipes having an equivalent section modulus)

Standard stanchion, rail, and stay sizes.
(Stay to be provided at every third stanchion)
1.5.3
The opening below the lowest course is not to exceed 230 mm (9 in.) The distance between the remaining courses is not to be more than 380 mm (15 in.)

1.5.4
For vessels with rounded gunwales, stanchions are to be placed on the flat of the deck.

1.5.5
Portable stanchions are to be retained with stainless steel toggle pins. The toggle pins are to be provided with stainless steel wire rope attached to the portable stanchion to prevent the loss of the pin.

1.5.6
The imposed loads from safety harness, or other rescue equipment connecting points that are located on the guardrails are to be considered.

1.6 Guard Rail Scantling Correction (1 July 2022)
When aluminum guard rails are used, an equivalent section modulus to the standard shown in 3-2-11/1.5.2. FIGURE 1 can be calculated using the following formula:

\[ SM_{al} = 0.9 Q SM_s \]

where
SM_{al} = \text{minimum section modulus of aluminum guardrail, cm}^3 (\text{in}^3)

SM_s = \text{offered section modulus of guardrail as shown in 3-2-11/1.5.2. FIGURE 1, cm}^3 (\text{in}^3)

Q = \text{material factor, as determined from 3-2-1/1.1.1}

1.7 Life Lines
Life lines, where fitted, are to be a minimum of 9.5 mm (0.375 in.) in diameter, 7 × 19 construction, and made of stainless steel wire rope. They are to have a stainless steel turnbuckle at one end and a stainless steel screw pin shackle at the other.

3 Freeing Ports

3.1 Basic Area
Where bulwarks on freeboard decks form wells, ample provision is to be made for rapidly freeing the decks of water and for draining them. The minimum freeing-port area on each side of the vessel for each well 20 m (66 ft.) or less in length is to be obtained from the following equation:

\[ A = 0.7 + 0.035 \ell \quad \text{m}^2 \]

\[ A = 7.6 + 0.115 \ell \quad \text{ft}^2 \]

Where the bulwark length exceeds 20 m (66 ft):

\[ A = 0.07 \ell \quad \text{m}^2 \]

\[ A = 0.23 \ell \quad \text{ft}^2 \]

where

\[ A = \text{freeing-port, area in m}^2 (\text{ft}^2) \]

\[ \ell = \text{bulwark length, in m (ft), but need not exceed 0.7L} \]

The minimum area for each well on superstructure decks is to be one half of the area obtained from the above equations.

If a bulwark is more than 1.2 m (3.9 ft) in height, the freeing-port area is to be increased by 0.004 m\(^2\) per meter (0.04 ft\(^2\) per foot) of length of well for each 0.1 m (1 ft) difference in height. If a bulwark is less than 0.9 m (3 ft) in height, the freeing-port area may be decreased by the same ratio. A freeing port area less than required by the equations above may be accepted providing that the reduced area is specifically requested by the Naval Administration.

3.3 Trunks, Deckhouses and Hatchway Coamings
Where a vessel is fitted with a trunk on the freeboard deck, and open rails are not fitted in way of the trunk for at least one-half its length, or where continuous or substantially continuous hatchway side coamings are fitted or long deckhouse exist between detached superstructures, the minimum area of freeing-port openings is to be obtained from the following table:

<table>
<thead>
<tr>
<th>Breadth of Trunk, Deckhouse or Hatchway in Relation to Breadth of Vessel</th>
<th>Area of Freeing Ports in Relation to Total Area of Bulwarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>40% or less</td>
<td>20%</td>
</tr>
<tr>
<td>75% or more</td>
<td>10%</td>
</tr>
</tbody>
</table>
The area of freeing ports at intermediate breadths is to be obtained by linear interpolation.

### 3.5 Superstructure Decks

Where bulwarks on superstructure decks form wells, the bulwarks are to comply with 3-2-11/3.1 except that the minimum freeing-port area on each side of the vessel for each well is to be one-half of the area obtained in 3-2-11/3.1 and 3-2-11/3.3.

### 3.7 Open Superstructures

In vessels having superstructures that are open at either end or both ends, adequate provisions for freeing the spaces within such superstructures are to be provided; the arrangements will be subject to special approval.

### 3.9 Details of Freeing Ports

The lower edges of the freeing ports are to be as near the deck as practicable. Two-thirds of the required freeing-port area is to be provided in the half of the well nearest the lowest point of the sheer curve. Freeing-port openings are to be protected by rails or bars in such a manner that the maximum clear vertical or horizontal space is 230 mm (9 in.). Where shutters are fitted, ample clearance is to be provided to prevent them from jamming. Hinges are to have pins and bearings of corrosion resistant material and in general, the hinges are to be located at the top of the shutter. If the shutters are equipped with securing appliances, the appliances are to be of approved construction.

### 5 Portlights

#### 5.1 Construction

Portlights fitted below the main weather deck or in superstructure and house side plating are to be of substantial construction and provided with steel, aluminum or other approved material inside deadlights, permanently attached and arranged to be capable of being closed and secured watertight. Except in way of the machinery space, portlights may be of the hinged opening type, with hinge pins of non-corrosive material. Where vessels are subject to damaged stability requirements of 3-3-1/3.3, portlights found to be situated below a final damage equilibrium waterline are to be of the non-opening type. Portlight frames are to be of steel or other approved material and are to be attached to the hull by through bolts or equivalent. Lower edges of portlights are not to be below a line parallel to the main weather deck at side having its lowest point at a distance above the design waterline either 2.5% of the vessel breadth or 500 mm (19.5 in.) whichever is greater.

When specifically requested by the Naval Administration, consideration will be given to the omission of deadlights depending on the type and thickness of the portlight.

The thickness of portlights of tempered or toughened monolithic safety glass is to be not less than given in 3-2-11/5.1 \(\text{T}A\) BLE 1. Consideration will also be given to laminated glass, acrylic and polycarbonate glazing materials based upon equivalent flexural strength and stiffness. See for glazing mechanical properties.

<table>
<thead>
<tr>
<th>Location</th>
<th>General</th>
<th>Limited Service Vessels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side Shell below main weather deck</td>
<td>0.050d</td>
<td>0.040d</td>
</tr>
<tr>
<td>Superstructure or deckhouse on main weather deck</td>
<td>0.033d</td>
<td>0.033d</td>
</tr>
<tr>
<td>Deckhouse above main weather deck</td>
<td>0.025d</td>
<td>0.025d</td>
</tr>
</tbody>
</table>
Note: \( d \) is to be taken as the diameter between inner edges of the portlight frame in mm (in.) For calculation of required thickness on limited service vessels, \( d \) is not to be taken less than 250 mm (10 in.).

b) Rectangular Portlights

<table>
<thead>
<tr>
<th>Location</th>
<th>General</th>
<th>Limited Service Vessels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side shell below main weather deck</td>
<td>( 0.091s\sqrt{k} )</td>
<td>( 0.073s\sqrt{k} )</td>
</tr>
<tr>
<td>Superstructures or deckhouses on main weather deck</td>
<td>( 0.060s\sqrt{k} )</td>
<td>( 0.060s\sqrt{k} )</td>
</tr>
<tr>
<td>Deckhouses above main weather deck</td>
<td>( 0.045s\sqrt{k} )</td>
<td>( 0.045s\sqrt{k} )</td>
</tr>
</tbody>
</table>

Note: \( k \) is to be taken from 3-2-11/7.1.3 TABLE 2; \( s \) is the short panel dimension and \( \ell \) is the long window dimension

5.3 Testing
All portlights are to be hose tested after installation.

7 Windows

7.1 Construction
Windows to spaces within enclosed superstructure and deckhouses are to be fitted with strong steel, aluminum or other approved material deadlight covers, unless specified otherwise by the Naval Administration. Windows are generally not to be fitted in the end bulkheads of superstructures or deckhouses in Position 1. Window frames are to be of steel or other approved material and are to be attached by through bolts or equivalent.

Windows on the second tier above the freeboard deck may not require deadlight depending upon the arrangement of the vessel. Window frames are to be metal or other approval material, and effectively secured to the adjacent structure. Windows are to have a minimum of a 6.5 mm (0.25 in.) radius at all corners. The glazing is to be set into the frames in a suitable, approved packing or compound. Where specifically deemed acceptable by the Naval Administration, the use of adhesively bonded windows may be considered.

The thickness of the window is not to be less than that obtained from 3-2-11/7.1.1, 3-2-11/7.1.2 or 3-2-11/7.1.3 below, whichever is greater.

7.1.1
\[
t = s \left( \sqrt{\frac{p k}{1000 \sigma_a}} \right) \text{ mm}
\]
\[
t = s \left( \frac{pk}{\sigma_a} \right) \text{ in.}
\]

7.1.2
\[
t = s \left( \sqrt{\frac{p k_1}{20E}} \right) \text{ mm}
\]
\[
t = s \left( \frac{p k_1}{0.02E} \right) \text{ in.}
\]

7.1.3 Minimum Tempered Monolithic Glass Thicknesses:
\[ t = 9.5 \text{ mm (0.37 in.) for front windows} \]
\[ t = 6.5 \text{ mm (0.25 in.) for side and end windows.} \]

where
\[
t = \text{required window thickness, in mm (in.)}
\]
\[
s = \text{lesser dimension of window, in mm (in.)}
\]
\[
p = \text{pressure head for window location as determined by 3-2-2/7}
\]
\[
k = \text{factor given in 3-2-11/7.1.3 TABLE 2}
\]
\[
k_1 = \text{factor given in 3-2-11/7.1.3 TABLE 2}
\]
\[
\sigma_a = 0.30\sigma_f
\]
\[
\sigma_f = \text{material flexural strength; see 3-2-11/7.1.3 TABLE 3}
\]
\[
E = \text{material flexural modulus; see 3-2-11/7.1.3 TABLE 3}
\]

### TABLE 2

<table>
<thead>
<tr>
<th>(\ell/s)</th>
<th>(k)</th>
<th>(k_1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;5</td>
<td>0.750</td>
<td>0.142</td>
</tr>
<tr>
<td>5</td>
<td>0.748</td>
<td>0.142</td>
</tr>
<tr>
<td>4</td>
<td>0.741</td>
<td>0.140</td>
</tr>
<tr>
<td>3</td>
<td>0.713</td>
<td>0.134</td>
</tr>
<tr>
<td>2</td>
<td>0.610</td>
<td>0.111</td>
</tr>
<tr>
<td>1.8</td>
<td>0.569</td>
<td>0.102</td>
</tr>
<tr>
<td>1.6</td>
<td>0.517</td>
<td>0.091</td>
</tr>
<tr>
<td>1.4</td>
<td>0.435</td>
<td>0.077</td>
</tr>
<tr>
<td>1.2</td>
<td>0.376</td>
<td>0.062</td>
</tr>
<tr>
<td>1</td>
<td>0.287</td>
<td>0.044</td>
</tr>
</tbody>
</table>

**Note:**

- \(s = \text{lesser dimension of window panel, in mm (in.)}\)
- \(\ell = \text{greater dimension of window panel, in mm (in.)}\)
- Intermediate values may be determined by linear interpolation.

### TABLE 3

<table>
<thead>
<tr>
<th>Glazing</th>
<th>Flexural Strength</th>
<th>Flexural Modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tempered Monolithic</td>
<td>119 MPa (17,200 psi)</td>
<td>73,000 MPa (10,600,000 psi)</td>
</tr>
<tr>
<td>Laminated Glass</td>
<td>69 MPa (10,000 psi)</td>
<td>2,620 MPa (380,000 psi)</td>
</tr>
<tr>
<td>Polycarbonate*</td>
<td>93 MPa (13,500 psi)</td>
<td>2,345 MPa (340,000 psi)</td>
</tr>
<tr>
<td>Acrylic (PMMA)*</td>
<td>110 MPa (16,000 psi)</td>
<td>3,000 MPa (435,000 psi)</td>
</tr>
</tbody>
</table>

* Indicated values are for reference. Aging effects are to be considered for design.

### 7.3 Testing

All windows are to be hose tested after installation.
9 Ventilators, Tank Vents and Overflows

9.1 General
Ventilators are to comply with the requirements of 3-2-11/9.3. Tank vents and overflows are to comply with the requirements in 3-2-11/9.5. In addition, for those located on the fore deck of vessels with length \( L \) (as defined in 3-1-1/3) not less than 80 meters (263 feet), the requirements given in 3-2-11/9.7 are to be complied with.

9.3 Ventilators

9.3.1 Coaming Construction (1 July 2016)
Ventilators on exposed freeboard decks, superstructure decks, or deckhouses are to have coamings of steel or equivalent material. Coaming plate thicknesses for steel are to be obtained from the following equation:

\[
t = 0.01d + 5.5 \text{ mm}
\]

\[
t = 0.01d + 0.22 \text{ in.}
\]

where

\[
t = \text{ thickness of coaming, in mm (in.)}
\]

\[
d = \text{ diameter of ventilator, in mm (in.), but not less than 200 mm (7.5 in.)}
\]

The maximum steel coaming plate thickness required is 10 mm (0.40 in.). The coamings are to be effectively secured to the deck. Coamings which are more than 900 mm (35.5 in.) high and which are not supported by adjacent structures are to have additional strength and attachment. Ventilators passing through superstructures other than enclosed superstructures are to have substantially constructed coamings of steel or equivalent material at the freeboard deck. Where a fire damper is located within a ventilation coaming, an inspection port or opening at least 150 mm (6 in.) in diameter is to be provided in the coaming to facilitate survey of the damper without disassembling the coaming or the ventilator. The closure provided for the inspection port or opening is to maintain the watertight integrity of the coaming and, if appropriate, the fire integrity of the coaming.

Coaming plate thickness of material other than steel will be specially considered.

9.3.2 Coaming Height
Ventilators in Position 1 are to have coamings at least 900 mm (35.5 in.) high. Ventilators in Position 2 are to have coamings at least 760 mm (30 in.) high. For definitions of Position 1 and Position 2, see 3-2-9/3. When requested by the Naval Administration, a reduction of the required coaming heights may be considered.

9.3.3 Means for Closing Ventilators
Except as provided below, ventilator openings are to be provided with efficient, permanently attached closing appliances. In vessels measuring 24 m (79 ft) or more in length (as defined in the International Convention on Load Lines, 1966), ventilators in Position 1, the coamings of which extend to more than 4.5 m (14.8 ft) above the deck and in Position 2, the coamings of which extend to more than 2.3 m (7.5 ft) above the deck, need not be fitted with closing arrangements.

These coaming height requirements may be modified in vessels measuring less than 24 m (79 ft) in length.
9.3.4 Ventilators in Way of Own-vessel Weapons-firing Effects

Typically, ventilation system intakes and exhausts are to be located outside the blast area. Where arrangements do not permit this, intakes and exhausts may be located in the blast area if fitted with blast shields, which withstand the blast. Supply ventilation weather openings within 15 m (50 ft) of a missile launcher or end of a gun muzzle are to be fitted with an automatically operated ventilation damper that will prevent the ingestion of gun propellant and missile exhaust gases into the vessel. Ventilation system exhausts serving flammable liquid storerooms or issue rooms are not to be located in missile blast zones.

9.5 Tank Vents and Overflows

Tank vents and overflows are to be in accordance with the requirements of 4-6-4/9.3 and 4-6-4/9.5 of these Rules and, where applicable, the requirements given below in 3-2-11/9.7.

9.7 Ventilators, Tank Vents and Overflows on the Fore Deck

9.7.1 Application

The requirements of this paragraph apply to all ventilators, tank vents and overflows located on the exposed fore deck within the forward 0.25 \(L\) on vessels with length \(L\) (as defined in 3-1-1/3) not less than 80 meters (263 feet) and where the height of the exposed deck in way of the item is less than 0.1 \(L\) or 22 meters (72 ft) above the summer load waterline, whichever is the lesser.

9.7.2 Applied Loading to the Air Pipes and Ventilators

9.7.2(a) Pressure.

The pressures \(p\), in kN/m\(^2\) (tf/m\(^2\), Ltf/ft\(^2\)), acting on air pipes, ventilator pipes and their closing devices, may be calculated from:

\[
p = f \rho V^2 C_d C_s C_p \text{kN/m}^2 \text{ (tf/m}^2\text{, Ltf/ft}^2\text{)}
\]

where:

\[
f = 0.5 \ (0.05, 0.0156)
\]
\[
\rho = \text{density of sea water, 1.025 t/m}^3 \ (1.025 \text{ t/m}^3, 0.0286 \text{ Lt/ft}^3)
\]
\[
V = \text{velocity of water over the fore deck, 13.5 m/sec (44.3 ft/sec)
}\]
\[
C_d = \text{shape coefficient}
\]
\[
= 0.5 \ \text{for pipes}
\]
\[
= 1.3 \ \text{for pipes or ventilator heads in general}
\]
\[
= 0.8 \ \text{for pipes or ventilator heads of cylindrical form with its axis in the vertical direction}
\]
\[
C_s = \text{slamming coefficient, 3.2}
\]
\[
C_p = \text{protection coefficient:}
\]
\[
= 0.7 \ \text{for pipes and ventilator heads located immediately behind a breakwater or forecastle}
\]
\[
= 1.0 \ \text{elsewhere including immediately behind a bulwark}
\]

9.7.2(b) Force.

Forces acting in the horizontal direction on the pipe and its closing device may be calculated from the above pressure using the largest projected area of each component.

9.7.3 Strength Requirements for Ventilators, Tank Vents and Overflows and their Closing Devices

9.7.3(a) Bending Moment and Stress.
Bending moments and stresses in air pipes and ventilator pipes are to be calculated at critical positions: at penetration pieces, at weld or flange connections, at toes of supporting brackets. Bending stresses in the net section are not to exceed 0.8Y, where Y is the specified minimum yield stress or 0.2% proof stress of the steel at room temperature. Irrespective of corrosion protection, a corrosion addition to the net section of 2.0 mm (0.08 in.) is then to be applied.

9.7.3(b) Tank Vents and Overflows

i) For standard tank vents and overflows of 760 mm (30 in.) height closed by heads of not more than the tabulated projected area, pipe thicknesses and bracket heights are specified in 3-2-11/9.7.3(e) TABLE 4. Where brackets are required, three or more radial brackets are to be fitted.

ii) Brackets are to be of gross thickness of 8 mm (0.32 in.) or more, of minimum length of 100 mm (4.0 in.), and height according to 3-2-11/9.7.3(e) TABLE 4, but need not extend over the joint flange for the head. Bracket toes at the deck are to be suitably supported.

iii) For other configurations, loads according to 3-2-11/9.7.2 are to be applied, and means of support determined in order to comply with the requirements above. Brackets, where fitted, are to be of suitable thickness and length according to their height.

iv) Final (gross) pipe thickness is not to be taken less than as indicated in 4-6-4/9.3.2 and 4-6-4/9.5.6

v) The minimum internal diameter of the air pipe or overflow is not to be less than 65 mm.

9.7.3(c) Ventilators

i) For standard ventilators of 900 mm (35.4 in.) height closed by heads of not more than the tabulated projected area, pipe thicknesses and bracket heights are specified in 3-2-11/9.7.3(e) TABLE 5. Brackets, where required, are to be as specified in 3-2-11/9.7.3(b).ii.

ii) For ventilators of height greater than 900 mm (35.4 in.), brackets or alternative means of support are to be provided. Coaming is not to be taken less than as indicated in 3-2-11/9.3 nor in 3-2-11/9.7.3(e) TABLE 4.

9.7.3(d) Components and Connections.
All component parts and connections of the tank vents and overflows or ventilators are to be capable of withstanding the loads defined in 3-2-11/9.7.2.

9.7.3(e) Rotary Heads.
Rotating type mushroom ventilator heads are not to be used for application in this location.

---

**TABLE 4**

760 mm (30 in.) High Tank Vents and Overflows Thickness and Bracket Standards (1 January 2004)

<table>
<thead>
<tr>
<th>Nominal Pipe Size</th>
<th>Minimum Fitted Gross Thickness</th>
<th>Maximum Projected Area of Head</th>
<th>Height (in.) of Brackets</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>mm</td>
</tr>
<tr>
<td>65</td>
<td>2 1/2</td>
<td>6.0</td>
<td>---</td>
</tr>
<tr>
<td>80</td>
<td>3</td>
<td>6.3</td>
<td>0.25</td>
</tr>
<tr>
<td>100</td>
<td>4</td>
<td>7.0</td>
<td>0.28</td>
</tr>
<tr>
<td>125</td>
<td>5</td>
<td>7.8</td>
<td>0.31</td>
</tr>
<tr>
<td>150</td>
<td>6</td>
<td>8.5</td>
<td>0.33</td>
</tr>
</tbody>
</table>

---
### TABLE 5
900 mm (35.4 in.) High Ventilator Thickness and Bracket Standards (1 January 2004)

<table>
<thead>
<tr>
<th>Nominal Pipe Size</th>
<th>Minimum Fitted Gross Thickness</th>
<th>Maximum Projected Area of Head</th>
<th>Height (^{(1)}) of Brackets</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
<td>cm(^2)</td>
<td>mm</td>
</tr>
<tr>
<td>mm</td>
<td>in.</td>
<td>in.</td>
<td>mm</td>
</tr>
<tr>
<td>80</td>
<td>3</td>
<td>6.3</td>
<td>0.25</td>
</tr>
<tr>
<td>100</td>
<td>4</td>
<td>7.0</td>
<td>0.28</td>
</tr>
<tr>
<td>150</td>
<td>6</td>
<td>8.5</td>
<td>0.33</td>
</tr>
<tr>
<td>200</td>
<td>8</td>
<td>8.5</td>
<td>0.33</td>
</tr>
<tr>
<td>250</td>
<td>10</td>
<td>8.5</td>
<td>0.33</td>
</tr>
<tr>
<td>300</td>
<td>12</td>
<td>8.5</td>
<td>0.33</td>
</tr>
<tr>
<td>350</td>
<td>14</td>
<td>8.5</td>
<td>0.33</td>
</tr>
<tr>
<td>400</td>
<td>16</td>
<td>8.5</td>
<td>0.33</td>
</tr>
<tr>
<td>450</td>
<td>18</td>
<td>8.5</td>
<td>0.33</td>
</tr>
<tr>
<td>500</td>
<td>20</td>
<td>8.5</td>
<td>0.33</td>
</tr>
</tbody>
</table>

Notes:

i. Brackets [see 3-2-11/9.7.3(b)] need not extend over the joint flange for the head.

ii. Brackets are required where the as fitted (gross) thickness is less than 10.5 mm (0.41 in.), or where the tabulated projected head area is exceeded.

Note: For other ventilator heights, the relevant requirements of 3-2-11/9.7.3 are to be applied.
CHAPTER 2
Hull Structures and Arrangements

SECTION 12
Protective Coatings

1 General
The extent, type, and amount of coating are to be specified by the Naval Administration. No final painting or coating is to be performed until all surveys and testing have been completed. All areas not being coated are to be protected during painting, and upon completion of the work any paint accidentally applied to the areas are to be removed.

3 Preparation
Surfaces that are to be painted are to be completely free of rust, loose paint, dirt, scale, oil, grease, salt deposits, and moisture. Protective coatings are to be applied as soon as practical after cleaning before corrosion or soil forms on the cleaned surface.

If more than seven days elapse between epoxy coats, the surface is to be cleaned prior to an application of a tack coat (1-2 wet mils) before the application of the next full coat.

5 Protection of Steel

5.1 Preparation
All steel surfaces that will be coated are to be abrasive blast cleaned. Prior to abrasive blast cleaning, surfaces contaminated with oil or grease are to be cleaned and weld splatters, slag, and flux compounds are to be removed by grinding, sanding, or chipping. In areas where abrasive blasting is not feasible, the surfaces are to be cleaned by mechanical means to remove foreign matter.

Galvanized steels are to be roughened with a light abrasive blast or by mechanical means prior to painting.

5.3 All Spaces (2023)
Unless otherwise approved, all steel surfaces are to be suitably coated with paint and/or cathodic protection, as applicable. For guidance, the ABS Guidance Notes on Cathodic Protection of Ships and the ABS Guidance Notes on the Application and Inspection of Marine Coating Systems may be referred to.

5.5 Salt Water Ballast Space
Tanks or holds for salt water ballast are to have a corrosion-resistant hard type coating such as epoxy or zinc on all structural surfaces. Where a long retention of salt water is expected due to the type of vessel or unit, special consideration for the use of inhibitors or sacrificial anodes may be given.

PART 3
ABS RULES FOR BUILDING AND CLASSING LIGHT WARSHIPS, PATROL AND HIGH-SPEED NAVAL VESSELS • 2023
5.7 Oil Spaces
Tanks intended for oil need not be coated.

5.9 Integral Tanks for Urea Based Ammonia Solution as SCR Reductants (2020)
Where urea based ammonia solution (e.g., 40%/60% urea/water solution) used for reducing NOx as SCR Reductants is stored in integral tanks, these tanks are to be coated with appropriate anti-corrosion coating recommended by a coating manufacturer as compatible with the solution. In no case is a reduction in scantlings in association with protective coatings is to be considered. See also Part 6, Chapter 3 of the Marine Vessel Rules.

7 Protection of Aluminum

7.1 General
Aluminum alloys intended for hull construction are to be used generally only under conditions that will not induce excessive corrosion. Where exposure to environment that would induce excessive corrosion is expected, suitable coatings, tapes, sacrificial anodes, impressed-current systems or other corrosion prevention measures are to be used. When tapes are used for corrosion protection, they are to be non-wicking and non-water absorbing. Grease containing graphite is not to be used with aluminum, instead, zinc or other suitable base grease is to be used.

7.3 Preparation
All aluminum surfaces that will be coated are to be thoroughly cleaned to bare metal, free of corrosion products, dirt, and other contaminants, by light abrasive blasting. Spot cleaning after blasting can be done by power brushing or orbital sanding.

7.5 Coatings
Coatings are to be applied in accordance with the manufacturer’s instructions, and are to be preceded by appropriate cleaning and possibly chemical conversion of surfaces as may be required in accordance with the manufacturer’s recommendations. Coatings are to be free from voids, scratches or other imperfections that are potential sites for localized corrosion.

The composition of coatings is to be compatible with aluminum. Coatings containing copper, lead, mercury or other metals that can induce galvanic or other forms of corrosion are not to be used. Zinc chromate coatings may be used. Insulating coatings intended to prevent galvanic corrosion are not to contain graphite or other conducting materials.

7.7 Faying Surfaces – Aluminum to Aluminum
Aluminum faying surfaces that will be exposed to weather, seawater, or other corrosive environment are to be suitable coated to minimize crevice corrosion in way of the faying surfaces.

7.9 Faying Surface between Aluminum and Other Metals
7.9.1 Hull
Suitable means are to be taken to avoid direct contact of faying surfaces of aluminum to other metals. When such faying surfaces occur in hull construction, suitable non-wicking and non-water absorbing insulation tapes or coatings are to be used. Faying surfaces between mechanically fastened metal components, except machinery foundations, are to be protected by the use of bedding compounds or adhesives. Other types of joints between aluminum and other metals may be approved in certain applications.

7.9.2 Piping
Suitable means, such as special pipe hangers, are to be used to avoid conductive connections between aluminum hulls and non-aluminum metal piping systems. Where watertightness is
required, such as when piping passes through bulkheads, decks, tanktops, and shell, special fittings will be required to maintain isolation between dissimilar metals.

7.9.3 Bearing Areas
Bearing areas such as engine beds, pump foundations, propeller shafts, rudder and other appendages of metals other than aluminum are to be suitably isolated by such means as non-metallic bearing casing, non-conductive packing (not containing graphite or other conductors) or suitable tapes and coatings. Alternative methods for minimizing corrosion at these locations will be specially considered. Wicking-type tapes or water-absorbing packing materials such as canvas are to not be used. The metals used for such applications are to be selected to minimize galvanic effects; stainless steels are to be considered. The use of copper-base alloys such as brass or bronze is generally not recommended where galvanic corrosion is of concern, and these materials may only be used when specially approved. In those cases where the use of dissimilar metals cannot be avoided, or where galvanic corrosion is of concern, such as in wet tanks, a suitable sacrificial anode or impressed current system is to be installed.

7.11 Faying Surface between Aluminum and Non-metals
Aluminum in contact with wood or insulating-type material is to be protected from the corrosive effects of the impurities in these materials by a suitable coating or covering. Concrete used with aluminum is to be free of additives for cold weather pouring. Preformed glass insulation is recommended for piping insulation. Any adhesives which may be used to connect insulation to aluminum are to be free of agents that would be corrosive to aluminum. Foaming agents harmful to aluminum, such as Freon, are not to be used for insulating foams. Areas where dirt or soot is likely to collect and remain for prolonged periods are to be protected from pitting corrosion by the use of coatings or other suitable means.

7.13 Corrosion of Wet Spaces
Suitable means are to be used to avoid arrangements that could induce crevice corrosion in wet spaces. In bilge spaces, chain lockers, and similar locations where exfoliation corrosion may be of concern, appropriate materials suitably heat treated for resistance to this form of corrosion are to be employed.

7.15 Service at Elevated Temperatures
For service temperatures of 66°C (150°F) or above, only aluminum alloys and filler metals specially designated for service at these temperatures are to be used.

7.17 Cathodic Protection for Corrosion Prevention
For application where corrosion is of concern, consideration is to be given to the use of sacrificial anode or impressed current systems of corrosion control. Details of sacrificial anodes and arrangements are to be submitted for review. Anodes are to be in accordance with ASTM or other recognized standard, as specified by the Naval Administration. When impressed current systems are used, adequate precautions are to be taken that the negative voltage is not excessive.

7.19 Stray Current Protection
Precautions are to be taken when in dock to prevent stray currents from welding power or other sources from adversely affecting the aluminum. Whenever possible, the cathodic protection system of the vessel is to be in place and operating when the vessel is in the water. AC power sources are to be insulated from the hull. For battery and other DC power sources, grounding is to be avoided if possible. Where safety considerations require grounding to the hull, the negative pole is to be connected to the hull.

7.21 Bi-material Joints
Such joints, when used, may be required to be appropriately painted, coated, wrapped or protected by other methods to prevent galvanic corrosion. Where aluminum is to be joined to other materials, each faying surface is to be suitably coated to minimize corrosion. In addition, when one or both sides of an aluminum
or steel connection to dissimilar metal joints are exposed to weather, sea water, or wet spaces, a minimum of 0.5 mm (0.02 in.) of suitable insulation is to be installed between faying surfaces and extended beyond the edge of the joint. Non-welded oil or water stops are to be of plastic insulation tape or equivalent which would provide a suitably corrosion resistant system. Insulating materials are to be non-porous and have mechanical properties suitable for the application.

9 Protection of Fiber Reinforced Plastic

9.1 General
Cured gel-coat resins and lay-up resin are to be highly resistant to water and other liquid absorption; appropriate materials, lay-up, and lay-up procedures are to be used and manufacturer’s recommendations followed to attain this. Care is to be taken in the use of laminates containing carbon fibers so that they are not close to or do not induce galvanic corrosion with metal fittings.

9.3 Preparation
Composite surfaces that are not coated in the mold are to be sanded lightly to remove any foreign matter. Care is to be taken not to expose any of the structural glass. Surfaces are to be cleaned with water and solvent to remove residual mold release compound, oil, or grease.

9.5 Tanks
In water, fuel oil, or other approved tanks, the resins used are to be compatible with the contents of the tanks; the contents of the tanks are not to affect the cured properties of the tank laminate. The cured laminate is to be highly resistant to absorption of the liquid, and is not to have harmful, deleterious, or undesirable effects on the contents of the tank. The tank is generally to be gel-coated on the inside. See also 3-2-5/5.1.

9.7 Cathodic Protection
Cathodic protection is to be provided where shaft struts, propeller shafts, propellers, rudders, fittings, etc. are constructed of manganese bronze, brass, stainless steel or mild steel. Details of the sacrificial anodes and arrangements are to be submitted for review. Anodes are to be in accordance with ASTM or other recognized standard, as specified by the Naval Administration.
Fillet Welds

1.1 General (1 July 2015)

Fillet welds may be made by an approved manual, semi-automatic or automatic process. The sizes of fillet welds are subject to approval in each case, and are to be indicated on detail drawings or on a separate welding schedule. The Naval Administration may specify a greater extent of continuous welding. Consideration will also be given to a lesser extent of continuous welding when specified by the Naval Administration. When terminating an aluminum weld, either continuous or intermittent, crater filling by back stepping is recommended to provide a sound ending for each fillet.

For all welds in ballast tanks required to be in compliance with the IMO PSPC and/or IMO PSPC-COT Regulations, continuous welding is to be adopted.

1.3 Tee Connections

In general, the required size and spacing of the fillets is to be as given in 3-2-13/1.5. Special consideration will be given where there is a substantial difference between the thickness of members being connected. Where the opening between members exceeds 1.0 mm (0.04 in.) and is not greater than 5 mm (0.1875 in.), the size of the fillets is to be increased by the amount of the opening. Spacing between plates forming tee joints is not to exceed 5 mm (0.1875 in.).

1.5 Fillet Sizes and Spacing

Tee connections are to be formed by continuous or intermittent fillet welds on each side, the leg size, \( w \), of the fillet welds is to be obtained from the following equations:

\[
w = t_p \times C \times \frac{s}{\ell} + 1.5 \text{ mm}
\]

\[
w = t_p \times C \times \frac{s}{\ell} + 0.06 \text{ in.}
\]

where

- \( w \) = size of the weld leg, in mm (in.)
- \( \ell \) = actual length of the weld fillet, clear of crater, in mm (in.). See 3-2-13/5 FIGURE 1
- \( s \) = distance between centers of weld fillets, in mm (in.). See 3-2-13/5 FIGURE 1
thickness of the thinner of the two members being joined, in mm (in.)

w is not to be taken less than 0.3t\textsubscript{p} or 3.5 mm (0.14 in.), whichever is greater.

The throat thickness of the fillet is to be not less than 0.7w.

In calculating weld factors, the leg length of matched fillet weld is to be taken as the designated leg length or 0.7t\textsubscript{p} + 2.0 mm (0.7t\textsubscript{p} + 0.08 in.), whichever is less.

Where it is intended to use continuous fillet welding, the leg size of fillet welds is to be obtained from the above equations taking s/\ell equal to 1.

For intermittent welding with plate thickness less than 7 mm (0.28 in.) welds are to be staggered.

1.7 Thin Plating

For plating of 6.5 mm (0.25 in.) or less, the requirements of 3-2-13/1.5 may be modified as follows:

\[ W = t_{p\ell} \times C \times \frac{s}{\ell} + 2.0[1.25 - (\ell/s)] \text{ mm} \]

\[ W = t_{p\ell} \times C \times \frac{s}{\ell} + 0.08[1.25 - (\ell/s)] \text{ in.} \]

\[ W_{\text{min}} = 3.5 \text{ mm (0.14 in.)} \]

For plates less than 4.5 mm (0.1875 in.), welds less than required above will be considered when requested by the Naval Administration depending upon the location and quality control procedure.

1.9 Length and Arrangement of fillet

Where an intermittent weld is permitted by 3-2-13/5 TABLE 1, the length of each fillet weld is to be not less than 75 mm (3 in.) for t\textsubscript{p\ell} of 7 mm (0.28 in.) or more, nor less than 65 mm (2.5 in.) for lesser t\textsubscript{p\ell}.

The unwelded length is to be not more than 32t\textsubscript{p\ell}.

1.11 Fillet Weld Arrangements

1.11.1 Intersections

Where beams, stiffeners, frames, etc., are intermittently welded and pass through slotted girders, shelves or stringers, there is to be a pair of matched intermittent welds on each side of each such intersection and the beams, stiffeners and frames are to be efficiently attached to the girders, shelves and stringers. The length of the matched intermittent fillet welds is to be 0.125 times the lspan or 100 mm (4 in.), whichever is greater.

1.11.2 Unbracketed End Attachments

Unbracketed beams, frames, etc., and stiffeners of watertight and tank bulkheads and superstructure and house fronts are to have double continuous welds for length at each end equal to the depth of the member but not less than 0.125 times the span or 100 mm (4 in.), whichever is greater.

1.11.3 Bracketed End Attachments

Frames, beams, stiffeners etc., are to be lapped onto the bracket a length not less than 1.5 times the depth of the member, and are to have continuous fillet welds all around. Lapped end connections of longitudinal strength members are also to have a throat size, \(t\), such that the total effective area of the lap welding is not less than the area of the member being attached.
1.11.4 Lapped Joints (2021)

Lapped joints are typically not to be used in structural applications or on plates greater than 6 mm (0.25 in.) thick, unless specially approved.

Lapped joints are generally to have a width of overlap not less than twice the thickness of thinner plate plus 25 mm (1 in.) with welds on both edges of the sizes required by 3-2-13/1.5.

In general, overlaps of collar plates in way of pipe penetrations through watertight boundaries are not to be less than 30 mm (1.2 in.) in width for pipes with Nominal Diameter (ND) up to 100 mm (4.0 in.), and need not exceed 50 mm (2.0 in.) in width for pipes with ND over 550 mm (21.7 in.). Intermediate widths may be obtained by interpolation for pipes with ND between 100 (4.0 in.) and 550 mm (21.7 in.), but an average value of 40 mm (1.6 in.) is considered acceptable.

The collar plate is to be equal to, or greater than, the thickness of the watertight boundary plate penetrated, of equivalent material, and continuously welded in accordance with 3-2-13/Table 1 for the boundaries of deep tank or watertight bulkheads.

On a case-by-case basis, strength verification is to be carried out for pipe penetrations in areas of high stress concentration such as an area close to a large bracket toe, a cluster of pipe penetrations or a hatch corner.

1.11.5 Plug Welds or Slot Welds

Plug welds or slot welds are to be specially approved for particular applications. When approved, an appropriate demonstration that adequate weld penetration and soundness is achieved is to be made to the Surveyor’s satisfaction. When used in the attachment of doublers and similar applications, plug or slot welds may be spaced at 16 times the doubler thickness, but not more than 300 mm (12 in.) between centers in both directions. In general, elongated slot welds are recommended. For closing plates on rudders, slots are to be 75 mm (3 in.) in length spaced at 150 mm (6 in.) between centers. The periphery of the plugs or slots are to be fillet welded, of fillet size, \( w \), generally not less than 0.70 times the plate thickness. Plugs and slots are not to be filled with welded deposit.

3 Bi-material Joints

Techniques required for joining two different materials will be subject to special consideration. The use of explosion bonding may be considered depending on the application and the mechanical and corrosive properties of the joint.

5 Alternatives

The foregoing are considered minimum requirements for welding in hull construction, but alternative methods, arrangements and details will be considered for approval.
### FIGURE 1

![Diagram of weld factors with labels for leg size and throat size.]

### TABLE 1

**Weld Factor $C$**

<table>
<thead>
<tr>
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<td>Hull Structures and Arrangements</td>
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<tr>
<td>Section</td>
<td>Welding, Forming and Weld Design</td>
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<table>
<thead>
<tr>
<th>Description</th>
<th>Aluminum</th>
<th>Steel</th>
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<tbody>
<tr>
<td><strong>Floors, Bottom Transverses, and Bottom Longitudinal Girders to Shell</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At Bottom forward $3L/8$,</td>
<td>0.25 DC</td>
<td>0.25 DC</td>
</tr>
<tr>
<td>At Bottom forward $L/4$, $V \leq 25$ knots</td>
<td>0.18 DC</td>
<td>0.16 DC</td>
</tr>
<tr>
<td>In way of propellers and shaft struts</td>
<td>0.25 DC</td>
<td>0.25 DC</td>
</tr>
<tr>
<td>In machinery space</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>Elsewhere</td>
<td>0.16</td>
<td>0.14</td>
</tr>
<tr>
<td><strong>Floors, Bottom Transverses and Bottom Longitudinal Girders to Inner Bottom or Face Bar</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In machinery space</td>
<td>0.25 DC</td>
<td>0.25 DC</td>
</tr>
<tr>
<td>To Inner bottom elsewhere</td>
<td>0.14</td>
<td>0.12</td>
</tr>
<tr>
<td>To face plate elsewhere</td>
<td>0.14</td>
<td>0.12</td>
</tr>
<tr>
<td><strong>Floors and Bottom Transverse to Bottom Girders</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$0.30$ DC</td>
<td></td>
<td></td>
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<tr>
<td><strong>Bottom Girders to Bulkheads and Deep Transverses or Floors</strong></td>
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</tr>
<tr>
<td>$0.30$ DC</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>End Attachments</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$0.50$ DC</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Longitudinals to Shell (including frames on transversely framed vessels)</strong></td>
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<td></td>
</tr>
<tr>
<td>Bottom and side forward $3L/8$, $V &gt; 25$ knots</td>
<td>0.25 DC</td>
<td>0.25 DC</td>
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<tr>
<td>Bottom and side forward $L/4$, $V \leq 25$ knots</td>
<td>0.18 DC</td>
<td>0.16 DC</td>
</tr>
<tr>
<td>In way of propellers and shaft struts</td>
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<td>0.25 DC</td>
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<tr>
<td>Elsewhere</td>
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</tr>
<tr>
<td><strong>End Attachments</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$0.50$ DC</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Side, Deck, and Bulkhead Girders, Transverses and Stringers</strong></td>
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<td></td>
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<tr>
<td>To Shell $3L/8$, $V &gt; 25$ knots</td>
<td>0.18 DC</td>
<td>0.16 DC</td>
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<tr>
<td>To Shell Forward $L/4$, $\leq 25$ knots</td>
<td>0.16 DC</td>
<td>0.14 DC</td>
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$w =$ leg size in mm (in.)  
$t =$ throat size in mm (in.)
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<tr>
<td>Section</td>
<td>13 Welding, Forming and Weld Design</td>
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<tr>
<td>To Deck and Bulkheads In way of Tanks</td>
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<td>0.16</td>
</tr>
<tr>
<td>To Face Bar</td>
<td>0.14</td>
<td>0.12</td>
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<tr>
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<p>| Beams, Longitudinals, and Stiffeners |</p>
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<td>To Face Bar</td>
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<tr>
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<p>| Bulkheads and Tank Boundaries |</p>
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</tr>
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<td>Tank</td>
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<tr>
<td>Diaphragms to Side Plating</td>
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<tr>
<td>Vertical Diaphragms to Horizontal Diaphragms, clear of Mainpiece</td>
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<tr>
<td>Horizontal Diaphragm to Vertical</td>
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<tr>
<td>Mainpiece Diaphragm</td>
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<tbody>
<tr>
<td>Shaft Brackets to boss and doubler</td>
<td>Full Penetration</td>
<td>Full Penetration</td>
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DC = double continuous
Chapter 2
Hull Structures and Arrangements

Appendix 1
Guidelines for Calculating Bending Moment and Shear Force in Rudders and Rudder Stocks

1. Application

Bending moments, shear forces and reaction forces of rudders, stocks and bearings may be calculated according to this Appendix for the types of rudders indicated. Moments and forces on rudders of different types or shapes than those shown are to be calculated using alternative methods and will be specially considered.


3.1 Rudder

3.1.1 Shear Force (2020)

For regular spade rudders as shown in 3-2-A1/3 FIGURE 1(a), the shear force, \( V(z) \), at a horizontal section of the rudder above baseline is given by the following equation:

\[
V(z) = \frac{z C_R}{A} \left[ c_\ell + \frac{z}{2 \ell_R} (c_u - c_\ell) \right] \text{kN (tf, Ltf)}
\]

where

- \( z \) = distance from the rudder baseline to the horizontal section under consideration, in m (ft)
- \( C_R \) = rudder force, as defined in 3-2-8/3, in kN (tf, Ltf)
- \( A \) = total projected area of rudder blade in m\(^2\) (ft\(^2\)), as defined in 3-2-8/3
- \( c_\ell, c_u \) and \( \ell_R \) are dimensions as indicated in 3-2-A1/3 FIGURE 1(a), in m (ft).

For spade rudders with embedded rudder trunks let deep in the rudder blade, as shown in 3-2-A1/3 FIGURE 1(b), the shear forces at rudder horizontal sections above rudder baseline in areas \( A_1 \) and \( A_2 \), are given by the following equations:
\[ V(z')_1 = \frac{z' C_{R1}}{A_1} \left[ c_u - \frac{z'}{2 \ell} (c_u - c_b) \right] \quad \text{kN (tf, Ltf), over area } A_1 \]

\[ V(z)_2 = \frac{z C_{R2}}{A_2} \left[ c_\ell + \frac{z}{2 \ell_b} (c_b - c_\ell) \right] \quad \text{kN (tf, Ltf), over area } A_2 \]

Where

\[ z' = \ell_R - z \]

\[ C_{R1} = \text{rudder force over rudder area } A_1, \text{ in kN (tf, Ltf)} \]

\[ = \frac{A_1}{A} C_R \]

\[ C_{R2} = \text{rudder force over rudder area } A_2, \text{ in kN (tf, Ltf)} \]

\[ = \frac{A_2}{A} C_R \]

\[ A_1 = \text{partial rudder blade area above neck bearing and below rudder top, in mm}^2 \text{ (ft}^2) \]

\[ A_2 = \text{partial rudder blade area above rudder baseline and below neck bearing, in mm}^2 \text{ (ft}^2) \]

\[ c_\ell, c_b, c_u, \ell_u, \text{ and } \ell_b \text{ are dimensions as illustrated in 3-2-A1/3 Figure 1(b).} \]

### 3.1.2 Bending Moment (2020)

For regular spade rudders, bending moment, \( M(z) \), at a horizontal section \( z \) meters (feet) above the baseline of the rudder is given by the following equations:

\[ M(z) = \frac{z^2 C_R}{2A} \left[ c_\ell + \frac{z}{3 \ell_b} (c_b - c_\ell) \right] \quad \text{kN \cdot m, (tf \cdot m, Ltf \cdot ft)} \]

For spade rudders with embedded rudder trunk, the bending moment at a horizontal section within area \( A_1 \) is obtained from the following:

\[ M(z')_1 = \frac{(z')^2 C_{R1}}{2A_1} \left[ c_u - \frac{z'}{2 \ell} (c_u - c_b) \right] \quad \text{kN \cdot m, (tf \cdot m, Ltf \cdot ft)} \]

With the maximum bending moment \( M_1 \) over area \( A_1 \) equals to:

\[ M_1 = C_{R1} \ell \left[ 1 - \frac{2c_b + c_u}{3(c_b + c_u)} \right] \quad \text{kN \cdot m, (tf \cdot m, Ltf \cdot ft)} \]

For spade rudders with embedded rudder trunk, the bending moment at a horizontal section within area \( A_2 \) is obtained from the following:

\[ M(z)_2 = \frac{z^2 C_{R2}}{2A_2} \left[ c_\ell + \frac{z}{3 \ell_b} (c_b - c_\ell) \right] \quad \text{kN \cdot m, (tf \cdot m, Ltf \cdot ft)} \]

With the maximum bending moment \( M_2 \) over area \( A_2 \) equals to:

\[ M_2 = C_{R2} \ell_b \left[ \frac{2c_\ell + c_b}{3(c_\ell + c_b)} \right] \quad \text{kN \cdot m, (tf \cdot m, Ltf \cdot ft)} \]
where $z$, $z'$, $C_{R1}$, $C_{R2}$, $A_1$, $A_2$, $c_\ell$, $c_u$ and $\ell_R$ are as defined in 3-2-A1/3.1.1.

### 3.3 Lower Stock

#### 3.3.1 Shear Force

For regular spade rudder, the shear force, $V_\ell$, at any section of the lower stock between the top of the rudder and the neck bearing is given by the following equation:

$$V_\ell = C_{R} \ kN(\text{tf}, \text{Ltf})$$

For spade rudder with embedded rudder trunk, the shear force at any section of the stock between the top of the rudder and the neck bearing is given by the following equation:

$$V_\ell = \frac{M_2 - M_1}{\ell_u + \ell_\ell} \ kN(\text{tf}, \text{Ltf})$$

where $C_R$, $\ell_\ell$, and $\ell_u$ are as defined in 3-2-A1/3.1.1.

#### 3.3.2 Bending Moment at Neck Bearing (2017)

For regular spade rudder, the bending moment in the rudder stock at the neck bearing, $M_n$, is given by the following equation:

$$M_n = C_{R} \left[ \ell_\ell + \frac{\ell_R(2c_\ell + c_u)}{3(c_\ell + c_u)} \right] \ kN - m(\text{tf} - \text{m}, \text{Ltf} - \text{ft})$$

where

$$C_{R} = \text{rudder force as defined in 3-2-8/3}$$

$c_\ell$, $c_u$, $\ell_\ell$, and $\ell_R$ are dimensions as indicated in 3-2-A1/Figure 1, in m (ft).

For spade rudder with embedded rudder trunk, the bending moment in the stock at the neck bearing is given by the following equation:

$$M_n = M_2 - M_1 \ kN - m(\text{tf} - \text{m}, \text{Ltf} - \text{ft})$$

where $M_1$ and $M_2$ are as defined in 3-2-A1/3.1.2.

Where partial submergence of the rudder leads to a higher bending moment in the rudder stock at the neck bearing (compared with the fully submerged condition), $M_n$ is to be calculated based on the most severe partially submerged condition.

### 3.5 Moment at Top of Upper Stock Taper

For regular spade rudder, the bending moment in the upper rudder stock at the top of the taper, $M_t$, is given by the following equation:

$$M_t = C_{R} \left[ \ell_\ell + \frac{\ell_R(2c_\ell + c_u)}{3(c_\ell + c_u)} \right] \times \left[ \frac{\ell_u + \ell_R + \ell_\ell - z_t}{\ell_u} \right] \ kN - m(\text{tf} - \text{m}, \text{Ltf} - \text{ft})$$

For spade rudder with embedded rudder trunk, the bending moment in the upper rudder stock at the top of the taper is given by the following equation:

$$M_t = M_R \left[ \frac{\ell_R + \ell_u - z_t}{\ell_u} \right] \ kN - m(\text{tf} - \text{m}, \text{Ltf} - \text{ft})$$
where

\[ z_t = \text{distance from the rudder baseline to the top of the upper rudder stock taper in m (ft)} \]
\[ C_R = \text{rudder force, as defined in 3-2-A1/3.1.1} \]
\[ M_R = \text{is the greater of } M_1 \text{ and } M_2, \text{ as defined in 3-2-A1/3.1.2} \]

\( c_c, c_u, \ell_c, \) and \( \ell_R \) are dimensions as indicated in 3-2-A1/Figure 1, in m (ft).

### 3.7 Bearing Reaction Forces

For regular spade rudder, the reaction forces at the bearings are given by the following equations:

\[ P_u = \text{reaction force at the upper bearing} \]
\[ = \frac{-M_n}{\ell_u} \text{kN(tf, Ltf)} \]
\[ P_n = \text{reaction force at the neck bearing} \]
\[ = C_R + \frac{M_n}{\ell_u} \text{kN(tf, Ltf)} \]

For spade rudder with embedded rudder trunk, the reaction forces at the bearings are given by the following equations:

\[ P_u = \frac{-M_n}{\ell_u + \ell_f} \text{kN(tf, Ltf)} \]
\[ P_n = C_R + P_u \text{kN(tf,Ltf)} \]

where

\[ M_n = \text{bending moment at the neck bearing, as defined in 3-2-A1/3.3.2} \]
\[ C_R = \text{rudder force, as defined in 3-2-8/3} \]

\( \ell_u \) is as indicated in 3-2-A1/Figure 1, in m (ft).
FIGURE 1(a)
Spade Rudder (2014)

(a) Regular Spade Rudder

FIGURE 1(b)
Spade Rudder (2014)

(b) Spade Rudder with Embedded Rudder Trunk
5. Rudders Supported by Shoepiece (2009)

5.1 Shear Force, Bending Moment and Reaction Forces

Shear force, bending moment and reaction forces may be calculated according to the model given in 3-2-A1/5.1 FIGURE 2.

\[ w_R = \text{rudder load per unit length} \]
\[ = \frac{C_R}{\ell_R} \text{ kN/m (tf/m, Ltf/ft)} \]

Where

\[ C_R = \text{rudder force, as defined in} \]
\[ k_s = \text{spring constant reflecting support of the shoepiece} \]
\[ = \frac{n_s I_s}{\ell_s^3} \text{ kN/m (tf/m, Ltf/ft)} \]

\[ n_s = 6.18 \text{ (0.630, 279)} \]
\[ I_s = \text{moment of inertia of shoepiece about the vertical axis, in cm}^4 \text{ (in}^4) \]

\[ \ell_P, \ell_s, \ell_R, \text{ and } \ell_u \text{ are dimensions as indicated in 3-2-A1/5.1 FIGURE 2, in m (ft).} \]
Shear Force, Bending Moment and Reaction Forces

Shear force, bending moment and reaction forces are to be assessed by the simplified beam model shown in 3-2-A1/7.1 FIGURE 3.

\[ W_{R1} = \frac{C_{R1}}{\ell_{R1}} \text{kN/m (tf/m, Ltf/ft)} \]

\[ W_{R2} = \frac{C_{R2}}{\ell_{R2}} \text{kN/m (tf/m, Ltf/ft)} \]

where

\[ C_{R1} = \text{rudder force, as defined in 3-2-8/3.3} \]

\[ C_{R2} = \text{rudder force, as defined in 3-2-8/3.3} \]

\[ k_h = \text{spring constant reflecting support of the horn} \]

\[ = \frac{1}{n_b n_t a^2} \text{kN/m (tf/m, Ltf/ft)} \]

\[ n_b = 4.75 (0.485, 215) \]

\[ n_t = 3.17 (0.323, 143) \]

\[ a = \text{mean area enclosed by the outside lines of the rudder horn, in cm}^2 \text{ (in}^2) \]

\[ s_i = \text{the girth length of each segment of the horn of thickness } t_i, \text{ in cm (in.)} \]

\[ t_i = \text{the thickness of each segment of horn outer shell of length } s_i, \text{ in cm (in.)} \]

\[ l_h = \text{moment of inertia of horn section at } \ell_h \text{ about the longitudinal axis, in cm}^4 \text{ (in}^4) \]

\[ e, \ell_{b}, \ell_{R1} \text{ and } \ell_{R2} \] are dimensions as indicated in 3-2-A1/7.1 FIGURE 3, in m (ft).
Shear force, bending moment and reaction forces are to be assessed by the simplified beam model shown in 3-2-A1/9.1 FIGURE 4.

\[ w_{R1} = \frac{C_{R1}}{\epsilon_{R1}} \text{ kN/m (tf/m, Ltf/ft)} \]

\[ w_{R2} = \frac{C_{R2}}{\epsilon_{R2}} \text{ kN/m (tf/m, Ltf/ft)} \]

where

\[ C_{R1} = \text{rudder force, as defined in 3-2-11/3.3} \]

\[ C_{R2} = \text{rudder force, as defined in 3-2-11/3.3} \]
ℓ_{R1} and ℓ_{R2} are dimensions as indicated in 3-2-A1/9.1 FIGURE 4, in m (ft).

In 3-2-A1/9.1 FIGURE 4 the variables \( K_{11}, K_{22}, K_{12} \) are rudder horn compliance constants calculated for rudder horn with 2-conjugate elastic supports. The 2-conjugate elastic supports are defined in terms of horizontal displacements, \( y_i \), by the following equations:

- At the lower rudder horn bearing:
  \[ y_1 = -K_{12}B_2 - K_{22}B_1 \text{ m (ft)} \]

- At the upper rudder horn bearing:
  \[ y_2 = -K_{11}B_2 - K_{12}B_1 \text{ m (ft)} \]

where

\( y_1, y_2 \) = horizontal displacement at lower and upper rudder horn bearings, respectively

\( B_1, B_2 \) = horizontal support force, in kN (tf, Ltf), at lower and upper rudder horn bearings, respectively

\( K_{11}, K_{22}, K_{12} \) = spring constant of the rudder support obtained from the following:

\[
K_{11} = m \left[ 1.3 \frac{\lambda^3}{3EJ_{1h}} + \frac{\lambda}{6J_{1h}} + \frac{\lambda^2 (d - \lambda)}{2EJ_{1h}} + \frac{\lambda}{6J_{1h}} \right] \text{ m/kN (m/ft, ft/Ltf)}
\]

\[
K_{22} = m \left[ 1.3 \frac{\lambda^3}{3EJ_{1h}} + \frac{\lambda^2 (d - \lambda)}{2EJ_{1h}} + \frac{\lambda}{6J_{1h}} + \frac{(d - \lambda)^2}{2EJ_{2h}} + \frac{\lambda}{6J_{1h}} \right] \text{ m/kN (m/ft, ft/Ltf)}
\]

\[
K_{12} = m \left[ 1.3 \frac{\lambda^3}{3EJ_{1h}} + \frac{\lambda^2 (d - \lambda)}{2EJ_{1h}} + \frac{\lambda (d - \lambda)^2}{2EJ_{2h}} + \frac{(d - \lambda)^2}{2EJ_{2h}} + \frac{\lambda}{6J_{1h}} \right] \text{ m/kN (m/ft, ft/Ltf)}
\]

\( m = 1.00 \) (9.8067, 32.691)

\( d \) = height of the rudder horn, in m (ft), defined in 3-2-A1/9.1 FIGURE 4. This value is measured downwards from the upper rudder horn end, at the point of curvature transition, to the mid-line of the lower rudder horn pintle.

\( \lambda \) = length, in m (ft), as defined in 3-2-A1/9.1 FIGURE 4. This length is measured downwards from the upper rudder horn end, at the point of curvature transition, to the mid-line of the upper rudder horn bearing. For \( \lambda = 0 \), the above formulae converge to those of spring constant \( k_h \) for a rudder horn with 1-pintle (elastic support), and assuming a hollow cross section for this part.

\( e \) = rudder-horn torsion lever, in m (ft), as defined in 3-2-A1/9.1 FIGURE 4 (value taken at vertical location \( \ell_{th}/2 \)).

\( E \) = Young’s modulus of the material of the rudder horn in kN/m² (tf/m², Ltf/in²)

\( G \) = modulus of rigidity of the material of the rudder horn in kN/m² (tf/m², Ltf/in²)

\( J_{1h} \) = moment of inertia of rudder horn about the x axis, in m⁴ (ft⁴), for the region above the upper rudder horn bearing. Note that \( J_{1h} \) is an average value over the length \( \lambda \) (see 3-2-A1/9.1 FIGURE 4).

\( J_{2h} \) = moment of inertia of rudder horn about the x axis, in m⁴ (ft⁴), for the region between the upper and lower rudder horn bearings. Note that \( J_{2h} \) is an average value over the length \( d - \lambda \) (see 3-2-A1/9.1 FIGURE 4).

\( J_{th} \) = torsional stiffness factor of the rudder horn, in m⁴ (ft⁴)
for any thin wall closed section, in m\(^4\) (ft\(^4\))

Note that the \(J_{th}\) value is taken as an average value, valid over the rudder horn height.

\[ F_T = \text{mean of areas enclosed by outer and inner boundaries of the thin walled section of rudder horn, in m}^2 \text{ (ft}^2\text{)} \]

\[ u_i = \text{length, in mm (in.), of the individual plates forming the mean horn sectional area} \]

\[ t_i = \text{thickness, in mm (in.), of the individual plates mentioned above} \]

**FIGURE 4**

Rudder Supported by a Horn Arranged with Two Pintles (Supports) (1 July 2016)
APPENDIX 2

Guidance on Analysis of the Cross Deck Structure of a Multi-Hull Craft

Note: This Appendix gives guidance on the analysis of a standard cross deck structure (similar to 3-2-A2/FIGURE 1) of a multihulled craft. The analysis includes the determination of the craft’s transverse bending stress, transverse shear stress, and the torsional stress acting on each element. The analysis of cross decks that are of advanced design or material will be specially considered.

FIGURE 1
Typical Geometry of Centerline Section of Cross Deck

1 Transverse Bending and Shear Stress
The transverse bending and shear stress of the cross structure are obtained by the following equations and are less than the allowable stresses defined in 3-2-1/3.5.3:

\[
\sigma_t = \frac{10M_{tb}}{SM_t} \text{ N/mm}^2
\]
\[
\sigma_t = \frac{M_{tb}}{SM_t} \text{ psi}
\]
\[
\tau_a = \frac{10Q_t}{At} \text{ N/mm}^2
\]
\[
\tau_a = \frac{Q_t}{At} \text{ psi}
\]

where
\[ \sigma_t = \text{transverse bending stress of the cross deck structure, in N/mm}^2 \text{ (psi)} \]

\[ M_{tb} = \text{design transverse bending moment as defined in 3-2-1/3.3, in kN-m (ft-lbs)} \]

\[ SM_t = \text{offered transverse section modulus of the cross deck, in cm}^3 \text{m (in}^2\text{-ft)} \]

\[ \tau_a = \text{transverse shear stress of the cross deck structure, in N/mm}^2 \text{ (psi)} \]

\[ Q_t = \text{design vertical shear force as defined in 3-2-1/3.3, in kN (lbs)} \]

\[ A_t = \text{offered shear area of the cross structure, in cm}^2 \text{ (in}^2) \]

3 Center of Torsional Rotation

The center of torsional rotation of the cross deck structure can be determined by the following formula:

\[ L_c = \frac{\sum_{i=1}^{n} k_i x_i}{\sum_{i=1}^{n} k_i} \text{ cm (in.)} \]

where

\[ k_i = \text{element stiffness} \]

\[ = \frac{12000E_i l_i}{L_i^3} \text{ N/m} \]

\[ = \frac{12E_i l_i}{L_i^3} \text{ lbs/in} \]

\[ x_i = \text{longitudinal distance from forward perpendicular, in cm (in.)} \]

\[ n = \text{total number of elements in the cross deck structure} \]

\[ E = \text{modulus of elasticity of the material, for each element, kN/m}^2 \text{ (psi)} \]

\[ l_i = \text{moment of inertia of the element being considered, in m}^4 \text{ (in}^4) \]

\[ L_i = \text{span of cross structure, in m (in.), see 3-2-A2/3 FIGURE 2} \]

FIGURE 2
Span of Cross Structure
5 Maximum Bending Stress on Each Element

The maximum bending stress on each element is to be less than the allowable torsional stress defined in 3-2-1/3.5.3.

5.1 Deflection

The total amount that each element deflects can be determined by the following formula:

\[ \delta_i = \frac{100000M_{tt}x_{ci}}{\sum_{i=1}^{n}x_{ci}^2k_i} \text{ m} \]

\[ \delta_i = \frac{12M_{tt}x_{ci}}{\sum_{i=1}^{n}x_{ci}^2k_i} \text{ in.} \]

where

- \( \delta_i \) = deflection of each member, in m (in.)
- \( M_{tt} \) = design torsional moment acting upon the transverse structure connecting the hulls, as determined 3-2-1/3.3, in kN-m (ft-lbs)
- \( x_{ci} \) = \( x_i - L_c \), in cm (in.)
- \( x_{ci} \), \( L_c \) and \( k_i \) are as defined in 3-2-A2/1.

5.3 Bending Moment

The bending moment that is acting on each element is determined by the following formula:

\[ BM_i = \frac{P_iL_i}{2} \]

where

- \( BM_i \) = bending moment that is acting on the element under consideration, in N-m (in-lbs)
- \( P_i \) = \( \delta_i k_i \), force that is acting on the element, in N (lbs)
- \( L_i \) = as defined in 3-2-A2/1
- \( \delta_i \) = as defined in 3-2-A2/5.1
- \( k_i \) = as defined in 3-2-A2/1

5.5 Maximum Stress

The maximum stress that is applied on each element can be determined by the following formula:

\[ \sigma_i = \frac{1000BM_i}{SM_i} \text{ kN/m}^2 \]

\[ \sigma_i = \frac{BM_i}{SM_i} \text{ psi} \]

where
σ_i = maximum stress that is acting upon the element, in kN/m^2 (psi)

BM_i = bending moment as defined, in 3-2-A2/5.3

SM_i = section modulus of the element being considered, in cm^3 (in^3)

### 5.7 Maximum Shear Stress on Each Element

The maximum shear stress on each element is to be less than the allowable transverse shear stress defined in 3-2-1/3.5.3.

\[
\tau_i = \frac{10P_i}{A_{wi}} \text{ kN/m}^2
\]

\[
\tau_i = \frac{P_i}{A_{wi}} \text{ psi}
\]

where

\( \tau_i \) = maximum shear stress that is acting upon the element, in kN/m^2 (psi)

\( P_i \) = force acting upon the element, in N (lbs), as defined in 3-2-A2/5.3

\( A_{wi} \) = area of the web of the element being considered, in cm^2 (in^2)
Alternative Method for the Determination of “V” Shaft Strut Requirements

1 General

The method outlined below may be used as an alternative to the method given in 3-2-7/9. Other alternatives may be considered providing they address loadings from unbalanced centrifugal forces from the propeller, hydrodynamic forces, inertial forces from ship motions, gravity forces from shaft and propeller, and vibrations resulting from all intended conditions.
FIGURE 1
Strut Dimensions

3 Loads and Moments Acting on Strut

The governing loads and moments acting on the shaft strut are as follows:

\[ M_1 = c_1 d_p \left( \frac{W_p}{c_0} \frac{R}{1000} \right)^2 + c_2 H_p \]  
kN - m (tf - m, lbf - in)

\[ M_2 = c_3 S M_5 \sigma_{ys} \]  
kN-m (tf-m, in-lbf)

\[ F_3 = \frac{S M_5 \sigma_{ys}}{d_p} \]  
kN (tf, lbf)

where

\[ c_0 = 1 \ (1, 1000) \]
\[ c_1 = 0.138 \ (0.138, 3.5) \]
\[ c_2 = 0.454 \ (0.034, 3.0) \]
\[ c_3 = 3.0 \times 10^{-4} \ (3.0 \times 10^{-4}, 300) \]
\[ d_p = \] diameter of the propeller, in m (in.)
\[ W_p = \] weight of the propeller, in kN (tf, lbf)
\[ \ell_p = \] length of the overhang, in m (in.), see 3-2-A3/1 FIGURE 1
\[
R = \text{maximum rated RPM of the shaft}
\]
\[
H_p = \text{power at maximum rated speed, in kW (PS, hp)}
\]
\[
V = \text{maximum calm water speed of the vessel, in knots}
\]
\[
SM_s = \text{offered section modulus of the shaft, in cm}^3 \text{ (in}^3\text{)}
\]
\[
d_s = \text{offered diameter of the shaft, in mm (in.)}
\]
\[
\sigma_{ys} = \text{yield strength of the shaft, in N/cm}^2 \text{ (kgf/cm}^2\text{, psi)}
\]

5 **Required Section Modulus of Strut at the Barrel**

\[
SM_{st} = 1000C_1[M + F_3(\ell_b\sin\phi / 1000)]\sigma_y cm^3
\]

\[
SM_{st} = C_1(M + F_3\ell_b\sin\phi) / \sigma_y in^3
\]

\[
C_1\sqrt{(C_2/\sin\theta)^2 + (0.5/\cos\theta)^2}
\]

\[
C_2 = \left[2 - (\ell_b\ell_s) - (\ell_b\ell_s)^2\right] / \left[4\left[1 + (\ell_b\ell_s) + (\ell_b\ell_s)^2\right]\right]
\]

where

\[
M = \text{the greater of } M_1 \text{ or } M_2, \text{ as defined in 3-2-A3/3, in kN-m (in-lbf)}
\]

\[
\ell_b = \text{distance from center of strut barrel to the connection of the strut, in mm (in.), see 3-2-A3/1 FIGURE 1}
\]

\[
\phi = \text{cant angle of strut, in degrees, see 3-2-A3/1 FIGURE 1}
\]

\[
\sigma_y = \text{yield strength for steel struts or the welded yield strength of aluminum struts, in kN/mm}^2 \text{ (psi)}
\]

\[
\theta = \text{vee angle of strut in degrees, see 3-2-A3/1 FIGURE 1}
\]

\[
\ell_s = \text{distance from center of strut barrel to the hull, in mm (in.), see 3-2-A3/1 FIGURE 1}
\]

7 **Required Section Modulus of Strut at the Hull**

\[
SM_{st} = 1000C_1[M + F_3(\ell_s\sin\phi / 1000)] / \sigma_y \text{ cm}^3
\]

\[
SM_{st} = C_1(M + F_3\ell_s\sin\phi) / \sigma_y \text{ in}^3
\]

where \(C_1, M, F_3, \ell_s, \phi \) and \(\sigma_y\) are as defined in 3-2-A3/5.

9 **Requirements for Struts Constructed of Aluminum**

The required stiffness, \(EI\), for aluminum strut is to be 90% of a strut constructed of ABS grade A steel that meets the requirements in 3-2-A3/5 and 3-2-A3/7.
Vessels designed and built to the requirements in this Appendix are intended to have a structural fatigue life of not less than 20 years. This Appendix provides an approach to fatigue strength assessment in lieu of more elaborate methods, such as spectral fatigue analysis. Where a spectral fatigue analysis is performed satisfactorily in accordance with the procedures and criteria included in the ABS Guide for Spectral-Based Fatigue Analysis for Vessels or equivalent, the vessel will be distinguished in the ABS Record by the optional notation \textit{SFA (year)}. The notation denotes that the designated fatigue life value is equal to 20 years or greater. The (year) will reflect the designated fatigue life, equal to 20 years or more (in 5-year increments) as specified by the applicant.

Fatigue strength assessment is a process where the fatigue demand on a structural element is established and compared to the predicted fatigue strength of that element. Fatigue demand is stated in terms of stress ranges that are produced by the variable loads imposed on the structure. A stress range is the absolute sum of stress amplitudes on either side of a "steady state" mean stress. Fatigue demand is to be determined using an appropriate structural analysis described in 3-2-A4/2. A coarse mesh finite element model is typically employed in the screening process to identify fatigue-sensitive areas. For the fatigue assessment of each identified area, a local detail model with a finer mesh is to be used.

When considering fatigue inducing stress ranges, consideration is to be given to the possible influences of stress concentrations and how these alter the predicted value of the acting stress. The model used to analyze the structure may not adequately account for local conditions that need to modify the stress range near the location of the structural detail subject to the fatigue assessment. In practice, this issue is resolved by modifying the results of the stress analysis by the application of a Stress Concentration Factor (SCF). The selection of an appropriate geometric SCF may be obtained from standard references, or by the performance of Finite Element Analysis that explicitly computes the geometric SCF.

1.1 \textbf{Applicability}

The criteria in this Appendix are specifically written for craft to which 1-1-4/TABLE 1A and 1-1-4/TABLE 2 of the ABS Rules for Conditions of Classification – Light and High-Speed Craft (Part 1) is applicable. As-built scantlings are ordinarily used for the simplified fatigue assessment method of a new-build vessel.
1.2 **Loadings**

The criteria has been written for ordinary wave-induced motions and loads. Other cyclic loadings, which may result in significant levels of stress ranges over the expected lifetime of the vessel, are also to be considered by the designer.

Where it is known that a vessel will be engaged in long-term service on a route with a more severe environment (e.g., along the west coast of North America to Alaska), the fatigue strength assessment criteria in this Appendix are to be modified accordingly.

1.3 **Tolerances and Alignments**

In addition to complying with the requirements in Section 2-4-5 of the ABS Rules for Materials and Welding (Part 2), the selection and use of nominal S-N curves are to reflect the tolerance and alignment criteria during construction that are provided in BS EN 1999-1-3/Annex J and EN ISO 10042, and are to be verified by the Surveyor. If the tolerance and/or the alignment exceed the fabrication tolerances, the hot spot stress method provided in 3-2-A4/3.4 is to be used.

1.4 **Definition**

The following definitions are used in the context of this Appendix:

- **Cumulative or Total Fatigue Damage, \( D \)**: The linear summation of the individual damage from all considered stress range intervals
- **Calculated Fatigue Life, \( T_f \) (or \( N_f \))**: The computed life, in units of time (or number of cycles) for a particular structural detail considering its appropriate S-N curve. If the total number of cycles, \( N_T \), corresponds to a required minimum design fatigue life of 20 years, the calculated fatigue life would then be equal to \( 20/D \)
- **Design Life, \( T \) (in years), or as \( N_T \) (in cycles)**: The required design life of the overall structure or number of stress cycles expected in the design life
- **Fatigue Capacity**: S-N curves representing the number of stress cycles at fatigue failure
- **Fatigue Strength**: Fatigue life (or damage) calculated per this Appendix
- **Fatigue Demand**: Design fatigue life
- **Geometric Stress Concentration Factor (SCF)**: The ratio between the geometric stress evaluated with the assumption of linear elastic behavior of the material and the nominal stress
- **Hot Spot Stress**: The surface value of the structural stress at the hot spot. The stress change caused by the weld profile is not included in the hot spot stress, but the overall effect of the connection geometry on the nominal stress is represented
- **Modified Nominal Stress**: A nominal stress increased by an appropriate geometric SCF, to allow only for geometric changes of cross section which have not been taken into account in the classification of a particular constructional detail
- **Nominal Stress**: The stress at a cross section of the specimen or structural detail away from the spot where fatigue crack initiation might occur, calculated in accordance with simple elastic strength of materials theory (i.e., assuming that plane sections remain plane and that all stress concentration effects are ignored)

2 **Simplified Fatigue Assessment Method**

2.1 **Introduction**

The simplified fatigue assessment method, also referred as the "permissible" stress range method, can be categorized as an indirect fatigue assessment method because the result is not necessarily a value of fatigue
damage or a fatigue life value. A "pass/fail" answer results depending on whether the acting stress range is below or above the permissible value.

This method is often used as the basis of a fatigue screening technique. A screening technique is typically a rapid, but usually conservatively biased, check of structural adequacy. If the structure’s strength is adequate when checked with the screening criterion, no further analysis is required. If the structural detail fails the screening criterion, the proof of its adequacy may still be found by analysis using more refined techniques such as spectral-based fatigue analysis. Also, a screening approach is quite useful in identifying fatigue sensitive areas of the structure, thus providing a basis to develop fatigue inspection planning for future periodic inspections of the structure and Condition Assessment surveys of the structure.

Three main steps of simplified fatigue assessment method typically involve:

- Load Conditions and Load Cases for Fatigue Analysis: See 3-2-A4/2.2.
- Structural Analysis: See 3-2-A4/2.3 and 3-2-A4/2.4.
- Fatigue Strength Assessment: To select S-N curves of a detail category and determine fatigue life or damage. See 3-2-A4/3 and 3-2-A4/4.

A schematic procedure of the simplified fatigue assessment method is shown in 3-2-A4/2.1 FIGURE 1.
2.2 Loading Conditions and Load Cases for Simplified Fatigue Assessment

Loading conditions that a vessel is expected to experience during its service life are to be reviewed and selected in accordance with 3-1-3/3.1 and 3-1-3/3.3. At least two loading conditions are to be analyzed, one representative of the most probable deepest draft and another representative of the most probable shallowest draft. For special designs or operations, additional loading conditions may be required by ABS on a case-by-case basis.
Load cases are defined by a combination of vessel loading conditions, a set of global motion and load effect parameters set forth in terms of Dominant Load Parameters (DLP), other load components accompanying the DLPs, and an equivalent wave system for the specified DLP.

For monohull craft, as a minimum, the following DLPs are to be considered:

1. Vertical bending moment amidships
2. Vertical shear force at 0.25L and 0.75L from AP

For multi-hull craft, as a minimum, the following DLPs are to be considered:

1. Vertical bending moment amidships
2. Squeezing/prying moment
3. Pitch torsion (connecting) moment
4. Transverse vertical shear at haunch

For each DLP, two load cases as a pair with the critical phase of DLP at its maximum and minimum are to be developed for further structural analysis to determine the stress range. The load cases considered possess the following attributes:

1. They use drafts, loading patterns, and other loading conditions that reflect the craft’s operating conditions.
2. They use equivalent design waves and/or design sea states that reflect the craft’s maximum and minimum responses and wave environmental conditions.
3. Dominant load component and other accompanying load components are combined to build each load case.

The guidance to select load cases is provided in Subsection 2/5 and Section 3 of the ABS Guidance Notes on the Structural Direct Analysis for High-Speed Craft.

2.3 Structural Analysis

2.3.1 Loading for Structural FE Analysis

For each Load Case, structural loadings are to be applied to the global (whole vessel) structural FE model. The structural loadings are to include external pressure, internal tank pressure, acceleration, and motion-induced loads for both static and dynamic load components. Guidance on applying these loadings is provided in the following Sections of the ABS Guidance Notes on the Structural Direct Analysis for High-Speed Craft:

- External pressure - Section 7
- Internal tank pressure - Section 9
- Acceleration and motion-induced loads - Section 10

2.3.2 Equilibrium Check

The applied hydrodynamic external pressure is to be in equilibrium with the other applied loads on a full length ship structural model. For each load case, the forces and moments in each global direction are to be summed to calculate the force and moment imbalances. A suitable load balancing scheme is to be applied to the structural model to balance the unbalanced forces and moments prior to conducting the structural analysis.
2.3.3 Global and Local Structural Analyses

A three dimensional (3-D) global FE model representing the entire hull structure is to be created in order to determine the stress transfer functions. While the global FE model analysis may produce results of sufficient accuracy, it is typically necessary to perform fine mesh FE analyses of local areas.

The FE models to be used for the local fine mesh analyses can be created either by refining a region of the global FE model or by creating a separate fine mesh FE model of the local area and applying boundary conditions determined from the global FE analysis. The load cases discussed in 3-2-A4/2.2 are to be used for both global and fine mesh FE analysis.

Guidance on modeling and analysis techniques for high-speed craft is provided in Subsections 12/5 and 12/7 of the ABS Guidance Notes on the Structural Direct Analysis for High-Speed Craft. The structural analysis using a FE model is based on the gross or as-built scantlings.

2.3.4 Determine Maximum Stress Range from Load Cases

i) The stress range of each structure detail for each DLP is to be determined by subtracting the minimum stress from the maximum stress from the paired load cases of each DLP defined in 3-2-A4/2.2.

ii) The maximum stress range of each structure detail will be selected by the absolute stress range among all DLPs for a loading condition.

iii) The maximum stress range is to be further calculated as fatigue damage or fatigue life in accordance with 3-2-A4/2.4 and 3-2-A4/4.2.

2.3.5 Determine Maximum Stress Range from Loading Conditions

If the permissible stress approach is used for the fatigue check provided in 3-2-A4/4.3.2 and 3-2-A4/4.3.3, the highest stress range of maximum stress range for each structural detail determined from 3-2-A4/2.3.4.ii. under all loading conditions is to be selected for the fatigue check.

2.4 Long-Term Stress Distribution

2.4.1 General Assumptions

In the simplified fatigue assessment method, the two-parameter Weibull distribution is used to model the long-term distribution of fatigue stresses. The cumulative distribution function of the stress range can be expressed as:

\[ F_S(S) = 1 - \exp \left[ -\left( \frac{S}{\delta} \right)^\gamma \right] \quad \text{for} \quad S > 0 \]

where

\[ S \quad = \quad \text{stress range (see 3-2-A4/2.3.5)} \]

\[ \delta \quad = \quad \text{Weibull scale parameter (see 3-2-A4/2.4.2)} \]

\[ \gamma \quad = \quad \text{long-term stress distribution parameter} \]

The long-term stress distribution parameter, \( \gamma \), can be established by the simplified fatigue assessment method described in this Appendix and calibrated using a detailed stress spectral analysis. The recommended \( \gamma \) for monohull craft over 150 m (492 ft) in length is provided in 5C-1-A1/5.5 of the ABS Rules for Building and Classing Marine Vessels (Marine Vessel Rules). The recommended \( \gamma \) for twin-hull craft as provided in 3-2-A4/2.4.3.

Commentary:

Based on the long-term stress range distribution, a closed form expression for fatigue damage can be derived. A major feature of the simplified method is that appropriate application of experience-based data can be made to establish or estimate the long-term stress distribution parameter, thus avoiding a lengthy spectral analysis. The
other major assumptions underlying the simplified approach are that the linear cumulative damage (Palmgren-Miner) rule applies, and that fatigue strength is defined by the S-N curves.

End of Commentary

2.4.2 Weibull Scale Parameter and Long-Term Stress Distribution Parameter

The scale parameter, \( \delta \), which is also called the "characteristic value" of the distribution, is obtained as follows:

\[
\delta = \frac{S_R}{(\ln N_R)^{1/\gamma}}
\]

where

\[
N_R = \text{number of cycles in a referenced period of time}
\]

\[
S_R = \text{reference stress range which the fatigue stress range exceeds on average once every } N_R \text{ cycles. The probability statement for } S_R \text{ can be expressed as } P(S > S_R) = 1/N_R
\]

The results of the simplified fatigue assessment method can be very sensitive to the values of the long-term stress distribution parameter. Therefore, where there is a need to refine the accuracy of the selected long-term stress distribution parameters, the performance of even a basic level global response analysis can be very useful in providing practical values. Alternatively, when the basis for the selection of a long-term stress distribution parameter is not well known, then a range of probable long-term stress distribution parameter values be employed so that a better appreciation of how selected values affect the fatigue assessment will be obtained.

2.4.3 Long-Term Stress Distribution Parameter, \( \gamma \) for Twin-hull Craft

For twin-hull craft, the long-term stress distribution parameter \( \gamma \) is given below.

\[
\gamma = \begin{cases} 
1.4 - 0.2 \alpha L^{0.2} & \text{for } 61m \leq L \leq 150m \\
1.4 - 0.16 \alpha L^{0.2} & \text{for } 200ft \leq L \leq 492ft 
\end{cases}
\]

where

\[
\alpha = \begin{cases} 
1.0 & \text{for deck structures, including side shell and longitudinal bulkhead structures within } 0.1D \text{ from the deck} \\
0.93 & \text{for bottom structures, including inner bottom, and side shell and longitudinal bulkhead structures within } 0.1D \text{ from the bottom} \\
0.3 & \text{for side shell and longitudinal bulkhead structures within the region of } 0.25D \text{ upward and } 0.3D \text{ downward from the mid-depth} \\
0.59 & \text{for transverse bulkhead structures}
\end{cases}
\]

\( \alpha \) may be linearly interpolated for side shell and longitudinal bulkhead structures between 0.1\( D \) and 0.25\( D \) (0.2\( D \)) from the deck (bottom).

\[
D = \text{craft's depth, measured at the middle of the length } L, \text{ from the molded keel line to the top of the strength deck beams at the side of the vessel}
\]

\[
L = \text{craft's length, as defined in 3-1-1/3}
\]

\[
\text{Part 3 Hull Construction and Equipment}
\]

\[
\text{Chapter 2 Hull Structures and Arrangements}
\]

\[
\text{Appendix 4 Simplified Fatigue Strength Assessment}
\]

\[
\text{ABS RULES FOR BUILDING AND CLASSING LIGHT WARSHIPS, PATROL AND HIGH-SPEED NAVAL VESSELS • 2023}
\]

\[
\text{265}
\]
3 Fatigue Strength Based on S-N Curves

3.1 Introduction

The capacity of a location to resist fatigue damage is characterized by using an S-N curve. An S-N curve is typically used in two ways: in the first, the nominal stress approach, it is assumed that the acting variable stress range can be adequately determined from the nominal stress distribution in the area surrounding the location for which the fatigue life is to be evaluated, and in the second method, the hot spot approach, is used for locations in which complicated geometry or relatively steep local stress gradients invalidate the use of the nominal stress approach.

For steel vessels, reference should be made to Appendix 5C-1-A1 of the Marine Vessel Rules for further explanation and application of these two approaches and for guidance on the categorization of structural details into the various S-N curve classes.

For aluminum vessels, 3-2-A4/3.2 ,3-2-A4/3.3 and 3-2-A4/3.4 of these Rules provide further guidance and application of these two approaches on the categorization of structural details into the various S-N category.

3.2 S-N Curves for Aluminum

3.2.1 General

To provide a ready reference, the S-N curves recommended by ABS are given in this section. Alternative S-N curves may also be accepted at ABS’s discretion. The use of a weld improvement technique such as weld toe grinding or peening to relieve ambient residual stress can be effective in increasing fatigue life. However, such effects are not to be considered in the design of the structure. Typically, an increase in fatigue capacity through weld improvement techniques will be considered only for situations arising during construction, operation or future reconditioning of the structure.

Where an improvement technique is applied, full details of the technique are to be submitted for review along with supporting calculations indicating the proposed fatigue life improvement factor. If grinding is used, the full details of the grinding standard, including the extents, profile smoothness particulars, final weld profile, improved workmanship technique and quality acceptance criteria are to be clearly indicated on the applicable drawings.

Grinding is to produce a smooth concave profile at the weld toe with a penetration depth of at least 0.5 mm (0.02 in.) into the plate surface below the bottom of any visible undercut. It is preferable that a rotary burr be used and that the grinding extend below the plate surface in order to remove toe defects. The grinding area is to have effective corrosion protection. The groove depth is to be minimized and generally should not exceed 1 mm (0.04 in.). In no circumstances may the grinding depth exceed the lesser of 2 mm (0.08 in.) or 5% of the plate gross thickness. The grinding area is to extend well beyond the high stress region.

A weld surface treated using ultrasonic peening should have a smooth finished shape and all traces of the weld toe are to be removed. The minimum peening depth is to be 0.2 mm (0.008 in.) below the original surface. Generally, the maximum peening depth is 0.5 mm (0.02 in.).

A maximum fatigue life improvement of 2 times may be granted provided the above recommendations are followed.

3.2.2 Effect of Exposure Conditions

The S-N curves given in 3-2-A4/3.3 and 3-2-A4/3.4 are not to apply in case of ambient temperature of more than 65°C (150°F) or more than 30°C (86°F) in marine environment unless an efficient corrosion prevention is provided.
5xxx Al-Mg-Mn and 6xxx Al-Mg-Si alloys may be intended for use in marine hull construction or in marine applications where frequent direct contact with seawater. The detail category of 5xxx Al-Mg-Mn alloy immersed in sea water is to be downgraded by which $S_C$ to be reduced by one level, and the value of $N_Q$ of the downgraded S-N curve is to be increased from $5 \times 10^6$ to $10^7$ cycles. The detail category of 6xxx Al-Mg-Si alloy immersed in sea water is to be downgraded by which $S_C$ to be reduced by two levels, and the value of $N_Q$ of the downgraded S-N curve is to be increased from $5 \times 10^6$ to $10^7$ cycles. $S_C$ and $N_Q$ are defined in 3-2-A4/3.3.3 depending on the detail category described in 3-2-A4/3.3.5. Downgrading is not needed for detail categories $S_C$ less than 25 MPa.

3.2.3 Corrosion Protection on Exposure Conditions

3.2.3(a) General

The execution specification is to describe type and amount of protective treatment. The type of corrosion protection is to be adapted to the corrosion mechanism such as surface corrosion, galvanic induced corrosion, crevice corrosion and corrosion due to contamination by other building materials. Crevice corrosion can occur in any type of crevice, also between metal and plastic.

For the selection of a suitable corrosion protection, the following items are to be taken into account:

i) Damages on organic coatings are to a certain degree repairable. Anodized parts have to be handled carefully in transport and protecting foils are to be used.

ii) Anodic oxidation and organic coating under many circumstances are equivalent, under special conditions the one or other surface treatment is doubtless to prefer, depending on corrosive agents and the environment that influence the corrosion effects.

iii) Passivation is a short-term protection for mild conditions.

iv) For the internal structure of the hull, considerations are to be given to prevent corrosion arising from ingress of corrosive agents. The internal protection is not necessary where no water can congregate inside the section.

3.2.3(b) Corrosion Protection

Rolled 5xxx Al-Mg-Mn alloys listed in the 2-5-5/7.3 TABLE 1B of the ABS Rules for Materials and Welding (Part 2), intended for use in marine hull construction or in marine applications where frequent direct contact with seawater, is expected to be corrosion tested with respect to exfoliation and intergranular corrosion resistance as per requirements in Section 2-5-6 of the ABS Rules for Materials and Welding (Part 2) and ASTM B 928/928M.

The alloy grades of the 6xxx series are not to be used in direct contact with seawater unless protected by anodes and/or paint system, refer to 2-5-6/1 of the ABS Rules for Materials and Welding (Part 2).

3.3 Nominal Stress Method

3.3.1 Nominal Stresses

The nominal stress is established in a simple manner, such as force divided by area and bending moment divided by section modulus ($P/A$ and $M/SM$). The structural properties used to establish the nominal stress are taken from locations away from any discontinuities to exclude local stress concentration effects arising from the presence of a weld or other local discontinuity. The nominal S-N curves were derived from fatigue test data obtained mainly from specimens subjected to axial and bending loads. The reference stresses used in the S-N curves are the nominal stresses typically calculated based on the applied loading and sectional properties of the specimens. Nominal stresses are to be used directly for the assessment of initiation sites in simple members and joints where any following conditions apply:
The construction details associated with the initiation site are represented by detail categories in 3-2-A4/3.3.5.

The detail category has been established by tests where the results have been expressed in terms of the nominal stresses.

The gross geometric effects listed in 3-2-A4/3.3.2 are not present in the vicinity of the initiation site.

### 3.3.2 Modified Nominal Stresses

The nominal stress range for the location where the fatigue assessment is conducted needs to be modified to account for local conditions that affect the local stress at that location. The example of nominal stress and modified nominal stress is shown in 3-2-A4/FIGURE 2, relating to a hole drilled in the middle of a flat plate traversed by a butt weld. In this example, the nominal stress $S_N$ is $P/\text{area}$, but the stress to be used to assess the fatigue strength at point A is $S_A$ or $S_N$ multiplies SCF. Modified nominal stresses are to be used in place of nominal stresses where the initiation site is in the vicinity of any following geometric stress concentrating effects. The geometric stress concentration effects are to be taken into account through the appropriate geometric SCF defined in 3-2-A4/1.4.

- Gross changes in cross section shape (e.g., at cut-outs or re-entrant corners)
- Gross changes in stiffness around the member cross-section at unstiffened angled junctions between open or hollow sections
- Changes in direction or alignment beyond those permitted in detail category tables
- Shear lag in wide plate
- Distortion of hollow members
- Non-linear out-of-plane bending effects in slender flat plates

General Guidance to derive the geometric SCF using finite element analysis is provided in 5C-1-A1/13.5 of the Marine Vessel Rules.

### FIGURE 2

**Example of Nominal and Modified Nominal Stresses**

![Diagram of nominal and modified stresses](image)

### 3.3.3 S-N Curve for Nominal Stress Method

The generalized form of the relationship between the number of cycles to failure, $N$ and the stress range $S$ is shown in 3-2-A4/FIGURE 3, plotted on logarithmic scales. Any stress cycles below the cut-off limit $S_L$, assumed at $10^8$ cycles, is assumed to be non-damaging. $S_C$ is the reference value of fatigue strength at $2 \times 10^6$ cycles, depending on the detail category. The fatigue strength curve is represented by the mean line minus 2 standard deviation from the experimental data. The three-segment S-N curve is expressed as:
\[ N = A \cdot S^{-m} \quad \text{for } N \text{ is less than } N_Q \]
\[ N = C \cdot S^{-r} \quad \text{for } N \text{ is greater than } N_Q \]

where

- \( m \) = inverse slope of the first segment of S-N curve
- \( r \) = inverse slope of the second segment of S-N curve
- \( A \) = constant of the first segment of S-N curve
- \( C \) = constant of the second segment of S-N curve
- \( N \) = number of cycles to failure
- \( N_Q \) = number of cycles at which the first slope of the S-N curve changes
- \( S_Q \) = stress range at which the first slope of the S-N curve changes
- \( S_L \) = stress range at which the second slope of the S-N curve changes

3-2-A4/TABLE 1 shows the parameters of aluminum S-N curves and 3-2-A4/FIGURES 4 to 7 show the aluminum S-N curves for various detail categories provided in 3-2-A4/3.3.5.

**FIGURE 3**
Example of Three-Segment S-N Curve
### TABLE 1
Parameters for Aluminum S-N Curves for Nominal Stress Method

<table>
<thead>
<tr>
<th>S-N Curve ($S_{C-m}$)</th>
<th>$A$</th>
<th>$m$</th>
<th>$C$</th>
<th>$r$</th>
<th>$N_Q$</th>
<th>$S_Q$</th>
<th>$S_L$</th>
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<td>For ksi Units</td>
<td>For MPa Units</td>
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</table>

For MPa

For ksi

$S_{C-m}$
FIGURE 4
Aluminum S-N Curves for Plain Material

FIGURE 5
Aluminum S-N Curves for Transverse Weld Toe
3.3.4 Effect of Stress Range Gradient

Where members containing transverse weld toe initiation sites are subject to stress gradients through their thickness, the reference value of fatigue strength $S_c$ provided in 3-2-A4/3.3.3 is to be factored by $k_b$ where $k_b$ is referred in 5.10 of BS PD 6702-1:2009+A1:2019.
3.3.5 Detail Category

The detail categories provided in BS EN 1999-1-3/Annex J with the revised S-N Curves given in 3-2-A4/TABLE 5 are to be used with nominal stresses.

The S-N curves are based on axial (membrane) stress range. Where bending stress components are present, the reference value of fatigue strength $S_C$ for certain detail types is to be adjusted (see 3-2-A4/3.3.4). In instances where two adjacent S-N curves cross each other, the lower value of $S_C$ is to be used for endurances less than that the crossing point.
### TABLE 2

Revised S-N Curves in BS EN 1999-1-3/Annex J

<table>
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<tr>
<th>Part</th>
<th>Chapter</th>
<th>Appendix</th>
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<td>13.3</td>
<td>31-3.5 See 3-2-4A/5.5.4</td>
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<td>13.4</td>
<td>25-3.2 None</td>
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<tr>
<td>13.5</td>
<td>20-3.2 See 3-2-4A/5.5.4</td>
</tr>
</tbody>
</table>

Note 1: Not applicable
Note 2: Applicable
Note 3: Applicable
3.4 Hot Spot Stress Method

3.4.1 Hot Spot Stress Concentration
The hot spot stress method, which is often used to characterize the fatigue strength of details such as the toe of a fillet weld, requires the use of a regimented procedure. The two major parts of the procedure are:

- The selection of an S-N curve class (see 3-2-A4/3.4.3) that applies for each instance.
- Creating the fine mesh FEM adjacent to the detail and calculating the stress at the hot spot location via extrapolation of the stress distribution.

Section 4, Figure 6 of the ABS Guide for Spectral-Based Fatigue Analysis for Vessels depicts an acceptable method that can be used to calculate the hot spot stress for a weld toe. Element sizes near the detail of interest are to be approximately equal to the plating thickness. The hot spot stress is found via linear extrapolation of the calculated stress results at distances of \( t/2 \) and \( 3t/2 \) from the detail. The surface stresses (considering a “bending plate”) should be used to determine the hot spot stress. A detailed description of the numerical extrapolation procedure can be found in 5C-1-A1/13.7 of the Marine Vessel Rules.

3.4.2 Suitable Applications
The hot spot method is primarily used for joints where the crack is assumed to grow from the weld toe and the weld toe orientation is transverse to the fluctuating stress component. Compared with the nominal stress method, the hot spot stress method is more suitable for use in the case where:

- No clearly defined nominal stress due to complicated geometric effects
- Structural discontinuity is not comparable with any classified details provided in the nominal stress approach.
- Testing of prototype structures is performed using strain gauge measurements.
- The offset or angular misalignments exceed the fabrication tolerances specified in the design S-N curves used in the nominal stress method.

3.4.3 S-N Curve for Hot Spot Stress Method
The S-N curves for hot spot stress method of weld toes are given in 3-2-A4/TABLE 3 and 3-2-A4/TABLE 4. The effect of stress range gradient in 3-2-A4/3.3.4 is not to be used in conjunction with the hot spot stress method.

TABLE 3
S-N Curves for Hot Spot Stress Method

<table>
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<tr>
<th>Thickness of Stressed Member</th>
<th>S-N Curves (S_{c-m})</th>
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<tr>
<td>0 &lt; t ≤ 4</td>
<td>44-3.2</td>
</tr>
<tr>
<td>4 &lt; t ≤ 10</td>
<td>39-3.2</td>
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<tr>
<td>10 &lt; t ≤ 15</td>
<td>35-3.2</td>
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<tr>
<td>15 &lt; t ≤ 25</td>
<td>31-3.2</td>
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<tr>
<td>25 &lt; t ≤ 40</td>
<td>28-3.2</td>
</tr>
<tr>
<td>t &gt; 40</td>
<td>25-3.2</td>
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TABLE 4
Parameters for Aluminum S-N Curves for Hot Spot Stress Method

<table>
<thead>
<tr>
<th>S-N Curve</th>
<th>A (For MPa Units)</th>
<th>A (For ksi Units)</th>
<th>m</th>
<th>C (For MPa Units)</th>
<th>C (For ksi Units)</th>
<th>r</th>
<th>N&lt;sub&gt;Q&lt;/sub&gt; (For MPa Units)</th>
<th>N&lt;sub&gt;Q&lt;/sub&gt; (For ksi Units)</th>
<th>S&lt;sub&gt;Q&lt;/sub&gt; (For MPa Units)</th>
<th>S&lt;sub&gt;Q&lt;/sub&gt; (For ksi Units)</th>
<th>S&lt;sub&gt;L&lt;/sub&gt; (For MPa Units)</th>
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<tr>
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FIGURE 8
Aluminum S-N Curves for Hot Spot Stress Method

4 Damage Accumulation Rule and Fatigue Safety Check

4.1 General
When the fatigue demand and fatigue strength are established, they are compared, and the adequacy of the structural component with respect to fatigue is assessed using a damage accumulation rule and a fatigue safety check. It is assumed that the fatigue damage experienced by the structure from each interval of applied stress range can be obtained as the ratio of the number of cycles (n) of that stress range applied to the structure to the number of cycles (N) that will cause a fatigue failure at that stress range, as determined from the S-N curve. The total or cumulative fatigue damage (D) is the linear summation of the individual
damage from all the considered stress range intervals. This approach is referred to as the Palmgren-Miner Rule. It is expressed mathematically by the following equation.

$$D = \sum_{i=1}^{I} \frac{n_i}{N_i}$$

where

- $n_i$ = number of cycles the structural detail endures at stress range $S_i$
- $N_i$ = number of cycles to failure at stress range $S_i$, as determined by the appropriate S-N curve
- $J = 0.59$ for transverse number of considered stress range intervals bulkhead structures

### 4.2 Fatigue Damage for Three Segment Aluminum S-N Curve

For the three segment S-N curve, the cumulative fatigue damage can be expressed as:

$$D = \frac{N_T}{A} \Gamma\left(\frac{m}{\gamma} + 1, z\right) + \frac{N_T}{c} \Gamma_0\left(\frac{r}{\gamma} + 1, z\right) - \frac{N_T}{c} \Gamma_0\left(\frac{r}{\gamma} + 1, u\right)$$

where

- $N_T$ = design life cycles
- $m$ = inverse slope of the first segment of S-N curve (see 3-2-A4/3.3.3 and 3-2-A4/3.4.3)
- $r$ = inverse slope of the second segment of S-N curve (see 3-2-A4/3.3.3 and 3-2-A4/3.4.3)
- $A$ = S-N Curve parameter (see 3-2-A4/3.3.3 and 3-2-A4/3.4.3)
- $C$ = S-N Curve parameter (see 3-2-A4/3.3.3 and 3-2-A4/3.4.3)
- $\Gamma_0(a, z)$ = incomplete gamma function
  
  $$\Gamma_0(a, z) = \int_0^z t^{a-1} e^{-t} dt$$

- $\Gamma(a, z)$ = incomplete gamma function
  
  $$\Gamma(a, z) = \int_0^z t^{a-1} e^{-t} dt = \Gamma(a) - \Gamma_0(a, z)$$

- $z = \left(\frac{S_Q}{S}\right)^{\gamma}$
- $\Gamma_0(a, u)$ = incomplete gamma function
  
  $$\Gamma_0(a, u) = \int_0^u t^{a-1} e^{-t} dt$$

- $u = \left(\frac{S_Q}{S}\right)^{\gamma}$

- $S_Q$ = stress range at which the 1st slope of the S-N curve changes (see 3-2-A4/3.3.3)
- $S_L$ = stress range at which the 2nd slope of the S-N curve changes (see 3-2-A4/3.3.3)
- $\delta$ = Weibull scale parameter (see 3-2-A4/2.4.2)
- $\gamma$ = long-term stress distribution parameter (see 3-2-A4/2.4.2 and 3-2-A4/2.4.3)

### 4.3 Fatigue Safety Check

The fatigue safety check expression can be based on either fatigue damage (life) or permissible stress range.
4.3.1 Criteria Based on Fatigue Damage or Fatigue Life

When based on damage, the structural detail is considered acceptable if:

\[ D \leq 1.0 \]

When based on life, the calculated fatigue life \( T_f \) used in design is not to be less than the design life \( T \). The structural detail is considered acceptable if:

\[ T_f \geq T \]

4.3.2 Criteria Based on Permissible Stress Range

When the fatigue is assessed in terms of permissible stress range, the permissible stress range \( S_R' \) is not to be less than the reference maximum stress range \( S_R \). The structural detail is considered acceptable if:

\[ S_R' \geq S_R \]

where

\[ S_R = \text{reference stress range defined in 3-2-A4/2.4.2} \]

\[ S_R' = \text{permissible stress range, at the probability level corresponding to } N_R \text{ can be found below} \]

\[ S_R' = \left[ \frac{FDF \cdot N_T}{\Gamma} \right]^{1/\eta} \]

where

\[ N_T = \text{design life cycles} \]

\[ FDF = \text{fatigue design factor } = 1.0 \]

\[ N_R = \text{number of cycles in a referenced period of time (see 3-2-A4/2.4.2)} \]

\[ m = \text{inverse slope of the first segment of S-N curve (see 3-2-A4/3.3.3 and 3-2-A4/3.4.3)} \]

\[ r = \text{inverse slope of the second segment of S-N curve (see 3-2-A4/3.3.3 and 3-2-A4/3.4.3)} \]

\[ A = \text{constant of the first segment of S-N curve (see 3-2-A4/3.3.3 and 3-2-A4/3.4.3)} \]

\[ C = \text{constant of the second segment of S-N curve (see 3-2-A4/3.3.3 and 3-2-A4/3.4.3)} \]

\[ \Gamma_0(a, z) = \text{incomplete gamma function} \]

\[ = \int_0^\infty t^{a-1} e^{-t} \, dt \]

\[ \Gamma(a, z) = \text{incomplete gamma function} \]

\[ = \int_z^\infty t^{a-1} e^{-t} \, dt = \Gamma(a) - \Gamma_0(a, z) \]

\[ z = \left( \frac{S_R}{\delta} \right)^{1/\gamma} \]

\[ S_R = \text{stress range at which the 1st slope of the S-N curve changes (see 3-2-A4/3.3.3)} \]

\[ \delta = \text{Weibull scale parameter (see 3-2-A4/2.4.2)} \]

\[ \gamma = \text{long-term stress distribution parameter (see 3-2-A4/2.4.2 and 3-2-A4/2.4.3)} \]

\[ \Gamma_0(a, u) = \text{incomplete gamma function} \]
\[ u = \int_0^u u a^{-1} e^{-t} \, dt \]

Note that iterative approach is needed to find the \( S'_R \) because \( \delta \) also depends on \( S'_R \).

4.3.3 Permissible Stress Range

3-2-A4/TABLES 6 to 10 contain a listing of the permissible stress ranges, \( PS \), for various S-N curves and various design fatigue cycles. The relation of design life and design life cycles are listed in 3-2-A4/Table 5. The permissible stress range is determined for the types of connections/details, the direction of dominant loading and the long-term stress distribution factor \( \gamma \) as defined in 3-2-A4/2.4. Linear interpolation is to be used to determine the values of permissible stress range for a value of \( \gamma \) between those given. For vessels designed for a fatigue life in excess of the minimum design life cycles of \( 5 \times 10^7 \) cycles, the permissible stress ranges, \( PS \), calculated above are to be modified by the following equation:

\[
PS[\text{design life cycles}] = C \cdot \left( \frac{5 \times 10^7}{\text{design life cycles}} \right)^{1/m} \cdot PS
\]

where

- \( PS[\text{design life cycles}] \) = permissible stress ranges for the target design life cycles
- \( Design\ life\ cycles \) = target value in cycles of design life
- \( m \) = inverse slope of the first segment of S-N Curve (see 3-2-A4/3.3.3 and 3-2-A4/3.4.3)
- \( C \) = correction factor related to target design life cycles considering the three-segment S-N curves (see 3-2-A4/Tables 11 to 14)

### TABLE 5

Design Life Cycles for Various Design Life and Length of Vessel

<table>
<thead>
<tr>
<th>Design Life (Years)</th>
<th>Vessel Rule Length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>61</td>
</tr>
<tr>
<td>20</td>
<td>8.84E+7</td>
</tr>
<tr>
<td>30</td>
<td>1.33E+8</td>
</tr>
<tr>
<td>40</td>
<td>1.77E+8</td>
</tr>
<tr>
<td>50</td>
<td>2.21E+8</td>
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</tbody>
</table>
### TABLE 6
Permissible Stress Range for Plain Material

<table>
<thead>
<tr>
<th>Long Term Stress Distribution Parameter</th>
<th>Design Life Cycle*</th>
<th>Design Life Cycle*</th>
<th>Design Life Cycle*</th>
</tr>
</thead>
<tbody>
<tr>
<td>ta = 10²</td>
<td>10²</td>
<td>10²</td>
<td>10²</td>
</tr>
<tr>
<td>0.60</td>
<td>356.6</td>
<td>304.6</td>
<td>304.6</td>
</tr>
<tr>
<td>0.70</td>
<td>356.6</td>
<td>304.6</td>
<td>304.6</td>
</tr>
<tr>
<td>0.80</td>
<td>356.6</td>
<td>304.6</td>
<td>304.6</td>
</tr>
<tr>
<td>0.90</td>
<td>356.6</td>
<td>304.6</td>
<td>304.6</td>
</tr>
<tr>
<td>1.00</td>
<td>356.6</td>
<td>304.6</td>
<td>304.6</td>
</tr>
</tbody>
</table>

**Note:** *Design life cycle is the total number of wave cycles experienced by vessel during the design life, taken as N = 1.557 × 10⁶ T/ (f kg) where T is the design life (in years) and f is the fatigue (in Hz).

### TABLE 7
Permissible Stress Range for Transverse Weld Toe

<table>
<thead>
<tr>
<th>Long Term Stress Distribution Parameter</th>
<th>Design Life Cycle*</th>
<th>Design Life Cycle*</th>
<th>Design Life Cycle*</th>
</tr>
</thead>
<tbody>
<tr>
<td>ta = 10²</td>
<td>10²</td>
<td>10²</td>
<td>10²</td>
</tr>
<tr>
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<td>356.6</td>
<td>304.6</td>
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<tr>
<td>0.70</td>
<td>356.6</td>
<td>304.6</td>
<td>304.6</td>
</tr>
<tr>
<td>0.80</td>
<td>356.6</td>
<td>304.6</td>
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<tr>
<td>0.90</td>
<td>356.6</td>
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<tr>
<td>1.00</td>
<td>356.6</td>
<td>304.6</td>
<td>304.6</td>
</tr>
</tbody>
</table>

**Note:** *Design life cycle is the total number of wave cycles experienced by vessel during the design life, taken as N = 1.557 × 10⁶ T/ (f kg) where T is the design life (in years) and f is the fatigue (in Hz).

### TABLE 8
Permissible Stress Range for Longitudinal Weld

<table>
<thead>
<tr>
<th>Long Term Stress Distribution Parameter</th>
<th>Design Life Cycle*</th>
<th>Design Life Cycle*</th>
<th>Design Life Cycle*</th>
</tr>
</thead>
<tbody>
<tr>
<td>ta = 10²</td>
<td>10²</td>
<td>10²</td>
<td>10²</td>
</tr>
<tr>
<td>0.60</td>
<td>356.6</td>
<td>304.6</td>
<td>304.6</td>
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<tr>
<td>0.70</td>
<td>356.6</td>
<td>304.6</td>
<td>304.6</td>
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<tr>
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<td>356.6</td>
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<tr>
<td>0.90</td>
<td>356.6</td>
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</tr>
<tr>
<td>1.00</td>
<td>356.6</td>
<td>304.6</td>
<td>304.6</td>
</tr>
</tbody>
</table>

**Note:** *Design life cycle is the total number of wave cycles experienced by vessel during the design life, taken as N = 1.557 × 10⁶ T/ (f kg) where T is the design life (in years) and f is the fatigue (in Hz).
### TABLE 9

<table>
<thead>
<tr>
<th>Permissible Stress Range for Welds Between Members</th>
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</thead>
<tbody>
<tr>
<td><strong>S-N Curve</strong></td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Long Term Stress Distribution Parameter</td>
</tr>
<tr>
<td>0.70</td>
</tr>
<tr>
<td>0.80</td>
</tr>
<tr>
<td>0.90</td>
</tr>
<tr>
<td>1.00</td>
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<tr>
<td>1.10</td>
</tr>
<tr>
<td>1.20</td>
</tr>
<tr>
<td>S-N Curve</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Long Term Stress Distribution Parameter</td>
</tr>
<tr>
<td>0.70</td>
</tr>
<tr>
<td>0.80</td>
</tr>
<tr>
<td>0.90</td>
</tr>
<tr>
<td>1.00</td>
</tr>
<tr>
<td>1.10</td>
</tr>
<tr>
<td>1.20</td>
</tr>
</tbody>
</table>

Note: *Design Life Cycle is the total number of wave cycles experienced by vessels during the design life, taken as \(N = 5.557 \times 10^7 \times T \) (hrs) \(T\) in the design life (in years) and \(N\) is the life length (in hrs).

### TABLE 10

<table>
<thead>
<tr>
<th>Permissible Stress Range for Hot Spot Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>S-N Curve</strong></td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Long Term Stress Distribution Parameter</td>
</tr>
<tr>
<td>0.70</td>
</tr>
<tr>
<td>0.80</td>
</tr>
<tr>
<td>0.90</td>
</tr>
<tr>
<td>1.00</td>
</tr>
<tr>
<td>1.10</td>
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<tr>
<td>1.20</td>
</tr>
<tr>
<td>S-N Curve</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Long Term Stress Distribution Parameter</td>
</tr>
<tr>
<td>0.70</td>
</tr>
<tr>
<td>0.80</td>
</tr>
<tr>
<td>0.90</td>
</tr>
<tr>
<td>1.00</td>
</tr>
<tr>
<td>1.10</td>
</tr>
<tr>
<td>1.20</td>
</tr>
</tbody>
</table>

Note: *Design Life Cycle is the total number of wave cycles experienced by vessels during the design life, taken as \(N = 5.557 \times 10^7 \times T \) (hrs) \(T\) in the design life (in years) and \(N\) is the life length (in hrs).
### TABLE 11

<table>
<thead>
<tr>
<th>S-N Curve</th>
<th>Design Life Cycles</th>
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</thead>
<tbody>
<tr>
<td>121-6</td>
<td>66-6</td>
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<tr>
<td>96-6</td>
<td>66-6</td>
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<td>86-6</td>
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#### Long Term Stress Distribution

<table>
<thead>
<tr>
<th>Parameter</th>
<th>5x10^7</th>
<th>7x10^7</th>
<th>3x10^8</th>
<th>2x10^9</th>
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</thead>
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<tr>
<td>0.60</td>
<td>1.0000</td>
<td>1.0001</td>
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### TABLE 12

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<tr>
<td>31-3.2</td>
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<tr>
<td>25-3.2</td>
<td>22-3.2</td>
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<tr>
<td>20-3.2</td>
<td>18-3.2</td>
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<td>18-3.2</td>
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<tr>
<td>16-3.2</td>
<td>14-3.2</td>
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</table>

#### Long Term Stress Distribution

<table>
<thead>
<tr>
<th>Parameter</th>
<th>5x10^7</th>
<th>7x10^7</th>
<th>3x10^8</th>
<th>2x10^9</th>
</tr>
</thead>
<tbody>
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<td>1.0001</td>
<td>1.0003</td>
<td>1.0005</td>
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</tbody>
</table>

### TABLE 13

<table>
<thead>
<tr>
<th>S-N Curve</th>
<th>Design Life Cycles</th>
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<tbody>
<tr>
<td>60-4.5</td>
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<tr>
<td>44-4.5</td>
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<tr>
<td>31-3.5</td>
<td>28-3.5</td>
</tr>
</tbody>
</table>

#### Long Term Stress Distribution

<table>
<thead>
<tr>
<th>Parameter</th>
<th>5x10^7</th>
<th>7x10^7</th>
<th>3x10^8</th>
<th>2x10^9</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.60</td>
<td>1.0000</td>
<td>1.0001</td>
<td>1.0003</td>
<td>1.0005</td>
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<tr>
<td>0.70</td>
<td>1.0002</td>
<td>1.0007</td>
<td>1.0012</td>
<td>1.0015</td>
</tr>
<tr>
<td>0.80</td>
<td>1.0003</td>
<td>1.0008</td>
<td>1.0015</td>
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<tr>
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<td>1.20</td>
<td>1.0012</td>
<td>1.0017</td>
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</table>

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**ABS RULES FOR BUILDING AND CLASSING LIGHT WARSHIPS, PATROL AND HIGH-SPEED NAVAL VESSELS • 2023**

Part 3: Hull Construction and Equipment
Chapter 2: Hull Structures and Arrangements
Appendix 4: Simplified Fatigue Strength Assessment
Combined Fatigue Life from Multiple Loading Conditions

To calculate combined fatigue life from multiple loading conditions, exposure time factors need to be specified for each individual loading condition. In addition, for conventional trading vessels, a factor of 0.85 is to be applied to account for non-sailing time for operations such as loading and unloading, repairs, etc. For vessels engaged in a service with less sailing time, special consideration may be given to accepting a lower factor subject to Owner agreement.

The fatigue life for each loading condition is to be calculated separately. If the exposure time ratios have been considered in the fatigue life calculations for each loading condition, the combined fatigue life is given by:

$$L_C = \alpha_S \left( \frac{1}{L_1} + \frac{1}{L_2} + \cdots + \frac{1}{L_n} \right)$$

where

- $L_C$ = combined fatigue life
- $\alpha_S$ = factor of 0.85 to account for non-sailing time
- $L_i$ = fatigue life for the $i^{th}$ loading condition ($i = 1$ to $n$) prior to accounting for non-sailing time
- $n$ = number of loading conditions

If the exposure time ratios have not been considered in the fatigue life calculations for each loading condition, the combined fatigue life is given by:

$$L_C = \alpha \left( \frac{P_1}{L_1} + \frac{P_2}{L_2} + \cdots + \frac{P_n}{L_n} \right)$$

where

- $P_i$ = exposure time ratio of the $i^{th}$ loading condition ($i = 1$ to $n$) satisfying:
  $$\sum_{i=1}^{n} P_i = 1.0$$
CHAPTER 3
Subdivision and Stability

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CHAPTER 3
Subdivision and Stability

SECTION 1
General Requirements

1 General

All vessels are to demonstrate that they have adequate subdivision and stability for the intended service as required by the criteria shown.

3 Criteria

The following applicable criteria may be used for assessment of intact/damage stability of the vessel unless the Naval Administration specifically requires specific criteria for the intended service of the vessel.

3.1 Intact Stability

All vessels are to have sufficient stability in the intact condition based on the following criteria:

3.1.1 (1 July 2020)

Vessels over 54 m (175 ft) in length are to comply with one of the following:


ii) Requirements as defined in Appendix 3-3-A1.

3.1.2 (1 July 2020)

Vessels over 24 m (79 ft) in length but less than 54 m (175 ft) are to comply with one of the following:


iii) Requirements as defined in Appendix 3-3-A1.

3.1.3 (1 July 2020)

Vessels over 12 m (40 ft) but less than 24 m (79 ft) in length are to comply with one of the following:


ii) The requirements in International Standard ISO 12217-1 "Small craft - Stability and buoyancy assessment and categorization - Part 1"

iii) Requirements as defined in Appendix 3-3-A1.
3.1.4 (1 July 2020)
Vessels under 12 m (40 ft) in length are to comply with one of the following:


ii) The requirements in International Standard ISO 12217-1 "Small craft - Stability and buoyancy assessment and categorization - Part 1"

3.3 Damage Stability
Vessels of applicable size, type, and service are to have subdivision and damage stability as required by the following:

3.3.1 Vessels over 24 m (79 ft) in length are to comply with one of the following:


ii) Requirements as defined in Appendix 3-3-A1.

3.3.2 Vessels under 24 m (79 ft) in length are to comply with the requirements defined by the Naval Administration for the intended service of the vessel, if any.

5 Review Procedures

5.1 Naval Administration Review
Where the Naval Administration undertakes the review of subdivision and stability, their acceptance of the subdivision and stability of the vessel will be required to be submitted for classification.

5.3 ABS Review
In all other cases the information and calculations for subdivision and stability are to be submitted to ABS for review. Where the intact stability criteria are not applicable to a particular vessel, the review will be in accordance with other recognized criteria acceptable to ABS and the Naval Administration.

7 Onboard Computers for Stability Calculations (1 July 2007)
The use of onboard computers for stability calculations is not a requirement of class. However, if stability software is installed onboard vessel contracted on or after 1 July 2005, it should cover all stability requirements applicable to the vessel and is to be approved by ABS for compliance with the requirements of Appendix 3-3-A2, “Onboard Computers for Stability Calculations”.

ABS RULES FOR BUILDING AND CLASSING LIGHT WARSHIPS, PATROL AND HIGH-SPEED NAVAL VESSELS • 2023
1 **Intact Stability Standards**

1.1 **General**
   The stability and buoyancy criteria specified herein are the minimum criteria that must be satisfied. When other considerations such as speed, arrangement, and cost permit, the minimum criteria should be exceeded. The adequacy of stability is measured by comparing the intact righting arm curve with the hazard heeling arm curve. The static heel angle, the associated righting arm, and the reserve of dynamic stability are the factors which are examined.

1.3 **Beam Winds Combined With Rolling**
   1.3.1 **Effect of Beam Winds and Rolling**
   Beam winds and rolling are considered simultaneously since a rough sea is to be expected when winds of high velocity exist. If the water is still, the vessel will require only sufficient righting moment to overcome the heeling moment produced by the action of the wind on the vessel’s “sail area”. When wave action is taken into account, an additional allowance of dynamic stability is required to absorb the energy imparted to the vessel by the wave motion.

   1.3.2 **Wind Velocities**
   The wind velocity which an intact vessel is expected to withstand depends upon its service, determined by the Naval Administration. For early stages of design, or when a wind speed is not specified, a wind speed of 60 knots is to be used.

   1.3.3 **Wind Heeling Arms**
   The formula which for the unit pressure on a vessel due to beam winds, using the full scale wind velocity gradient in 3-3-A1/1.3.3 TABLE 1, is:

   \[ P = 0.004 \cdot V^2 \]

   where

   \[ P \quad = \quad \text{pressure (lb/ft}^2\text{)} \]
   \[ V \quad = \quad \text{velocity (knots)} \]
The heeling arm due to wind is:

\[ HA_{\text{WIND}} = 0.004 \frac{V^2 A L \cos^2(\theta)}{240 \cdot \Delta} \]

where

- \( A \) = projected sail area, in square feet
- \( L \) = lever arm from half draft to centroid of “sail area”, in feet
- \( V \) = nominal wind velocity, in knots
- \( \theta \) = angle of inclination, in degrees
- \( \Delta \) = vessel displacement, in long tons

The full-scale wind velocity gradient curve in 3-3-A1/1.3.3 FIGURE 1 assumes that the nominal velocity occurs 33 feet above the waterline. Use of 3-3-A1/1.3.3 FIGURE 1 for determining the value of \( V \) in the formula for heeling arm due to wind, properly favors the smaller vessel which normally would be the most affected by the velocity gradient and would also be somewhat sheltered from the wind by the accompanying waves. 3-3-A1/1.3.3 TABLE 1 may be used in determining wind heeling moments for a nominal 100 knot wind, for varying heights above the waterline. For other wind velocities, the values developed 3-3-A1/1.3.3 TABLE 1 are multiplied by \((V/100)^2\).

On most vessels, a first approximation using the above formula for \( HA_{\text{WIND}} \) to estimate the heeling arm, without allowance for wind gradient, will establish whether or not wind heel will be a governing criterion and whether or not any further calculations will be required. The most accurate method of determining wind-pressure effects would be to conduct wind-tunnel tests for each design.
### FIGURE 1
Wind Velocity Gradient

### TABLE 1
Wind Heeling Factors for a 100-Knot Wind

Heeling Moment (Ft-Tons) Per Square Foot for a Nominal 100-Knot Wind

<table>
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**Notes:**
To obtain the total heeling moment using this table, follow the procedure below:

a  Divide the “sail” area into 5-foot layers, starting from the waterline.
b  Determine the number of square feet in each layer.
c  Multiply the area of each layer by the appropriate factor from the above table and add the products. This sum is the heeling moment for a 100 knot wind.
d  For wind velocities other than 100 knots, multiply the moment by \((V/100)^2\)

The vessel center of lateral resistance is taken at the half draft.

### 1.3.4 Criteria for Adequate Stability
The criteria for adequate stability under adverse wind conditions are based on a comparison of the vessel’s righting arm curve and the wind heeling arm curve, as illustrated in 3-3-A1/1.3.4(b) FIGURE 2, where the range of the righting arm curve terminates at the angle of unrestricted downflooding. If analysis shows that the vessel can survive this flooding, a composite righting arm may be used. The “points” and “areas” referred to below are those depicted in 3-3-A1/1.3.4(b) FIGURE 2. Stability is considered to be satisfactory if:

**1.3.4(a)**
The heeling arm at the intersection of the righting arm and heeling arm curves, \(\Theta\) equilibrium or Point C, is not greater than six-tenths of the maximum righting arm:

\[
HA_{EQUIL} \leq 0.6 \cdot RA_{MAX}
\]

A wind heeling arm in excess of the vessel’s righting arm would cause the vessel to capsize. The requirement that the heeling arm be not greater than six-tenths of the maximum righting arm is intended to provide a margin for gusts.

**1.3.4(b)**
Area \(A_1\) is not less than \(1.4 \cdot A_2\), where Area \(A_2\) extends either 25 degrees or \(\Theta_R\) (if roll angle determined from model tests) to windward from Point C:

\[1.40 \cdot A_2 \leq A_1\]

In the second criterion, the vessel is assumed to be heeled over by the wind to Point C and rolling 25 degrees or \(\Theta_R\) from this point to windward, where 25 degrees is a reasonable roll amplitude for heavy wind and sea conditions. Area \(A_2\) is a measure of the energy imparted to the vessel by the
wind and the vessel's righting arm in returning to point C. The margin of 40% in $A_1$ is intended to account for gusts and waves.

**FIGURE 2**
Intact Stability-Beam Winds with Rolling

1.5 Lifting of Heavy Weights over the Side

1.5.1 Effects of Lifting Weights

Lifting of weights will be a governing factor in required stability only on vessels which are used to lift heavy items over the side. Lifting of weights has a double effect upon transverse stability. The first effect is that the added weight, which acts at the upper end of the boom, will raise the vessel’s center of gravity and thereby reduce the righting arm. The second effect is the heel caused by the transverse moment when lifting a weight over the side.

1.5.2 Heeling Arms

For the purpose of applying the criteria, the vessel’s righting arm curve is modified by correcting VCG and displacement to show the effect of the added weight at the end of the boom. The heeling arm curve is calculated as follows:

$$HA_{LIFT} = \frac{W_{ACS}(\theta)}{\Delta}$$

where
1.5.3 Criteria for Adequate Stability

The criteria for adequate stability when lifting weights over the side are based on a comparison of the righting arm and heeling arm curves as illustrated in 3-3-A1/1.5.3(c) FIGURE 3. Stability is considered satisfactory if:

1.5.3(a)

The limiting angle of heel (as indicated by Point C) is not to exceed 15 degrees or the angle at which one-half the freeboard submerges, whichever angle is smaller. A continuous heel angle of 15 degrees is the maximum acceptable from the standpoint of personnel safety.

\[ \Theta_{EQUIL} \leq 15 \text{ degrees or } \frac{1}{2} \text{ freeboard} \]

1.5.3(b)

The heeling arm at the intersection of the righting arm and heeling arm curves, \( \Theta \) equilibrium or Point C, is not more than six-tenths of the maximum righting arm:

\[ HA_{EQUIL} \leq 0.6 \cdot RA_{MAX} \]

This provides a margin against capsizing.

1.5.3(c)

The reserve of dynamic stability (Area \( A_1 \)) is not less than four-tenths of the total area, \( A_0 \), under the righting arm curve.

\[ 0.4 \cdot A_0 \leq A_1 \]
1.7 Crowding of Personnel to one Side

1.7.1 Effect of Crowding of Personnel

The movement of personnel will have an important effect only on vessels which carry a large number of personnel. The concentration of personnel on one side of the vessel can produce a heeling moment which results in a significant reduction in residual dynamic stability.

1.7.2 Heeling Arm

The heeling arm produced by the transverse movement of personnel is calculated by:

\[ H_{ACROWD} = \frac{W \cos(\Theta)}{\Delta} \]

where:

- \( W \) = weight of personnel (tons)
- \( a \) = distance from centerline of vessel to center of gravity of personnel (feet)
- \( \Delta \) = displacement (L-tons)
- \( \Theta \) = angle of inclination (degrees)
In determining the heeling moment produced by the personnel, it is assumed that all personnel have moved to one side of the main deck or above and as far outboard as possible.

1.7.3 Criteria for Adequate Stability

The criteria for adequate stability are based on the angle of heel, and a comparison of the vessel’s righting arm and the heeling arm curves, as illustrated in 3-3-A1/1.7.3(c) FIGURE 4. Stability is considered to be satisfactory if:

1.7.3(a)
The angle of heel, as indicated by Point C, does not exceed 15 degrees. An angle of heel of 15 degrees is considered to be the maximum acceptable from the standpoint of personnel safety.

\[ \Theta_{EQUIL} \leq 15 \text{degrees} \]

1.7.3(b)
The heeling arm at the intersection of the righting arm and heeling arm curves, \( \Theta \) equilibrium or Point C, is not more than six-tenths of the maximum righting arm.

\[ H_A_{EQUIL} \leq 0.6 \cdot R_{A_{MAX}} \]

1.7.3(c)
The reserve of dynamic stability (Area \( A_1 \)) is not less than four-tenths of the total area, \( A_0 \), under the righting arm curve.

\[ 0.4 \cdot A_0 \leq A_1 \]

The requirements that the heeling arm be not more than six-tenths of the righting arm and that the reserve of dynamic stability be not less than four-tenths of the total area under the righting arm curve are intended to provide a margin against capsizing.
1.9 High-Speed Turns

1.9.1 Effect of High-Speed Turns

Heel in a high-speed turn may be a governing factor in required stability on highly maneuverable vessels. The heel towards the outside of the turn is affected by the velocity in the turn and the turning radius associated with that velocity. The maximum heel may be associated with rudder angles less than full rudder due to the decreased speed in the tightest turns. The stability may differ due to the direction of the turn because most high-speed craft respond differently depending on the direction of the rudder and propeller thrusts at the higher speeds and rudder angles.

1.9.2 Heeling Arms

The centrifugal force acting on a vessel during a turn may be expressed by the formula:

\[ \text{Centrifugal Force} = \frac{\Delta v^2}{gR} \]

where

\[ \Delta = \text{displacement of vessel (L-tons)} \]
\[ v = \text{steady-state velocity of vessel in the turn (ft/sec)} \]
The lever arm used, in conjunction with this force, to obtain the heeling moment is the vertical distance between the vessel’s center of gravity and the center of lateral resistance of the underwater body, adjusted for the angle of inclination. The center of lateral resistance may be assumed to be at the half-draft. If the centrifugal force is multiplied by the lever arm and divided by the vessel’s displacement, the following expression for heeling arm is obtained:

$$ H_{A_{\text{TURN}}} = \frac{v^2 a \cos(\theta)}{gR} $$

where

- $a$ = distance between vessel’s center of gravity and center of lateral resistance with vessel upright (ft)
- $\theta$ = angle of inclination (degrees)

$v$, $g$, and $R$ are as defined above.

### 1.9.3 Criteria for Adequate Stability

The criteria for adequate stability in high-speed turns are based on the relationship between the righting arm curve and the heeling arm curve, as illustrated in 3-3-A1/1.9.3(c) FIGURE 5. Referring to this figure, stability is considered to be satisfactory if:

1.9.3(a)
The angle of steady heel, as indicated by Point C, does not exceed 15 degrees. An angle of heel of 15 degrees is considered to be the maximum acceptable from the standpoint of personnel safety.

$$ \theta_{\text{EQUIL}} \leq 15 \text{ degrees} $$

1.9.3(b)
The heeling arm at the intersection of the righting arm and heeling-arm curves, $\theta$ equilibrium or Point C, is not more than six-tenths of the maximum righting arm.

$$ H_{A_{\text{EQUIL}}} \leq 0.6 \cdot R_{\text{MAX}} $$

1.9.3(c)
The reserve of dynamic stability (Area $A_1$) is not less than four-tenths of the total area, $A_0$, under the righting arm curve.

$$ 0.4 \cdot A_0 \leq A_1 $$

The requirements that the heeling arm be not more than six-tenths of the maximum righting arm and that the reserve of dynamic stability be not less than four-tenths of the total area under the righting arm curve are intended to provide a margin against capsizing.
1.11  Topside Icing

1.11.1  Effects of Topside Icing

The primary effect of topside icing is to raise the center of gravity of the vessel; in addition, “unevenly distributed” topside ice will result in heel and trim angle.

The criteria for adequate stability under adverse wind and topside icing are based on a comparison of the vessel’s righting arm curve and the wind heeling arm curve for the vessel in the minimum operating load condition with appropriate water ballast tanks full. The ballast tanks which are to be filled in the icing condition are those which can be filled without causing excessive trim by the bow, when the vessel is severely iced. This will normally allow only for the after water ballast tanks to be filled.

1.11.2  Heeling Arm

When not specified by the Naval Administration, the assumed weight of ice is to be 10 percent of the vessel’s displacement. The majority of ice build-up is likely to occur on the forecastle deck and arises from wind-blown spray. It is generally accepted that ice build-up occurs over the forward one-third of the overall length of the vessel. The center of gravity of the ice may be assumed to be located on the centerline one-third of the overall length forward of midships and 4 feet above the weather deck.
1.11.3 Criteria for Adequate Stability

Stability is considered satisfactory if as defined in 3-3-A1/1.11.3(b) FIGURE 6:

1.11.3(a)

\[ H_{EQUIL} \leq 0.6 \cdot R_{MAX} \]

1.11.3(b)

\[ 1.4 \cdot A_2 \leq A_1 \] (\( A_2 \) being defined for an angle of 25 degrees)

### FIGURE 6

Intact Stability-The Effects of Icing, Beam Winds and Rolling

---

### 3 Damage Stability Standards

#### 3.1 General

The Vessels is assumed to be in a full-load condition, with all tanks full, for the shell-to-shell flooding case. If appropriate, flooding on one side is to be investigated in order to take heel into account, with tanks loaded in such a manner as to produce unsymmetrical flooding consistent with liquid loading instructions.
3.3 Extent of Damage

Vessels greater than 30 m (100 ft) in length are to be capable of withstanding the flooding of any two adjacent main compartments. Vessels between 30 m (100 ft) and 12 m (40 ft) in length are to be capable of withstanding the flooding of any single compartment. Lesser or greater extents of damage may be specified by the Naval Administration.

3.5 Damaged-vessel Stability Curves

Curve A, in 3-3-A1/3.7.v FIGURE 8, is a representative righting arm curve for the damaged vessel. A reduction of righting arm equal to 0.05·\cos(\Theta) is included in Curve A to account for unknown unsymmetrical flooding and transverse shift of loose material.

Curve B, in 3-3-A1/3.7.v FIGURE 8, is a beam-wind heeling arm curve which has been calculated by the method outlined in 3-3-A1/1.3.3 “Wind Heeling Arm”. In a damaged condition, it is to be assumed that the vessel experiences a wind of lesser velocity than in the intact condition. The wind velocity used to develop Curve B is obtained from 3-3-A1/1.3.3. The analysis of adequate stability, thereafter is the same as in the intact case.

3.7 Criteria for Adequate Damaged-vessel Stability

The criteria for adequate stability are based on a comparison of the vessel’s righting arm and heeling arm curves, as illustrated in 3-3-A1/3.7.v FIGURE 8. The range of the righting arm curve terminates at the angle of unrestricted down flooding or 45 degrees, whichever occurs first. The following criteria are to be satisfied:

i) Damaged-vessel stability is satisfactory if the initial angle of heel after damage, (Point D, 3-3-A1/3.7.v FIGURE 8), does not exceed 15 degrees. An angle of heel of 15 degrees is considered to be the maximum acceptable from the standpoint of personnel safety.

\[ \Theta_{STATIC} \leq 15 \text{ degrees} \]

ii) The dynamic stability available to absorb the energy imparted to the vessel by moderately rough seas in combination with beam winds is a measure of adequacy of the stability after damage. The reserve of dynamic stability (Area \( A_1 \)) is not to be less than 1.40 times the energy imparted to the vessel by rough seas and beam winds (Area \( A_2 \)). The \( \Theta_R \) value used in the calculation is to be based on experience and model testing, or from 3-3-A1/3.7.v FIGURE 7.

\[ 1.40 \cdot A_2 \leq A_1 \]

iii) Area \( A_1 \) is not less than the amount specified by the Naval Administration.

iv) The value of the maximum righting arm minus the value of the wind heeling arm at the same angle of heel is to be greater than 0.25 feet.

\[ 0.25 \text{ feet} \leq R_{MAX} - H\text{A} \]

v) After damage, the trim and heel angles at the equilibrium position is not to not submerge the margin line.
FIGURE 7
Rollback Angles for Monohulls After Damage

Rollback Angle (degrees)

Intact Full Load Displacement (Long Tons/1000)

5 Degrees Above 80,000 Long Tons
FIGURE 8
Damage Stability-Beam Winds Combined with Rolling

Righting Arm Maximum

Righting Arm Curve (A)

Heeling Arm Curve (B)

Point C

Point D

\[ R_A^{\text{MAX}} - H_A \]

\[ \Theta_d \]

\[ A_1 \]

\[ A_2 \]

\[ A_1 \text{ Area} \]

\[ A_2 \text{ Area} \]
1 General

1.1 Scope (1 July 2021)

The scope of stability calculation software is to be in accordance with the stability information as approved by the Naval Administration or ABS on behalf of the Naval Administration. The requirements for computer software for onboard stability calculations are specified in Appendix 3-3-A7 of the Marine Vessel Rules.
CHAPTER 4
Fire Safety Measures

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1 General

1.1 IMO 1994 High-Speed Craft Code Application
For classification purposes, the fire and safety measures contained in the IMO International Code of Safety for High-Speed Craft (1994 HSC Code) – Chapter 7 for cargo craft are applicable to craft over 50 m (175 ft) in length, unless otherwise specified by the Naval Administration.

1.3 Other Craft
For craft other than indicated above, the structural fire protection requirements are to be specified by the Naval Administration.

3 Review Procedures

3.1 Administration Review
Where the Naval Administration undertakes any part of the review, for vessels over 54 m (175 ft), their acceptance of the arrangements will be required to be submitted for classification.

3.3 ABS Review
In all other cases, the required information and plans are to be submitted to ABS for review.

5 The Review of Vessels Constructed of Fiber Reinforced Plastic (FRP)
FRP fire-restricting divisions may be considered provided they meet the required tests for fire-restricting materials and fire-resisting divisions, or comply with an acceptable fire risk assessment. FRP divisions may also be considered on the basis of location with regard to diminished fire risk and enhanced fire detection/extinguishing means.
CHAPTER 5
Equipment

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1 General (1 July 2018)

All vessels are to have a complete equipment set of anchor(s) and chains as outlined in this Section. The symbol Ⓒ, a condition of classification, placed after the symbols of classification in the Record, thus: Ⓒ A1 Ⓒ, indicates that the equipment of the vessel is in compliance with the requirements of these Rules, and tested in accordance with 3-5-1/7, or with requirements, which have been specially approved for the particular service. The following is an example:

 Cookies and Ⓒ A1 Ⓒ, HSC, OE, Ⓒ AMS

Cables which are intended to form part of the equipment are not to be used as deck chains when the vessel is launched. The inboard ends of the cables of the bower anchors are to be secured by efficient means (see 3-5-1/15). Anchors and their cables are to be connected and positioned, ready for use. Means are to be provided for stopping each cable as it is paid out, and the windlass is to be capable of heaving in either cable. Suitable arrangements are to be provided for securing the anchors and stowing the cables. See 3-5-1/16.

Equipment Number calculations for unconventional vessels with unique topside arrangements or operational profiles may be specially considered. Such consideration may include accounting for additional wind areas of widely separated deckhouses or superstructures in the equipment number calculations or equipment sizing based on direct calculations. However, in no case may direct calculations be used to reduce the equipment size to be less than that required by 3-5-1/3.

3 Calculation of EN

3.1 Monohulls (1 July 2022)

The basic Equipment Number (EN) is to be obtained from the following equation for use in determining required equipment.

\[ EN = k \Delta^{2/3} + m(Ba + \Sigma h_i + S_{fun}) + nA \]

where

\[ k = 1.0 \quad (1.0, 1.012) \]
\[ m = 2 \quad (2, 0.186) \]
\( n = 0.1 \) (0.1, 0.00929)

\( \Delta = \) molded displacement, in metric tons (long tons), at the summer load waterline.

\( B = \) molded breadth, as defined in 3-1-1/5, in m (ft)

\( a = \) vertical distance at hull side, in m (ft), from the Summer Load waterline amidships to the upper deck

\( b_i = \) breadth, in m (ft), of the widest superstructure or deckhouse on each tier.

\( h_i = \) height, in m (ft), on the centerline of each tier of houses having a breadth greater than \( B/4 \), as applicable. For the lowest tier, \( h_i \) is to be measured at the centerline from the upper deck or from a notional deck line where there is local discontinuity in the upper deck, see 3-5-1/3.1 FIGURE 1A for an example. See Notes 1, 2 and 3.

\( S_{fun} = \) effective front projected area, in m² (ft²), of the funnel

\[ S_{fun} = A_{FS} - S_{shield} \]

\( A_{FS} = \) front projected area, in m² (ft²), of the funnel calculated between the upper deck at the centerline, or the notional deck line where there is local discontinuity in the upper deck, and the top of the effective height \( h_F \). See 3-5-1/3.1 FIGURE 1A and Note 5.

\( A_{FS} \) is taken equal to zero if the funnel breadth is less than or equal to \( B/4 \) at all elevations along the funnel height.

\( h_F = \) effective height, in m (ft), of the funnel measured from the upper deck at the centerline, or the notional deck line where there is local discontinuity in the upper deck, and the top of the funnel. See 3-5-1/3.1 FIGURE 1A and Note 5.

The top of the funnel may be taken at the level where the funnel breadth reaches \( B/4 \).

\( S_{shield} = \) the section of front projected area \( A_{FS} \), in m² (ft²), which is shielded by all deck houses having breadth greater than \( B/4 \). If there is more than one shielded section, the individual shielded sections (i.e., \( S_{shield1}, S_{shield2}, \) etc.), as shown in 3-5-1/3.1 FIGURE 1A, are to be added together. To determine \( S_{shield} \), the deckhouse breadth is assumed \( B \) for all deck houses having breadth greater than \( B/4 \) as shown for \( S_{shield1} \) and \( S_{shield2} \) in 3-5-1/3.1 FIGURE 1A.
\[ A = \text{side projected area, in m}^2 (\text{ft}^2), \text{of the hull, superstructures, houses and funnels above} \]
\[ \text{the Summer Load waterline which are within } L \text{ (see 3-1-1/3) and also have a} \]
\[ \text{breadth greater than } B/4. \text{ The side projected area of the funnel is considered in } A \]
\[ \text{when } A_{FS} \text{ is greater than zero. In this case, the side projected area of the funnel is to} \]
\[ \text{be calculated between the upper deck, or notional deck line where there is local} \]
\[ \text{discontinuity in the upper deck, and the top of the effective height } h_F. \text{ See Notes 1,} \]
\[ 2, 3, 4 \text{ and 5.} \]

**Notes:**

1. The sheer and trim may be neglected. Superstructures or deckhouses having a breadth at any point no greater than 0.25B may be excluded.
2. Screens and bulwarks more than 1.5 m (4.9 ft) in height are to be regarded as parts of houses when calculating \( h \) and \( A \).
3. The height of the hatch coamings and that of any deck cargo, such as containers, may be disregarded when determining \( h \) and \( A \), except as specified by 3-5-1/17.3.
4. When a bulwark is more than 1.5 m (4.9 ft) high, the area \( A_2 \) as illustrated in 3-5-1/3.1 FIGURE 1B), is to be included in \( A \).
5. When several funnels are fitted on the craft, \( A_{FS}, h_F \) and \( A \) are taken as follows:
   - \( A_{FS} \): sum of the front projected area of each funnel, in m\(^2\) (ft\(^2\)), calculated between the upper deck, or notional deck line where there is local discontinuity in the upper deck, and the effective height \( h_F \). \( A_{FS} \) is to be taken equal to zero if the sum of each funnel breadth is less than or equal to \( B/4 \) at all elevations along the funnels height.
   - \( h_F \): effective height of the funnel, in m (ft), measured from the upper deck, or notional deck line where there is local discontinuity in the upper deck, and the top of the highest funnel. The top of the highest funnel may be taken at the level where the sum of each funnel breadth reaches \( B/4 \).
   - \( A \): Side projected area, in m\(^2\) (ft\(^2\)), of the hull, superstructures, houses and funnels above the Summer Load waterline which are within \( L \) (see 3-1-1/3). The total side projected area of the funnels is to be considered in the side projected area of the craft, \( A \), when \( A_{FS} \) is greater than zero. The shielding effect of funnels in transverse direction may be considered in the total side projected area (i.e., when the side projected areas of two or more funnels fully or partially overlap, the overlapped area needs only to be counted once).
FIGURE 1A
Effective Heights and Widths of Deck Houses – Monohulls (1 July 2022)
3.3 Multi-Hulled Craft (2022)

Anchors and chains are to be not less than given in 3-5-1/3.3 TABLE 1 and the numbers, weights and sizes of these are to be based on the equipment number obtained from the following equation. Special consideration will be given where anchoring and mooring conditions are specified.

Equipment Number = \( 2k \left( \frac{\Delta}{2} \right)^{2/3} + m[(2BA) + B_1(a_1 + \sum h)] + nA \)

\( k, \Delta, m, n \) and \( A \) are defined in 3-5-1/3.1.

\( B, B_1, a, a_1, h_1, h_2, h_3, \sum h \) are shown in 3-5-1/3.3 FIGURE 1C.
SI, MKS Units
The weight per anchor of bower anchors given in this Table is for anchors of equal weight. The weight of individual anchors may vary 7% plus or minus from the tabular weight provided that the combined weight of all anchors is not less than that required for anchors of equal weight. The total length of chain required to be carried on board, as given in this Table, is to be reasonably divided between the two bower anchors.

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**Note:** *For intermediate values of equipment number, use equipment complement in sizes and weights given for the lower equipment number in the table.

**TABLE 1B**

Equipment for Self-propelled Ocean-going Vessels (1 July 2018)

**US Units**

The weight per anchor of bower anchors given in this Table is for anchors of equal weight. The weight of individual anchors may vary 7% plus or minus from the tabular weight, provided that the combined weight of all anchors is not less than that required for anchors of equal weight. The total length of chain required to be carried onboard, as given in this Table, is to be reasonably divided between the two bower anchors.
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### Note:
* For intermediate values of equipment number, use equipment complement in sizes and weights given for the lower equipment number in the table.
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Mooring Lines for Self-propelled Ocean-going Vessels with $EN \leq 2000$
(1 July 2018)

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<tr>
<td>Equipment Number</td>
<td>Minimum length of each line</td>
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<td>280</td>
</tr>
<tr>
<td>3600</td>
<td>-</td>
<td>300</td>
</tr>
</tbody>
</table>

5 Equipment, Weight and Size
The equipment, weight and size of all vessels is to be in accordance with 3-5-1/3 TABLE 1, in association with the EN calculated in 3-5-1/3.

5.1 Alternatives for Anchor Size
The requirements for anchor sizing given in 3-5-A1 may be used in lieu of the anchor size and number given by 3-5-1/3 TABLE 1. The requirements in 3-5-1/9 are not applicable when the alternative anchor sizing requirements are used. Where one anchor is required by using the alternative arrangement, the total length of chain required is one-half the value given in 3-5-1/3 TABLE 1.

5.3 Wire Rope
Wire rope may be used in lieu of chain. The wire is to have a breaking strength not less than the grade 1 chain of required size and a length of at least 1.5 times the chain it is replacing. Between the wire rope and anchor, chain cable of the required size and having a length of 12.5 m (41.0 ft), or the distance between the anchor in the stored position and winch, whichever is less, is to be fitted.
5.5 Synthetic Fiber Rope

Synthetic fiber rope may be used in lieu of anchor chain cable provided the vessel meets the following:

i) The vessel is less than 54 m (175 ft) in length.

ii) A length of chain is to be fitted between the anchor and synthetic fiber line.

iii) The chain is not to be less than the required Grade 1 chain for the equipment number.

iv) The chain length is to be at least the distance between the windlass and the anchor in the stowed position and not less than 0.2L meters (feet).

v) The ropes are to be stowed on drums or lockers, protected from the weather and sea, and are to be lead over rollers.

vi) The rope length is to be at least 1.5 times the required chain length.

vii) The breaking strength of the rope is to be at least equal to the breaking strength of the required Grade 1 chain cable.

viii) Synthetic fiber ropes for this application are to be polyamide fiber rope or equivalent. Polypropylene rope is not to be used.

ix) If the anchors are HHP or SHHP, the combined cable/synthetic rope is to be adequate for the verified holding power of the anchor.

5.7 Naval Administration Requirements

Consideration will be given to anchor and chain weight and size specified by the Naval Administration based on the type and service of the vessel. Justifications supporting the size and weight selection may be requested to be submitted for review.

7 Materials and Tests

Material and testing for anchors and chains on vessels are to be in accordance with the requirements of Part 2, Chapter 2 for the respective sizes of anchors and chains. See Sections 2-2-1 and 2-2-2. Materials and tests for wire rope are to be in accordance with a national or other recognized standard.

9 Anchor Types

9.1 General

Anchors are in general to be of the stockless type. The weight of the head of a stockless anchor, including pins and fittings, is not to be less than three-fifths of the total weight of the anchor.

9.3 High Holding Power Anchors (HHP)

Where the anchor has a proven holding power of not less than two times that of an ordinary stockless anchor and has been tested in accordance with Section 2-2-1, a weight reduction of 25% from the weight specified in 3-5-1/3 TABLE 1 will be given. For HHP anchors an appropriate notation will be made in the Record.

9.5 Super High Holding Power Anchors (SHHP) (2019)

For vessels intended for restricted service, provided the anchor has a proven holding power of not less than four times that of an ordinary stockless anchor and has been tested in accordance with 2-2-1, a weight reduction of 50% from the weight specified in 3-5-1/3 TABLE 1 will be given. For SHHP anchors an appropriate notation will be made in the Record.
11 Windlass Supporting Hull Structure and Cable Stopper (2022)

11.1 General (2014)

The windlass is to be of good and substantial make suitable for the size of intended anchor cable. The winch is to be well bolted down to a substantial bed, and deck beams below the windlass are to be of extra strength and additionally supported. Where wire ropes are used in lieu of chain cables, winches capable of controlling the wire rope at all times are to be fitted.

Construction and installation of all windlasses and winches used for anchoring are to be carried out in accordance with the following requirements, to the satisfaction of the Surveyor. In general, the design is to conform to an applicable standard or code of practice. As a minimum, standards or practices are to indicate strength, performance and testing criteria.

The manufacturer or builder is to submit in accordance with 4-1-1/5, the following, as applicable:

11.1.1 Plans

i) Arrangement and details of the windlass or winch, drums, brakes, shaft, gears, coupling bolts, wildcat, sheaves, pulleys and foundation.

ii) Electric one line diagram

iii) Piping system diagrams

iv) Control arrangements.

Plans or data are to show complete details including power ratings, working pressures, welding details, material specifications, pipe and electric cable specifications, etc.

11.1.2 Calculations

Detailed stress calculations for the applicable system components listed in 3-5-1/11.1.1.i) above. The calculations are to be based on the breaking strength of the chain or wire rope; are to indicate maximum torque or load to which the unit will be subjected and also show compliance with either applicable sections of the Rules, such as 4-3-1 and 4-3-1-A1 for the gears and shafts, or to other recognized standard or code of practice.

11.3 Supporting Hull Structure (2022)

The windlass is to be bolted down to a substantial foundation, which is to meet the following load cases and associated criteria.

An independent cable stopper and its components are to be adequate for the load imposed. The arrangements and details of the cable stopper are to be submitted for review.

11.3.1 Design Loads (2022)

11.3.1(a) Load on Windlass Support Structure.

The following load is to be applied in the direction of the chain.

With cable stopper not attached to windlass: 45% of B.S.

With cable stopper attached to windlass: 80% of B.S.

Without cable stopper: 80% of B.S.

where

B.S. = minimum breaking strength of the chain, as indicated in 2-2-2/Tables 2 and 3 of the Rules for Materials and Welding (Part 2).
11.3.1(b) Load on Cable Stopper and Support Structure (2006).

A load of 80% of B.S. is to be applied in the direction of the chain

11.3.1(c) Allowable Stresses. (2022)

The stresses, based on gross thickness, in the structures supporting the windlass and cable stopper are not to exceed the following values:

i) For strength assessment by means of beam theory or grillage analysis:
   - Normal stress: 100% of the specified minimum yield stress of the material
   - Shear stress: 60% of the specified minimum yield stress of the material

   The normal stress is the sum of bending stress and axial stress. The shear stress to be considered corresponds to the shear stress acting perpendicular to the normal stress. No stress concentration factors are to be taken into account.

ii) For strength assessment by means of finite element analysis:
   - Von Mises stress: 100% of the specified minimum yield stress of the material

   For strength assessment by means of finite element analysis, the mesh is to be fine enough to represent the geometry as realistically as possible. The ratio of element length to width is not to exceed 3. Girders are to be modelled using shell or plane stress elements. Symmetric girder flanges may be modelled by beam or truss elements. The element height of girder webs is not to exceed one-third of the web height. In way of small openings in girder webs, the web thickness is to be reduced to a mean thickness over the web height. Large openings are to be modelled. Stiffeners may be modelled using shell, plane stress, or beam elements. The mesh size of stiffeners is to be fine enough to obtain proper bending stress. If flat bars are modelled using shell or plane stress elements, dummy rod elements are to be modelled at the free edge of the flat bars and the stresses of the dummy elements are to be evaluated. Stresses are to be read from the center of the individual element. For shell elements, the stresses are to be evaluated at the mid plane of the element.

11.3.2 Sea Loads (2014)

For vessels with length, \( L \) (as defined in 3-1-1/3), over 80 meters (263 feet), where the height of the exposed deck in way of the item is less than \( 0.1L \) or 22 m above the summer load waterline, whichever is the lesser, the windlass supporting structures located on the exposed fore deck within the forward \( 0.25L \) are to meet the following requirements Where the mooring winch is integral with the windlass, it is to be considered as a part of the windlass for the purpose of said paragraph.

11.3.2(a) Pressures.

The following pressures and associated areas are to be applied (see 3-5-1/11.3.2(d) FIGURE 2):

- 200 kN/m\(^2\) (20.4 tf/m\(^2\), 4178 lbs/ft\(^2\)) normal to the shaft axis and away from the forward perpendicular, over the projected area in this direction,
- 150 kN/m\(^2\) (15.3 tf/m\(^2\), 3133 lbs/ft\(^2\)) parallel to the shaft axis and acting both inboard and outboard separately, over the multiple of \( f \) times the projected area in this direction,

where \( f \) is defined as:

\[
 f = 1 + \frac{B}{H} , \text{ but need not be taken as greater than } 2.5
\]

\[
 B = \text{width of windlass measured parallel to the shaft axis}
\]

\[
 H = \text{overall height of windlass}
\]
11.3.2(b) Forces.
Forces in the bolts, chocks and stoppers securing the windlass to the deck are to be calculated. The windlass is supported by N groups of bolts, each containing one or more bolts, see 3-5-1/11.3.2(d) FIGURE 2.

i) Axial Forces. The aggregate axial force \( R_i \) in respective group of bolts (or bolt) \( i \), positive in tension, may be calculated from the following equations:

\[
R_{xi} = P_x h x_i A_i / I_x
\]

\[
R_{yi} = P_y h y_i A_i / I_y
\]

and

\[
R_i = R_{xi} + R_{yi} - R_{si}
\]

where

\[
P_x = \text{force, kN (tf, lbs), acting normal to the shaft axis}
\]

\[
P_y = \text{force, kN (tf, lbs), acting parallel to the shaft axis, either inboard or outboard, whichever gives the greater force in bolt group } i
\]

\[
h = \text{shaft height above the windlass mounting, cm (in.)}
\]

\[
x_i, y_i = x \text{ and } y \text{ coordinates of bolt group } i \text{ from the centroid of all } N \text{ bolt groups, positive in the direction opposite to that of the applied force, cm (in.)}
\]

\[
A_i = \text{cross sectional area of all bolts in group } i, \text{ cm}^2 (\text{in}^2)
\]

\[
I_x = A_i x_i^2 \text{ for } N \text{ bolt groups}
\]

\[
I_y = A_i y_i^2 \text{ for } N \text{ bolt groups}
\]

\[
R_{si} = \text{static reaction at bolt group } i \text{, due to weight of windlass.}
\]

ii) Shear forces. Aggregated shear forces, \( F_{xi}, F_{yi} \), applied to the respective bolt group, \( i \), of bolts, and the resultant combined force, \( F_i \), may be calculated from:

\[
F_{xi} = (P_x - \alpha g M) / N
\]

\[
F_{yi} = (P_y - \alpha g M) / N
\]

and

\[
F_i = (F_{xi}^2 + F_{yi}^2)^{0.5}
\]

where

\[
\alpha = \text{coefficient of friction (0.5)}
\]

\[
M = \text{mass of windlass, in tonnes (Ltons)}
\]

\[
g = \text{gravity: 9.81 m/sec}^2 (32.2 \text{ ft/sec}^2)
\]

\[
N = \text{number of groups of bolt.}
\]

The axial tensile/compressive and lateral forces from the above equations are also to be considered in the design of the supporting structure.
11.3.2(c) Stresses in Bolts.

Tensile axial stresses in the individual bolts in each group of bolts, i, are to be calculated. The horizontal forces, \( F_{xi} \) and \( F_{yi} \), are normally to be reacted by shear chocks. Where “fitted” bolts are designed to support these shear forces in one or both directions, the von Mises equivalent stresses in the individual “fitted” bolts are to be calculated, and compared to the stress under proof load. Where pour-able resins are incorporated in the holding down arrangements, due account is to be taken in the calculations.

11.3.2(d) Allowable Stresses (2022)

i) **Bolts.** The safety factor against bolt proof strength is to be not less than 2.0.

ii) **Supporting Structures.** The stresses, based on gross thickness, acting on the above deck framing and the hull structure supporting the windlass and chain stopper are not to be greater than the following allowable values:

   a) For strength assessment by means of beam theory or grillage analysis:
      - Normal stress: 100% of the specified minimum yield stress of the material
      - Shear stress: 60% of the specified minimum yield stress of the material

   The normal stress is the sum of bending stress and axial stress. The shear stress to be considered corresponds to the shear stress acting perpendicular to the normal stress. No stress concentration factors are to be taken into account.

   b) For strength assessment by means of finite element analysis:
      - Von Mises stress: 100% of the specified minimum yield stress of the material

   For strength assessment by means of finite element analysis, the mesh is to be fine enough to represent the geometry as realistically as possible. The ratio of element length to width is not to exceed 3. Girders are to be modelled using shell or plane stress elements. Symmetric girder flanges may be modelled by beam or truss elements. The element height of girder webs is not to exceed one-third of the web height. In way of small openings in girder webs, the web thickness is to be reduced to a mean thickness over the web height. Large openings are to be modelled. Stiffeners may be modelled using shell, plane stress, or beam elements. The mesh size of stiffeners is to be fine enough to obtain proper bending stress. If flat bars are modelled using shell or plane stress elements, dummy rod elements are to be modelled at the free edge of the flat bars and the stresses of the dummy elements are to be evaluated. Stresses are to be read from the center of the individual element. For shell elements, the stresses are to be evaluated at the mid plane of the element.
FIGURE 2
Direction of Forces and Weight (2004)

Note:
P_x to be examined from both inboard and outboard directions separately - see 3-5-1/11.3.2(a). The sign convention for y is reversed when P_x is from the opposite direction as shown.

FIGURE 3
Sign Convention (2004)

Coordinates x and y are shown as either positive (+ve) or negative (-ve).
11.5 **Vessels Less Than 54 m (175 ft) in Length**

Where it is not practical to fit an anchor windlass or winch that has been approved by ABS in accordance with 3-5-1/11.1, consideration will be given to fitting an anchor windlass that is provided with a certificate from the manufacturer. This certificate is to state that the equipment has been designed to accommodate the breaking strength of the required chain or wire rope. If the required anchor weight is less than 38.5 kg (85 lbs) no winch or windlass is required.

13 **Trial**

See 3-6-2/1.

14 **Hawse Pipes**

Hawse pipes are to be of ample size and strength; they are to have full rounded flanges and the least possible lead, in order to minimize the nip on the cables; they are to be securely attached to thick doubling or insert plates by continuous welds the size of which are to be in accordance with Section 3-2-13 for the plating thickness and type of joint selected. When in position they are to be thoroughly tested for watertightness by means of a hose in which the water pressure is not to be less than 2.06 bar (2.1 kgf/cm$^2$, 30 psi). Hawse pipes for stockless anchors are to provide ample clearances; the anchors are to be shipped and unshipped so that the Surveyor may be satisfied that there is no risk of the anchor jamming in the hawse pipe. Care is to be taken to provide a fair lead for the chain from the windlass to the hawse pipes and to the chain pipes.

15 **Securing of the Inboard Ends of Chain Cables (1 July 2018)**

Arrangements are to be provided for securing the inboard ends of the bower anchor chain cables. The chain cables are to be secured to structures by a fastening able to withstand a force not less than 15% nor more than 30% of the breaking load of the chain cable. The fastening is to be provided with a mean suitable to permit, in case of emergency, an easy slipping of the chain cables to sea, operable from an accessible position outside the chain locker.

16 **Securing of Stowed Anchors (1 July 2020)**

Arrangements are to be provided for securing the anchors and stowing the cables. To hold the anchor tight in against the hull or the anchor pocket, respectively, it is recommended to fit anchor lashings (e.g., a “devil’s claw”) are to be fitted. If fitted, anchor lashings are to be designed to resist a load at least corresponding to twice the anchor mass plus 10 m (32.8 ft) of cable without exceeding 40% of the yield strength of the material.
CHAPTER 5
Equipment

APPENDIX 1
Alternative Standard for the Required Anchor Size

1 General

All vessels are to have anchor and chain that comply with the requirements in Section 3-5-1 of these Rules or the requirements listed below. The letter ☼ will signify that the equipment of the vessel is in compliance with the requirements in these Rules and tested in accordance with Section 3-5-1/9 of these Rules.

3 Anchor Size Requirement

A minimum of one (1) anchor is to be provided that has a holding power in a bottom that has an average consistency between mud and sand that is greater than determined by the following equation. The holding power of the anchor is to be certified by the anchor manufacturer.

\[
HP = 0.0195AV_w^2 + 0.114\sqrt{\Delta L(V_c)^{1.825}} + 7.74N_pA_pV_c^2 \text{ kg}
\]

\[
HP = 0.004AV_w^2 + 0.14\sqrt{\Delta L(V_c)^{1.825}} + 1.59N_pA_pV_c^2 \text{ lbf}
\]

where

- \( HP \) = required holding power of anchor, in kg (lbf)
- \( A \) = projected frontal area of the vessel above the waterline, in m\(^2\) (ft\(^2\))
- \( V_w \) = velocity of wind acting on the vessel, not to be taken less than 50 knots
- \( \Delta \) = molded displacement of the vessel, in mt (lbf), to the summer load line
- \( L \) = length of vessel, in m (ft), as defined in 3-1-1/3
- \( V_c \) = velocity of current acting on the vessel, not to be taken less than 3 knots
- \( N_p \) = number of propellers fitted on the vessel
- \( A_p \) = area of one propeller, in m\(^2\) (ft\(^2\))

5 Anchor Chain, Cable, or Rope

The required size and length of chain, cable, or rope is to be as indicated in Section 3-5-1. Where one anchor is allowed the required chain length is one half the length required from 3-5-1/3 TABLE 1.
CHAPTER 6

Testing, Trials and Surveys During Construction – Hull

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CHAPTER 6
Testing, Trials and Surveys During Construction – Hull

SECTION 1
Tank, Bulkhead and Rudder Tightness Testing (2018)

1 General

Testing to confirm the watertightness of tanks and watertight boundaries and the structural adequacy of tanks which form the watertight subdivisions of vessels is to be completed. Verification of the weathertightness of structures and shipboard outfitting is to be carried out. The tightness of all tanks and tight boundaries of new vessels and those tanks and boundaries whose structural integrity is affected by major conversions or major repairs is to be confirmed prior to the delivery of the vessel or prior to the completion of the modification or repair as relevant.

Testing procedures of watertight compartments for vessels built in compliance with SOLAS 1974 as amended are to be carried out in accordance with 3-6-1/3, unless:

i) The shipyard provides documentary evidence of the Owner’s agreement to a request to the flag Administration for an exemption from the application of Chapter II-1, Regulation 11 of SOLAS 1974 as amended, or for an equivalency agreeing that the content of 3-6-1/5 is equivalent to Chapter II-1, Regulation 11 of SOLAS 1974 as amended; and

ii) The above-mentioned exemption/equivalency has been granted by the responsible flag Administration.

Testing procedures of watertight compartments are to be carried out in accordance with 3-6-1/5 for vessels not built in compliance with SOLAS 1974 as amended and those vessels built in compliance with SOLAS 1974 as amended for which:

i) The shipyard provides documentary evidence of the Owner’s agreement to a request to the flag Administration for an exemption from the application of Chapter II-1, Regulation 11 of SOLAS 1974 as amended, or for an equivalency agreeing that the content of 3-6-1/5 is equivalent to Chapter II-1, Regulation 11 of SOLAS 1974 as amended; and

ii) The above-mentioned exemption/equivalency has been granted by the responsible flag Administration.

Notes:

1 Watertight subdivision means the transverse and longitudinal subdivisions of the vessel required to satisfy the subdivision requirements of SOLAS Chapter II-1.

2 Major repair means a repair affecting structural integrity.
Testing Requirements for Vessels Built in Compliance with SOLAS 1974 as Amended

3.1 Application

All gravity tanks which are subjected to vapor pressure not greater than 0.7 bar (0.7 kgf/cm², 10 psi) and other boundaries required to be watertight or weathertight are to be tested in accordance with this Subsection and proven to be tight or structurally adequate as follows:

3.1.1 Gravity Tanks for their structural adequacy and tightness,

3.1.2 Watertight Boundaries Other Than Tank Boundaries for their watertightness, and

3.1.3 Weathertight Boundaries for their weathertightness.

Testing of structures not listed in 3-6-1/3.5.7 TABLE 1 is to be specially considered.

3.3 Test Types and Definitions

3.3.1 The following two types of tests are specified in this requirement.

3.3.1(a) Structural Test.
A test to verify the structural adequacy of tank construction. This may be a hydrostatic test or, where the situation warrants, a hydropneumatic test.

3.3.1(b) Leak Test.
A test to verify the tightness of a boundary. Unless a specific test is indicated, this may be a hydrostatic/hydropneumatic test or an air test. A hose test may be considered an acceptable form of leak test for certain boundaries, as indicated by Note 3 of 3-6-1/3.5.7 TABLE 1.

3.3.2 The definition of each test type is as follows:

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrostatic Test:</td>
<td>A test wherein a space is filled with a liquid to a specified head.</td>
</tr>
<tr>
<td>(Leak and Structural)</td>
<td>A test combining a hydrostatic test and an air test, wherein a space is partially filled with a liquid and pressurized with air.</td>
</tr>
<tr>
<td>Hydropneumatic Test:</td>
<td>A test to verify the tightness of a joint by a jet of water with the joint visible from the opposite side.</td>
</tr>
<tr>
<td>(Leak and Structural)</td>
<td>A test to verify tightness by means of air pressure differential and leak indicating solution. It includes tank air test and joint air tests, such as compressed air fillet weld tests and vacuum box tests.</td>
</tr>
<tr>
<td>Hose Test:</td>
<td>An air test of fillet welded tee joints wherein leak indicating solution is applied on fillet welds.</td>
</tr>
<tr>
<td>(Leak)</td>
<td>A box over a joint with leak indicating solution applied on the welds. A vacuum is created inside the box to detect any leaks.</td>
</tr>
<tr>
<td>Air Test:</td>
<td></td>
</tr>
<tr>
<td>(Leak)</td>
<td></td>
</tr>
</tbody>
</table>
### Ultrasonic Test:
*(Leak)*
A test to verify the tightness of the sealing of closing devices such as hatch covers by means of ultrasonic detection techniques.

### Penetration Test:
*(Leak)*
A test to verify that no visual dye penetrant indications of potential continuous leakages exist in the boundaries of a compartment by means of low surface tension liquids (i.e. dye penetrant test).

### 3.5 Test Procedures

#### 3.5.1 General

Tests are to be carried out in the presence of a Surveyor at a stage sufficiently close to the completion of work with all hatches, doors, windows, etc., installed and all penetrations including pipe connections fitted, and before any ceiling and cement work is applied over the joints. Specific test requirements are given in 3-6-1/3.5.4 and 3-6-1/3.5.7 TABLE 1. For the timing of the application of coating and the provision of safe access to joints, see 3-6-1/3.5.5, 3-6-1/3.5.6, and 3-6-1/3.5.7 TABLE 2.

#### 3.5.2 Structural Test Procedures

**3.5.2(a) Type and Time of Test.**

Where a structural test is specified in 3-6-1/3.5.7 TABLE 1, a hydrostatic test in accordance with 3-6-1/3.5.4(a) will be acceptable. Where practical limitations (strength of building berth, light density of liquid, etc.) prevent the performance of a hydrostatic test, a hydropneumatic test in accordance with 3-6-1/3.5.4(b) may be accepted instead.

A hydrostatic test or hydropneumatic test for the confirmation of structural adequacy may be carried out while the vessel is afloat, provided the results of a leak test are confirmed to be satisfactory before the vessel is afloat.

**3.5.2(b) Testing Schedule for New Construction or Major Structural Conversion.**

i) Tanks which are intended to hold liquids, and which form part of the watertight subdivision of the vessel*, shall be tested for tightness and structural strength as indicated in 3-6-1/3.5.7 TABLE 1 and 3-6-1/3.5.7 TABLE 2

ii) The tank boundaries are to be tested from at least one side. The tanks for structural test are to be selected so that all representative structural members are tested for the expected tension and compression.

iii) The watertight boundaries of spaces other than tanks for structural testing may be exempted, provided that the watertightness of boundaries of exempted spaces is verified by leak tests and inspections. Structural testing may not be exempted and the requirements for structural testing of tanks in 3-6-1/3.5.2(b)(i) to 3-6-1/3.5.2(b)(ii) shall apply, for ballast holds, chain lockers and a representative cargo hold if intended for import ballasting.

iv) Tanks which do not form part of the watertight subdivision of the vessel*, may be exempted from structural testing provided that the watertightness of boundaries of exempted spaces is verified by leak tests and inspections.

*Note:* *Watertight subdivision means the main transverse and longitudinal subdivisions of the vessel required to satisfy the subdivision requirements of SOLAS Chapter II-1.*

#### 3.5.3 Leak Test Procedures

For the leak tests specified in 3-6-1/3.5.7 TABLE 1, tank air tests, compressed air fillet weld tests, vacuum box tests in accordance with 3-6-1/3.5.4(d) through 3-6-1/3.5.4(f), or their combination, will be acceptable. Hydrostatic or hydropneumatic tests may also be accepted as leak tests provided that 3-6-1/3.5.5, 3-6-1/3.5.6, and 3-6-1/3.5.7 are complied with. Hose tests will also be acceptable for such locations as specified in 3-6-1/3.5.7 TABLE 1, note 3, in accordance with 3-6-1/3.5.4(c).
The application of the leak test for each type of welded joint is specified in 3-6-1/3.5.7 TABLE 2.

Air tests of joints may be carried out in the block stage provided that all work on the block that may affect the tightness of a joint is completed before the test. See also 3-6-1/3.5.5(a) for the application of final coatings and 3-6-1/3.5.6 for the safe access to joints and the summary in 3-6-1/3.5.7 TABLE 2.

### 3.5.4 Test Methods

#### 3.5.4(a) Hydrostatic Test.

Unless another liquid is approved, hydrostatic tests are to consist of filling the space with fresh water or sea water, whichever is appropriate for testing, to the level specified in 3-6-1/3.5.7 TABLE 1. See also 3-6-1/3.5.7.

In cases where a tank is designed for cargo densities greater than sea water and testing is with fresh water or sea water, the testing pressure height is to simulate the actual loading for those greater cargo densities as far as practicable.

All external surfaces of the tested space are to be examined for structural distortion, bulging and buckling, other related damage and leaks.

#### 3.5.4(b) Hydropneumatic Test.

Hydropneumatic tests, where approved, are to be such that the test condition, in conjunction with the approved liquid level and supplemental air pressure, will simulate the actual loading as far as practicable. The requirements and recommendations for tank air tests in 3-6-1/3.5.4(d) will also apply to hydropneumatic tests. See also 3-6-1/3.5.7.

All external surfaces of the tested space are to be examined for structural distortion, bulging and buckling, other related damage and leaks.

#### 3.5.4(c) Hose Test.

Hose tests are to be carried out with the pressure in the hose nozzle maintained at least at 2 bar (2 kgf/cm², 30 psi) during the test. The nozzle is to have a minimum inside diameter of 12 mm (0.5 in.) and be at a perpendicular distance from the joint not exceeding 1.5 m (5 ft). The water jet is to impinge directly upon the weld.

Where a hose test is not practical because of possible damage to machinery, electrical equipment insulation or outfitting items, it may be replaced by a careful visual examination of welded connections, supported where necessary by means such as a dye penetrant test or ultrasonic leak test or the equivalent.

#### 3.5.4(d) Tank Air Test.

All boundary welds, erection joints and penetrations, including pipe connections, are to be examined in accordance with approved procedure and under a stabilized pressure differential above atmospheric pressure not less than 0.15 bar (0.15 kgf/cm², 2.2 psi), with a leak indicating solution such as soapy water/detergent or a proprietary brand applied.

A U-tube with a height sufficient to hold a head of water corresponding to the required test pressure is to be arranged. The cross sectional area of the U-tube is not to be less than that of the pipe supplying air to the tank. Arrangements involving the use of two calibrated pressure gauges to verify the required test pressure may be accepted taking into account the provisions in F5.1 and F7.4 of IACS Recommendation 140, “Recommendation for Safe Precautions during Survey and Testing of Pressurized Systems”.

Other effective methods of air testing, including compressed air fillet weld testing or vacuum testing, may be considered in accordance with 3-6-1/3.5.4(i).
A double inspection is to be made of tested welds. The first is to be immediately upon applying the leak indication solution; the second is to be after approximately four or five minutes, without further application of leak indication solution, in order to detect those smaller leaks which may take time to appear.

3.5.4(e) Compressed Air Fillet Weld Test.
In this air test, compressed air is injected from one end of a fillet welded joint and the pressure verified at the other end of the joint by a pressure gauge. Pressure gauges are to be arranged so that an air pressure of at least 0.15 bar (0.15 kgf/cm², 2.2 psi) can be verified at each end of all passages within the portion being tested.

For limited portions of the partial penetration or fillet welded joints forming tank boundaries, such as corners and section of the weld adjacent to the testing apparatus, the attending Surveyor may accept the use of Magnetic Particle Inspection or Dye Penetration examination as an alternative to fillet air testing.

Where a leaking test of partial penetration welding is required and the root face is sufficiently large such as 6-8 mm (0.24-0.32 inch), the compressed air test is to be applied in the same manner as for a fillet weld.

3.5.4(f) Vacuum Box Test.
A box (vacuum testing box) with air connections, gauges and an inspection window is placed over the joint with a leak indicating solution applied to the weld cap vicinity. The air within the box is removed by an ejector to create a vacuum of 0.20 bar (0.20 kgf/cm², 2.9 psi) – 0.26 bar (0.27 kgf/cm², 3.8 psi) inside the box.

3.5.4(g) Ultrasonic Test.
An ultrasonic echo transmitter is to be arranged inside of a compartment and a receiver is to be arranged on the outside. The watertight/weathertight boundaries of the compartment are scanned with the receiver in order to detect an ultrasonic leak indication. A location where sound is detectable by the receiver indicates a leakage in the sealing of the compartment.

3.5.4(h) Penetration Test.
A test of butt welds or other weld joints uses the application of a low surface tension liquid at one side of a compartment boundary or structural arrangement. If no liquid is detected on the opposite sides of the boundaries after the expiration of a defined period of time, this indicates tightness of the boundaries. In certain cases, a developer solution may be painted or sprayed on the other side of the weld to aid leak detection.

3.5.4(i) Other Test.
Other methods of testing, except as provided in 3-6-1/5, may be considered upon submission of full particulars prior to the commencement of testing.

3.5.5 Application of Coating
3.5.5(a) Final Coating.
For butt joints welded by an automatic process, the final coating may be applied any time before the completion of a leak test of spaces bounded by the joints, provided that the welds have been carefully inspected visually to the satisfaction of the Surveyor.

Surveyors reserve the right to require a leak test prior to the application of final coating over automatic erection butt welds.

For all other joints, the final coating is to be applied after the completion of the leak test of the joint. See also 3-6-1/3.5.7 TABLE 2.

3.5.5(b) Temporary Coating.
Any temporary coating which may conceal defects or leaks is to be applied at the time as specified for the final coating (see 3-6-1/3.5.5(a)). This requirement does not apply to shop primer.

### 3.5.6 Safe Access to Joints

For leak tests, safe access to all joints under examination is to be provided. See also 3-6-1/3.5.7 TABLE 2.

### 3.5.7 Hydrostatic or Hydropneumatic Tightness Test

In cases where the hydrostatic or hydropneumatic tests are applied instead of a specific leak test, examined boundaries must be dew-free, otherwise small leaks are not visible.

**TABLE 1**

Testing Requirements for Tanks and Boundaries (2018)

<table>
<thead>
<tr>
<th>Tank or Boundary to be Tested</th>
<th>Test Type</th>
<th>Test Head or Pressure</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Double bottom tanks&lt;sup&gt;(4)&lt;/sup&gt;</td>
<td>Leak &amp; Structural &lt;sup&gt;(1)&lt;/sup&gt;</td>
<td>The greater of - top of the overflow, - to 2.4 m (8 ft) above top of tank&lt;sup&gt;(2)&lt;/sup&gt;, or - to bulkhead deck</td>
<td></td>
</tr>
<tr>
<td>2 Double bottom voids&lt;sup&gt;(5)&lt;/sup&gt;</td>
<td>Leak</td>
<td>See 3-6-1/3.5.4(d) through 3-6-1/3.5.4(f), as applicable</td>
<td>Including pump room double bottom and bunker tank protection double hull required by MARPOL Annex I</td>
</tr>
<tr>
<td>3 Double side tanks</td>
<td>Leak &amp; Structural &lt;sup&gt;(1)&lt;/sup&gt;</td>
<td>The greater of - top of the overflow, - to 2.4 m (8 ft) above top of tank&lt;sup&gt;(2)&lt;/sup&gt;, or - to bulkhead deck</td>
<td></td>
</tr>
<tr>
<td>4 Double side voids</td>
<td>Leak</td>
<td>See 3-6-1/3.5.4(d) through 3-6-1/3.5.4(f), as applicable</td>
<td></td>
</tr>
<tr>
<td>5 Deep tanks other than those listed elsewhere in this table</td>
<td>Leak &amp; Structural &lt;sup&gt;(1)&lt;/sup&gt;</td>
<td>The greater of - top of the overflow, or - to 2.4 m (8 ft) above top of tank&lt;sup&gt;(2)&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>6 Cargo oil tanks</td>
<td>Leak &amp; Structural &lt;sup&gt;(1)&lt;/sup&gt;</td>
<td>The greater of - top of the overflow, - to 2.4 m (8 ft) above top of tank&lt;sup&gt;(2)&lt;/sup&gt;, or - to top of tank&lt;sup&gt;(2)&lt;/sup&gt; plus setting of any pressure relief valve</td>
<td></td>
</tr>
<tr>
<td>7 Ballast hold of bulk carriers</td>
<td>Leak &amp; Structural &lt;sup&gt;(1)&lt;/sup&gt;</td>
<td>Top of cargo hatch coaming</td>
<td>See item 16 for hatch covers.</td>
</tr>
<tr>
<td>8 Peak tanks</td>
<td>Leak &amp; Structural &lt;sup&gt;(1)&lt;/sup&gt;</td>
<td>The greater of - top of the overflow, or - to 2.4 m (8 ft) above top of tank&lt;sup&gt;(2)&lt;/sup&gt;</td>
<td>After peak to be tested after installation of stern tube</td>
</tr>
<tr>
<td>Tank or Boundary to be Tested</td>
<td>Test Type</td>
<td>Test Head or Pressure</td>
<td>Remarks</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-----------</td>
<td>-----------------------</td>
<td>---------</td>
</tr>
<tr>
<td>.1 Fore peak spaces with equipment</td>
<td>Leak</td>
<td>See 3-6-1/3.5.4(c) through 3-6-1/3.5.4(f), as applicable</td>
<td></td>
</tr>
<tr>
<td>.2 Fore peak voids</td>
<td>Leak</td>
<td>See 3-6-1/3.5.4(d) through 3-6-1/3.5.4(f), as applicable</td>
<td></td>
</tr>
<tr>
<td>.3 Aft peak spaces with equipment</td>
<td>Leak</td>
<td>See 3-6-1/3.5.4(c) through 3-6-1/3.5.4(f), as applicable</td>
<td>After peak to be tested after installation of stern tube</td>
</tr>
<tr>
<td>.4 Aft peak voids</td>
<td>Leak</td>
<td>See 3-6-1/3.5.4(d) through 3-6-1/3.5.4(f), as applicable</td>
<td></td>
</tr>
<tr>
<td>9. Cofferdams</td>
<td>Leak</td>
<td>See 3-6-1/3.5.4(d) through 3-6-1/3.5.4(f), as applicable</td>
<td></td>
</tr>
<tr>
<td>.1 Watertight bulkheads</td>
<td>Leak</td>
<td>See 3-6-1/3.5.4(c) through 3-6-1/3.5.4(f), as applicable</td>
<td></td>
</tr>
<tr>
<td>.2 Superstructure end bulkheads</td>
<td>Leak</td>
<td>See 3-6-1/3.5.4(c) through 3-6-1/3.5.4(f), as applicable</td>
<td></td>
</tr>
<tr>
<td>.3 Cable penetrations in watertight bulkheads</td>
<td>Hose</td>
<td>See 3-6-1/3.5.4(c)</td>
<td></td>
</tr>
<tr>
<td>12. Watertight doors below freeboard or bulkhead deck</td>
<td>Leak</td>
<td>See 3-6-1/3.5.4(c) through 3-6-1/3.5.4(f), as applicable</td>
<td>See 3-2-9/9.11 of the Marine Vessel Rules for additional test at the manufacturer.</td>
</tr>
<tr>
<td>.3 Freeboard ships</td>
<td>Leak</td>
<td>See 3-6-1/5.3, 3-6-1/5.5, 3-6-1/5.9 and 3-6-1/5.11, as applicable</td>
<td></td>
</tr>
<tr>
<td>.3 Freeboard vessels with a length of more than 20 meters</td>
<td>Leak</td>
<td>See 3-6-1/5.3, 3-6-1/5.5, 3-6-1/5.9 and 3-6-1/5.11, as applicable</td>
<td></td>
</tr>
<tr>
<td>.3 Freeboard vessels</td>
<td>Leak</td>
<td>See 3-6-1/5.3, 3-6-1/5.5, 3-6-1/5.9 and 3-6-1/5.11, as applicable</td>
<td></td>
</tr>
<tr>
<td>.3 Freeboard vessels with a length of more than 20 meters</td>
<td>Leak</td>
<td>See 3-6-1/5.3, 3-6-1/5.5, 3-6-1/5.9 and 3-6-1/5.11, as applicable</td>
<td></td>
</tr>
<tr>
<td>14. Shaft tunnels clear of deep tanks</td>
<td>Leak</td>
<td>See 3-6-1/5.3, 3-6-1/5.5, 3-6-1/5.9 and 3-6-1/5.11, as applicable</td>
<td></td>
</tr>
<tr>
<td>15. Shell doors</td>
<td>Leak</td>
<td>See 3-6-1/5.3, 3-6-1/5.5, 3-6-1/5.9 and 3-6-1/5.11, as applicable</td>
<td></td>
</tr>
<tr>
<td>.3 Weathertight hatch covers and closing appliances</td>
<td>Leak</td>
<td>See 3-6-1/5.3, 3-6-1/5.5, 3-6-1/5.9 and 3-6-1/5.11, as applicable</td>
<td>Hatch covers closed by tarpaulins and battens excluded</td>
</tr>
<tr>
<td>17. Dual purpose tanks/dry cargo hatch covers</td>
<td>Leak</td>
<td>See 3-6-1/5.3, 3-6-1/5.5, 3-6-1/5.9 and 3-6-1/5.11, as applicable</td>
<td>In addition to structural test in item 6 or 7</td>
</tr>
<tr>
<td>18. Chain lockers</td>
<td>Leak &amp; Structural</td>
<td>Top of chain pipe</td>
<td></td>
</tr>
<tr>
<td>19. L.O. sump tanks and other similar tanks/spaces under main engine</td>
<td>Leak</td>
<td>See 3-6-1/3.5.4(c) through 3-6-1/3.5.4(f), as applicable</td>
<td></td>
</tr>
</tbody>
</table>
### Table: Tank or Boundary to be Tested

<table>
<thead>
<tr>
<th>Tank or Boundary to be Tested</th>
<th>Test Type</th>
<th>Test Head or Pressure</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 Ballast ducts</td>
<td>Leak &amp; Structural (1)</td>
<td>The greater of - ballast pump maximum pressure, or - setting of any pressure relief valve</td>
<td></td>
</tr>
<tr>
<td>21 Fuel Oil Tanks</td>
<td>Leak &amp; Structural (1)</td>
<td>The greater of - top of the overflow, or - to 2.4 m (8 ft) above top of tank (2), or - to top of tank (2) plus setting of any pressure relief valve, or - to bulkhead deck</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**

1. *(2018)* Refer to 3-6-1/3.5.2(b).
2. Top of tank is the deck forming the top of the tank, excluding any hatchways.
3. *(2018)* Hose Test may also be considered as a medium of the test. See 3-6-1/3.3.2.
4. Including tanks arranged in accordance with the provisions of SOLAS regulation II-1/9.4
5. *(2016)* Including duct keels and dry compartments arranged in accordance with the provisions of SOLAS regulation II-1/11.2 and II-1/9.4 respectively, and/or oil fuel tank protection and pump room bottom protection arranged in accordance with the provisions of MARPOL Annex I, Chapter 3, Part A regulation 12A and Chapter 4, Part A, regulation 22, respectively.
6. Where water tightness of a watertight door has not confirmed by prototype test, testing by filling watertight spaces with water is to be carried out. See SOLAS regulation II-1/16.2 and MSC/Circ.1176.
7. *(2018)* As an alternative to the hose testing, other testing methods listed in 3-6-1/3.5.4(g) through 3-6-1/3.5.4(i) may be applicable subject to adequacy of such testing methods being verified. See SOLAS regulation II-1/11.1. For watertight bulkheads (item 11.1) alternatives to the hose testing may only be used where a hose test is not practicable.
8. *(2018)* A “Leak and structural test”, see 3-6-1/3.5.2(b), is to be carried out for a representative cargo hold if intended for in-port ballasting. The filling level requirement for testing cargo holds intended for in-port ballasting is to be the maximum loading that will occur in-port as indicated in the loading manual.
9. *(2018)* Where L.O. sump tanks and other similar spaces under main engines intended to hold liquid form part of the watertight subdivision of the vessel, they are to be tested as per the requirements of Item 5, Deep tanks other than those listed elsewhere in this table.
### TABLE 2
Application of Leak Testing, Coating and Provision of Safe Access for Type of Welded Joints (2016)

<table>
<thead>
<tr>
<th>Type of Welded Joints</th>
<th>Leak Testing</th>
<th>Coating (1)</th>
<th>Safe Access (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Before Leak Testing</td>
<td>After Leak Testing &amp; Before Structural Test</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Butt</td>
<td>Automatic</td>
<td>Not required</td>
<td>Allowed&lt;sup&gt;(3)&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Manual or Semi-automatic&lt;sup&gt;(4)&lt;/sup&gt;</td>
<td>Required</td>
<td>Not allowed</td>
</tr>
<tr>
<td>Fillet</td>
<td>Boundary including penetrations</td>
<td>Required</td>
<td>Not allowed</td>
</tr>
</tbody>
</table>

**Notes:**

1. Coating refers to internal (tank/hold coating), where applied, and external (shell/deck) painting. It does not refer to shop primer.
2. Temporary means of access for verification of the leak testing.
3. The condition applies provided that the welds have been carefully inspected visually to the satisfaction of the Surveyor.
4. (2016) Flux Core Arc Welding (FCAW) semiautomatic butt welds need not be tested provided that careful visual inspections show continuous uniform weld profile shape, free from repairs, and the results of the Rule and Surveyor required NDE testing show no significant defects.

### 5 Testing Requirements for Vessels Not Built in Compliance with SOLAS 1974 as Amended

#### 5.1
Testing procedures are to be carried out in accordance with the requirements of 3-6-1/3 in association with the following alternative procedures for 3-6-1/3.5.2(b) “Testing Schedule for New Construction or Major Structural Conversion” and alternative test requirements for 3-6-1/3.5.7 TABLE 1.

#### 5.3
The tank boundaries are to be tested from at least one side. The tanks for structural test are to be selected so that all representative structural members are tested for the expected tension and compression.

#### 5.5
Structural tests are to be carried out for at least one tank of a group of tanks having structural similarity (i.e., same design conditions, alike structural configurations with only minor localized differences determined to be acceptable by the attending Surveyor) on each vessel provided all other tanks are tested for leaks by an air test. The acceptance of leak testing using an air test instead of a structural test does not apply to cargo space boundaries adjacent to other compartments in tankers and combination carriers or to the boundaries of tanks for segregated cargoes or pollutant cargoes in other types of vessels.
5.7 Additional tanks may require structural testing if found necessary after the structural testing of the first tank.

5.9 Where the structural adequacy of the tanks of a vessel were verified by the structural testing required in 3-6-1/3.5.7 TABLE 1, subsequent vessels in the series (i.e. sister vessels built from the same plans at the same shipyard) may be exempted from structural testing of tanks, provided that:

i) watertightness of boundaries of all tanks is verified by leak tests and thorough inspections are carried out

ii) Structural testing is carried out for at least one tank of each type among all tanks of each sister vessel

iii) Additional tanks may require structural testing if found necessary after the structural testing of the first tank or if deemed necessary by the attending Surveyor

For cargo space boundaries adjacent to other compartments in tankers and combination carriers or boundaries of tanks for segregated cargoes or pollutant cargoes in other types of vessels, the provisions of 3-6-1/5.3 shall apply in lieu of 3-6-1/5.5.

5.11 Sister vessels built (i.e., keel laid) two years or more after the delivery of the last vessel of the series, may be tested in accordance with 3-6-1/5.5 at the discretion of the Surveyor, provided that:

i) General workmanship has been maintained (i.e., there has been no discontinuity of shipbuilding or significant changes in the construction methodology or technology at the yard and shipyard personnel are appropriately qualified and demonstrate an adequate level of workmanship as determined by the Surveyor).

ii) An NDT plan is implemented and evaluated by the Surveyor for the tanks not subject to structural tests. Shipbuilding quality standards for the hull structure during new construction are to be reviewed and agreed during the kick-off meeting. Structural fabrication is to be carried out in accordance with IACS Recommendation 47, “Shipbuilding and Repair Quality Standard”, or a recognized fabrication standard to the satisfaction of the attending Surveyor prior to the commencement of fabrication/construction. The work is to be carried out in accordance with the Rules and under survey of the Surveyor.
1 Anchor Windlass Trials (1 July 2012)

Each windlass is to be tested under working conditions after installation onboard to demonstrate satisfactory operation. Each unit is to be independently tested for braking, clutch functioning, lowering and hoisting of chain cable and anchor, proper riding of the chain over the chain lifter, proper transit of the chain through the hawsepipe and the chain pipe, and effecting proper stowage of the chain and the anchor. It is to be confirmed that anchors properly seat in the stored position and that chain stoppers function as designed if fitted. The mean hoisting speed, as specified in 4-5-1/5.1.4, is to be measured and verified, with each anchor and at least 82.5 m (45 fathoms) length of chain submerged and hanging free. The braking capacity is to be tested by intermittently paying out and holding the chain cable by means of the application of the brake. Where the available water depth is insufficient, the proposed test method will be specially considered.

3 Bilge System Trials

All elements of the bilge system are to be tested to demonstrate satisfactory pumping operation, including emergency suctions and all controls. Upon completion of the trials, the bilge strainers are to be opened, cleaned and closed up in good order.

5 Steering Trials

Refer to 4-3-4/21.7 for the technical details of the steering trials.
1 Construction Welding and Fabrication

For surveys of hull construction welding and fabrication, refer to Chapter 4 of the ABS Rules for Materials and Welding (Part 2) and Section 2-4-5 of the ABS Rules for Materials and Welding (Part 2) and to the ABS Guide for Nondestructive Inspection.

1.1 Hull Construction Monitoring Plan (1 July 2022)

For vessels requiring a Construction Monitoring Plan, the shipyard is to incorporate the requirements of the approved hull construction monitoring plan as required by 3-1-2/9.7 into the construction process quality documents. The Surveyor is to review and accept the shipyard construction process quality documents for identification of hold points, monitoring points and documentation reviews to ensure each aspect identified in the Construction Monitoring Plan is documented and accepted. An approved copy of the completed Construction Monitoring Plan is to be placed on board the vessel at delivery.

i) Critical joints and details are to be examined, measured, corrected (if required), and recorded. The shipyard quality personnel are responsible for recording in accordance with the approved record format. The Surveyor is to endorse the monitor records submitted by the shipyard.

ii) Construction standards and control procedures to be applied.

iii) Verification and recording procedures at each stage of construction.

iv) Locations of nondestructive testing as required by 1/3.3 of the ABS Guide for Nondestructive Inspection are also to be selected from critical joints in the Construction Monitoring Plan.

v) Where defect correction is required in critical joints, the defect is to be reported to the Surveyor prior to repairs. Repairs are to be carried out in accordance with the procedures indicated in the approved Construction Monitoring Plan and to the satisfaction of the Surveyor. Nondestructive testing (NDT) is to be applied to those critical joints that require defect correction at the discretion of the attending Surveyor.

1.1.1 Aluminum Vessels

For vessels requiring a Construction Monitoring Plan (CMP), in addition to the requirements in 3-1-2/9.7 and 3-6-3/1.1, the number of welding thermal cycles are to be tracked during production and recorded to the satisfaction of the attending Surveyor. In general, this is to include:

i) Failed NDT requiring weld rework

ii) Structure cut loose for misalignment and fitting
iii) Any major rewelding carried out

Note: Minor weld “pick-up” is not considered a heat cycle unless the repair is extensive. “Major rewelding” is to be defined in the CMP and is generally considered structure that is cut loose for realignment, gouged and rewelded areas beyond normal pick-up such as failed NDT and other significant rewelding activities.

1.1.2 Fatigue Assessment Surveys

Where the fatigue strength assessment is carried out in accordance with 1-1-4/Table 2 of ABS Rules for Conditions of Classification – Light and High-Speed Craft (Part 1), the additional survey requirements for hull construction in 3-2-A4/1.5 are to be followed.

3 Hull Castings and Forgings

For surveys in connection with the manufacture and testing of hull castings and forgings, refer to Chapter 1 of the ABS Rules for Materials and Welding (Part 2).

5 Piping

For surveys in connection with the manufacture and testing of piping, refer to Part 4, Chapter 6 of these Rules.