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“*Study & Comparison of Classification Societies’ Rules and Regulations on Metallic Materials, Composite Materials & Design Loads of Small Crafts*”

ΑΓΓΕΛΟΣ ΜΠΑΡΔΟΥΤΣΟΣ

ΕΠΙΒΛΕΠΩΝ ΚΑΘΗΓΗΤΗΣ: ΝΙΚΟΛΑΟΣ ΤΣΟΥΒΑΛΗΣ

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1 Introduction

The scope of this thesis is to lay the foundations of an extended study on the field of the ship structures, in terms of evaluating the quality of metallic and composite materials and of estimating loading on small crafts. To achieve this, the rules and regulations of five IACS classification societies have been collected in order to be primarily compared. The classification societies, of which rules are going to be inspected, are ABS, BV, DNV-GL, LR and RINA.

The secondary purpose that this thesis serves, is for it to work as a consultative guide to any designer of small crafts or even a shipbuilder. Since the market of high-speed craft is in growth, a collection of the rules and regulations of five major classification societies would be a great tool to the naval architect. It would help to choose the class of the shell envelope materials, whether they are metallic (steels or aluminum) or composite (FRP) materials. Also, in conjunction with rules referring to the design loads, it would assist the designer to predict the pressures that are going to act on primary and secondary stiffening elements, thus help them determine their thicknesses.

Small crafts used to get made mostly with metallic materials, steels and aluminium but over 30 years composite materials have been widely used in naval shipbuilding. The classification societies’ requirements to be examined refer to those materials due to their utility and market significance.

The type of craft whose rules on design loads are going to be compared are the High-Speed Crafts and Yachts. Intention for this choice is to pick a type of craft that is extensively used, for passenger and cargo services, and a type of crafts that can be built to use sails as its primary means of propulsion.

In the first chapter the rules on metallic materials as given by ABS, BV, DNV-GL, LR and RINA are collocated. The rules that mainly define the quality of the product to wit, those referring to chemical composition, mechanical properties and testing procedures are presented. The classification societies are tested for discrepancies among them, variety of classified grade of materials, quality of classified materials and completeness of their rules.

The next chapter is arranged in a similar fashion and its topic is composite materials, specifically fibre reinforced materials. Firstly, each constituent material’s mechanical properties, as regulated by the classification societies, are compared separately. Then a calculative comparison is arranged in order to examine the differences on the mechanical properties of a combined laminate form.

The design loads under survey, of the last chapter, are the ones that each classification society suggests that is necessary to be considered. Of course, several locations that are of major importance for a craft’s strength and are specially referred by all the societies are particularly set side by side, while a segment, containing the various regions of the craft that each society forecasts, is also included. Due to its importance on design pressures of High-Speed Crafts and Yachts, the vertical acceleration requirements are discussed at the start of the third chapter. Parallel to the chapter’s topic an example application of the rules on a hypothetical high-speed craft is carried out, to have a practical view on the matter.

To summarize, the conclusions refer to the attributes that each classification society has shown and the characteristics that may slightly distinguish them from the rest. In terms of materials, the societies will be evaluated for the variety of classified products, the quality of those and the competency of their rules. Considering design loads, conclusions will be drawn through the calculations of a rule application example. Those calculations will help to set a primary comparison among the rules of the societies, as of which one’s estimations result to greater values. Moreover it is investigated whether the answer to which society forecasts greater loading is affected by the vertical or the longitudinal position of the load point considered. For example: *would the classification society, which estimates the greater pressure at the bottom, estimate also the greater pressure at the side or the deck?* Or *would the classification society, which estimates the greater pressure near the stem, estimate also the greater pressure near the stern or amidships?*

Chapter

2 Metallic Materials (Steels & Aluminum Alloys)

Section

2.1 Introduction

2.1.1 Scope

At the present chapter rules and regulations of the five classification societies concerning basic metallic materials for shipbuilding are examined for any differentiations or discrepancies among them. The referring materials are normal and higher strength steels, low temperature and “Z” grade with specified through thickness properties steels and aluminum alloys. The rules that are inspected concern chemical compositions, testing procedures and mechanical properties that each classification society suggests.

Section

2.2 Chemical Composition

2.2.1 General

Although the referred materials are very common and it is expected of them not to have many differences in chemical composition, it is possible that a classification society would provide rules for more grades than another or could differentiate on compositional details of a specific grade.

In cases where two or more classification societies completely agree on chemical compositions of a certain grade, only one’s information are presented analytically. The rest will be presented by name as equal grades.

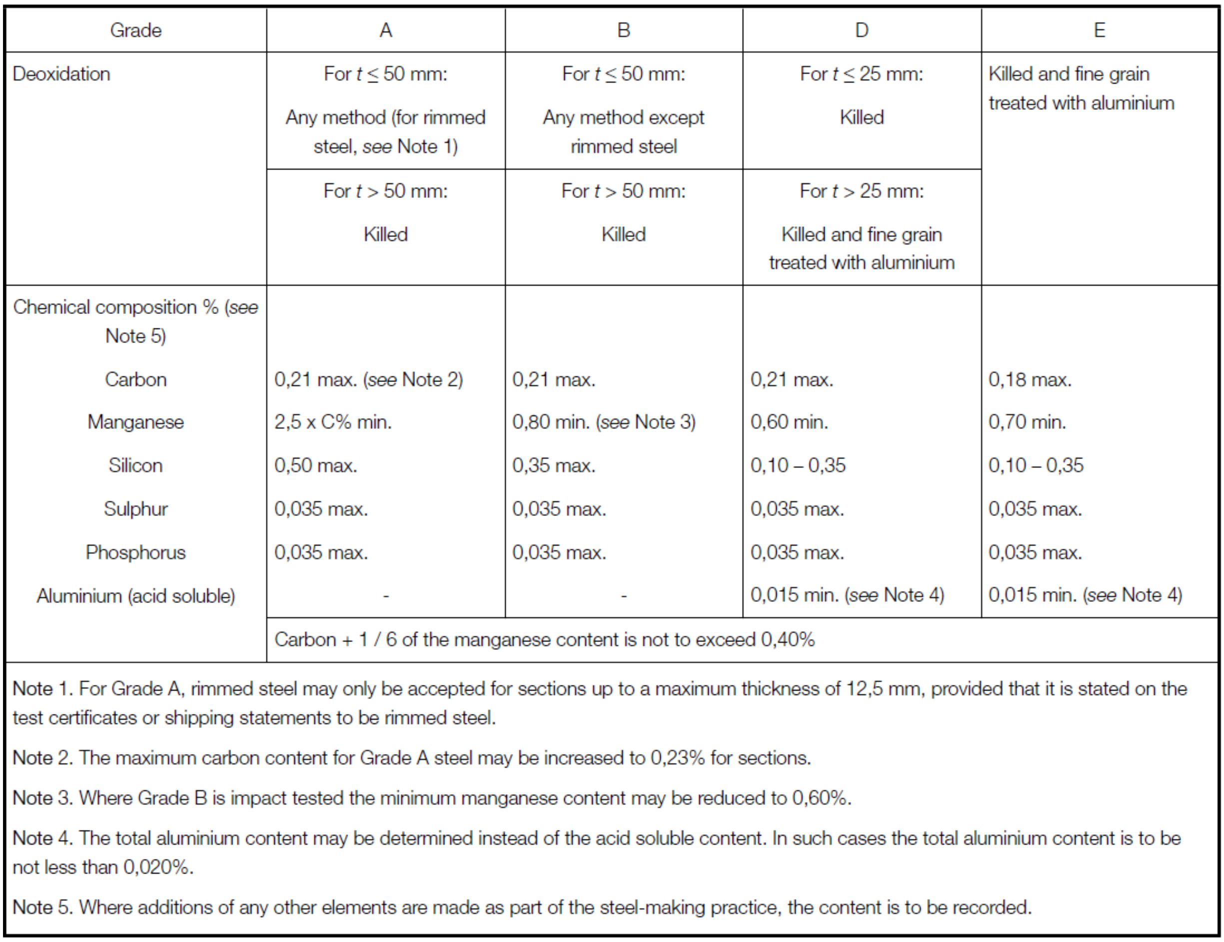
2.2.2 Normal Strength Steels (NSS)

2.2.2.1 Lloyd’s Register (NSS)

The requirements of this section are primarily intended to apply to steel plates and wide flats not exceeding 100 mm in thickness and to sections and bars not exceeding 50 mm in thickness in Grades A, B, D and E.

In *Rules for the Manufacture, Testing and Certification of Materials (July 2018)*[1] by LR, the grades of normal strength steels are presented in Ch. 3, sec.2, respective data of which are listed in *Table 2.2.1 Chemical composition and deoxidation practice (LR).*

Table 2.2. 1 Chemical composition and deoxidation practice (LR)



Grade	A	B	D	E
Deoxidation	For $t \leq 50$ mm: Any method (for rimmed steel, *see* Note 1)	For $t \leq 50$ mm: Any method except rimmed steel	For $t \leq 25$ mm: Killed	Killed and fine grain treated with aluminium
	For $t > 50$ mm: Killed	For $t > 50$ mm: Killed	For $t > 25$ mm: Killed and fine grain treated with aluminium	
Chemical composition % (*see* Note 5)				
Carbon	0,21 max. (*see* Note 2)	0,21 max.	0,21 max.	0,18 max.
Manganese	2,5 x C% min.	0,80 min. (*see* Note 3)	0,60 min.	0,70 min.
Silicon	0,50 max.	0,35 max.	0,10 – 0,35	0,10 – 0,35
Sulphur	0,035 max.	0,035 max.	0,035 max.	0,035 max.
Phosphorus	0,035 max.	0,035 max.	0,035 max.	0,035 max.
Aluminium (acid soluble)	-	-	0,015 min. (*see* Note 4)	0,015 min. (*see* Note 4)
	Carbon + 1 / 6 of the manganese content is not to exceed 0,40%			

Note 1. For Grade A, rimmed steel may only be accepted for sections up to a maximum thickness of 12,5 mm, provided that it is stated on the test certificates or shipping statements to be rimmed steel.

Note 2. The maximum carbon content for Grade A steel may be increased to 0,23% for sections.

Note 3. Where Grade B is impact tested the minimum manganese content may be reduced to 0,60%.

Note 4. The total aluminium content may be determined instead of the acid soluble content. In such cases the total aluminium content is to be not less than 0,020%.

Note 5. Where additions of any other elements are made as part of the steel-making practice, the content is to be recorded.

2.2.2.2 American Bureau of Shipping (NSS)

In **ABS** *Rules for Materials and Welding (January 2018)*[2]*, Ch.1 Sec.2* a similar table with *Table 2.2.1 Chemical composition and deoxidation practice (LR)* can be found. Equal grades of ABS's are marked as AB/A, AB/B, AB/D and AB/E respectively. Beyond marking ABS table of chemical composition differs on the amount of notes, as it includes four more than LR. These notes are the following:

- Considering Grade D and E. Where the content of soluble aluminum is not less than 0,015%, the minimum required Si content does not apply.
- Including indication for Ni, Cr, Mo and Cu elements. The contents of nickel, chromium, molybdenum and copper are to be determined and reported. When the amount does not exceed 0,02%, these elements may be reported as ≤0,02%.
- Specific Grade indication based on deoxidation practice. Grade D hull steel which is normalized, thermo-mechanical control processed or control rolled is to be marked AB/DN.

- Note for a certain quality. (2015) For steels of cold flanging quality, the maximum sulfur content is 0,020%.

2.2.2.3 Bureau Veritas (NSS)

BV *Rules on Materials and Welding for the Classification of Marine Units (January 2018)*[3] set requirements which are also similar to LR *Table 2.2.1 Chemical composition and deoxidation practice (LR)*. However, in Table 1 of Rules on Materials and Welding for the Classification of Marine Units, Ch. 2 Sec.1, two more added notes can be found. Also, considering Grade D and E, BV does not provide a lower limit for the content of Si, thus the BV's respective value is max. 0,35%. BV marks of grades are as LR to wit, A, B, D and E. The additional comments are the following:

- Allowing variation on chemical composition under certain condition. When any grade of steel is supplied in the thermo-mechanically rolled condition, variations in the specified chemical composition may be allowed or required by the Society and are to be stated at the approval.
- Warning on use of other elements. The Society may limit the amount of residual elements which may have an adverse effect on the working and use of the steel, e.g. Cu and Sn.

2.2.2.4 Det Norske Veritas – Germanischer Lloyd (NSS)

Besides a note that refers to the contents of Si, Cu, Mo and Cr, DNV-GL's *Rules for classification: Ships (July 2018)*[4] Pt.2 Ch.2 Sec.2 totally agrees with LR.

DNV-GL marks of grades are VL-A, VL-B, VL-D and VL-E.

- Additional note on elements' content, unless otherwise approved, the following additional limits apply:
  - — Cu Max. 0,35%
  - — Cr Max. 0,20%
  - — Ni Max. 0,40%
  - — Mo Max. 0,08%

2.2.2.5 Registro Italiano Navale (NSS)

RINA requirement in *Rules for the Classification of Ships (January 2018)*[5] in Pt. D of *Materials and Welding* Ch. 2, Sec.1 is identical to BV. Thus, no further comments are made.

2.2.2.6 Conclusion (NSS)

DNV-GL rules seem to be more firm as they include limits on the alloying elements Cu, Cr, Ni and Mo, which can affect the mechanical properties of the material, while the other classification societies simply request additional elements to be reported. BV and RINA are the most flexible of the five, which may warn about the use of other element but they allow variations on chemical composition. Another example of flexibility is that they do not apply a lower limit of silicon content for grades D and E.

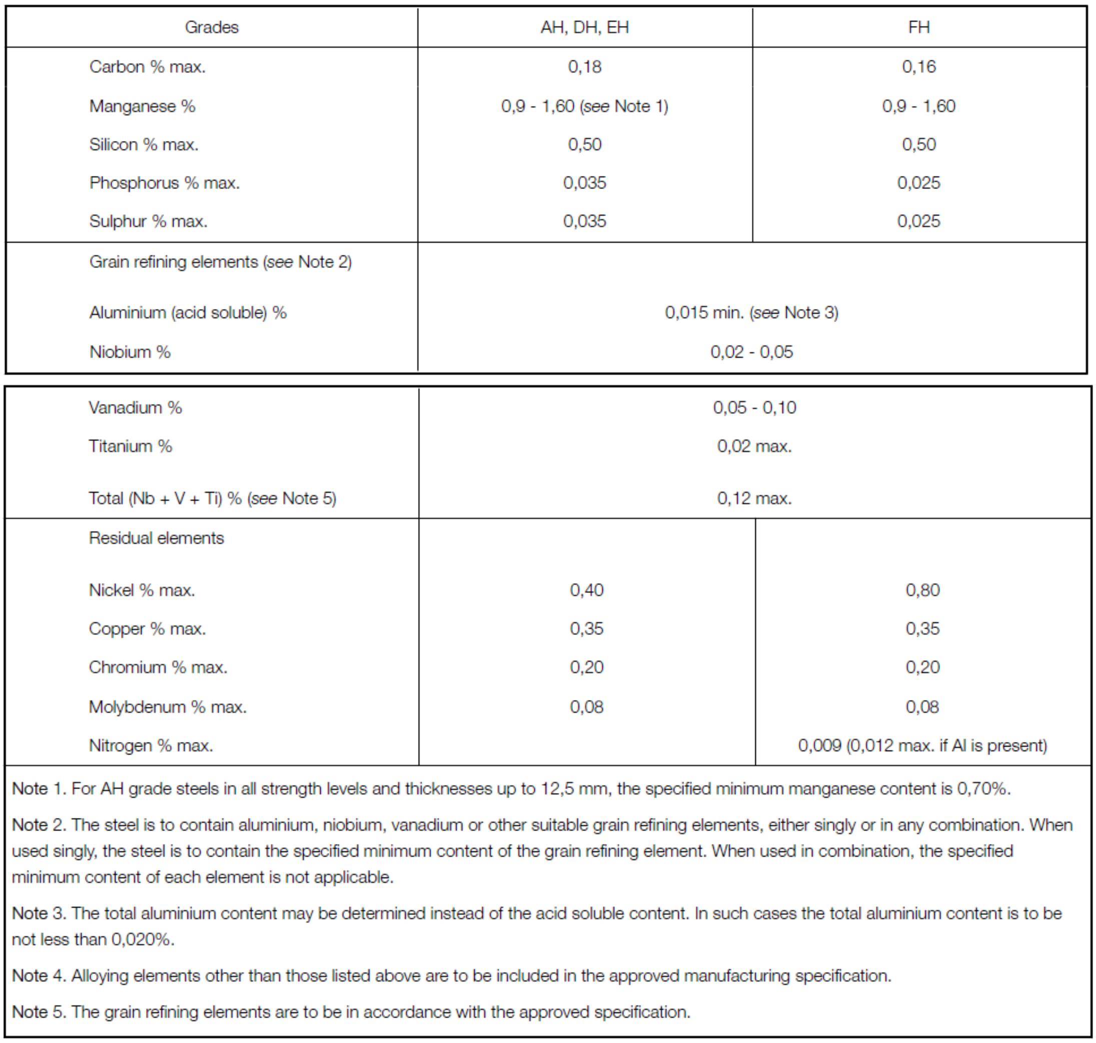
2.2.3 Higher Strength Steels (HSS)

2.2.3.1 Lloyd’s Register (HSS)

LR make provision for material to be supplied in four strength levels, 27S, 32, 36 and 40. Also LR includes requirements for strength level 47 considering grade EH and is the only classification society that does so. Like normal strength steels, the requirements are primarily intended to apply to steel plates and wide flats not exceeding 100 mm in thickness and sections and bars not exceeding 50 mm in thickness, except grade EH47, which is not applicable in sections and bars.

The chemical composition of higher strength steels is presented by LR in *Rules for the Manufacture, Testing and Certification of Materials (July 2018)* Ch. 3, Sec. 3 and in this document is given in *Table 2.2.2 Chemical composition (LR*) below. As per Grade EH 47, the chemical composition is given separately in *Table 2.2.3 Chemical composition for Grade EH 47 (LR)*. Also it should be mentioned that all the grades of steel are to be in the killed and fine grain treated condition.

Table 2.2. 2 Chemical composition (LR)



Grades	AH, DH, EH	FH
Carbon % max.	0,18	0,16
Manganese %	0,9 - 1,60 (*see* Note 1)	0,9 - 1,60
Silicon % max.	0,50	0,50
Phosphorus % max.	0,035	0,025
Sulphur % max.	0,035	0,025
Grain refining elements (*see* Note 2)		
Aluminium (acid soluble) %	0,015 min. (*see* Note 3)	
Niobium %	0,02 - 0,05	
Vanadium %	0,05 - 0,10	
Titanium %	0,02 max.	
Total (Nb + V + Ti) % (*see* Note 5)	0,12 max.	
Residual elements		
Nickel % max.	0,40	0,80
Copper % max.	0,35	0,35
Chromium % max.	0,20	0,20
Molybdenum % max.	0,08	0,08
Nitrogen % max.		0,009 (0,012 max. if Al is present)

Note 1. For AH grade steels in all strength levels and thicknesses up to 12,5 mm, the specified minimum manganese content is 0,70%.

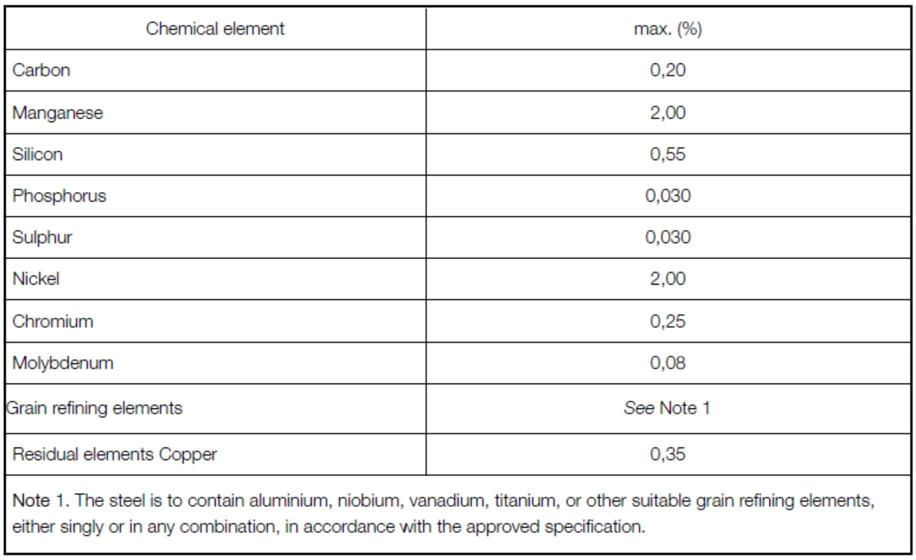
Note 2. The steel is to contain aluminium, niobium, vanadium or other suitable grain refining elements, either singly or in any combination. When used singly, the steel is to contain the specified minimum content of the grain refining element. When used in combination, the specified minimum content of each element is not applicable.

Note 3. The total aluminium content may be determined instead of the acid soluble content. In such cases the total aluminium content is to be not less than 0,020%.

Note 4. Alloying elements other than those listed above are to be included in the approved manufacturing specification.

Note 5. The grain refining elements are to be in accordance with the approved specification.

Table 2.2. 3 Chemical composition for Grade EH 47 (LR)



Chemical element	max. (%)
Carbon	0,20
Manganese	2,00
Silicon	0,55
Phosphorus	0,030
Sulphur	0,030
Nickel	2,00
Chromium	0,25
Molybdenum	0,08
Grain refining elements	*See* Note 1
Residual elements Copper	0,35
Note 1. The steel is to contain aluminium, niobium, vanadium, titanium, or other suitable grain refining elements, either singly or in any combination, in accordance with the approved specification.	

2.2.3.2 American Bureau of Shipping (HSS)

The counterpart table of ABS's is located in *Rules for Materials and Welding (January 2018), Ch.1 Sec.3.* On ABS's table the marking is presented distinctly as follows: AB/XHYY (X = A, D, E or F YY = 32, 36 or 40). Obviously, ABS does not include steels with specified minimum yield strength 265 MPa.

Furthermore, there are two more differentiations concerning the chemical compositions shown in *Table 2.2.2 Chemical composition (LR).* Firstly, ABS instead of determining the maximum quantity of Si, as LR gives the value of 0,50%, ABS suggest a specified range of 0,10 – 0,50% (for A,D,E and F grades), on which is noted that where the content of soluble aluminum is not less than 0,015%, the minimum required silicon content does not apply. Secondarily, ABS adds the element Ca, and is the only classification society that does so, in ladle analysis of all the grades with maximum content by weight of 0,005%. Calcium would make the material easier to be machined and also is effective as inclusion modifier.

Additionally ABS includes notes that LR does not and are presented below:

- Concerning grain refining elements: The steel is to contain at least one of the grain refining elements in sufficient amount to meet the fine grain practice requirement. This comment is followed by a reference to the fine grain practice, which may be met by one of the following conditions
    - — A McQuaid-Ehn austenite grain size of 5 or finer in accordance with ASTM E112 for each ladle of each heat, or
    - — Minimum Acid-soluble Aluminum content of 0,015% or minimum total Aluminum content of 0,020% for each ladle of each heat, or
    - — Minimum Columbium (Niobium) content of 0,020% or minimum Vanadium content of 0,050% for each ladle of each heat, or
    - — When Vanadium and Aluminum are used in combination, minimum Vanadium content of 0,030% and minimum acid-soluble Aluminum content of 0,010% or minimum total Aluminum content of 0,015%.

  - When Columbium (Niobium) and Aluminum are used in combination, minimum Columbium (Niobium) content of 0,010% and minimum acid-soluble Aluminum content of 0,010% or minimum total Aluminum content of 0,015%.
- Concerning elements Nb, V, Ti and Ca: These elements need not be reported on the mill sheet unless intentionally added.
- Concerning elements Cu, Cr, Ni and Mo: These elements may be reported as ≤ 0,02% where the amount present does not exceed 0,02%.

Lastly, while ABS gives specifications on grain refining elements, it does not include the equation of total content by weight of Nb+V+Ti = 0,12%max.

2.2.3.3 Bureau Veritas (HSS)

Bureau Veritas indications on chemical composition of higher strength is quite similar to L *Table 2.2.2 Chemical composition (LR)* and are presented in *Rules on Materials and Welding for the Classification of Marine Units (January 2018)* Ch. 2 Sec. 1. Of course grade EH 47 is not included and like ABS, BV does not include steels with a specified minimum yield strength of 265 MPa.

Also, two differentiations are presented on the cell notes. As per LR note 1, where it is indicated that for AH grade steels in all strength levels and thicknesses up to 12,5 mm, the specified minimum manganese content is 0,70%, while BV suggests that this applies to all strength levels of grades D and E too, which is reasonable as less manganese content would increase materials' machinability, especially concerning their low thickness. The following note is also added by BV:

- Variations in chemical composition allowed when steel is supplied in specified condition: When any grade of higher strength steel is supplied in the thermo-mechanically rolled condition, variations in the specified chemical composition may be allowed or required by the Society and are to be stated at the approval.

Beside the above no further differences are presented by BV.

2.2.3.4 Det Norske Veritas Germanischer Lloyd – DNV-GL (HSS)

In DNV-GL *Rules for classification: Ships (July 2018) Pt.2 Ch.2 Sec.2* the chemical composition of higher strength steels is presented with some discrepancies compared to *Table 2.2.2 Chemical composition (LR)*.

Two differences concerning the element contents are observed as DNV-GL gives a Mn content range of 0,70 to 1,60 % by weight concerning 27 strength level grade A, D and E steels and in terms of Ti, which is a grain refiner, instead of giving maximum content, DNV-GL determines range of 0,007 to 0,020 % for all grades. Another differentiation is that DNV-GL, alike BV, gives minimum Mn content of 0,70% for thicknesses up to and including 12,5 mm for strength levels 32, 36 and 40 for grades A, D and E, while LR suggests this only for grade AH. Concerning notes the additions are the following:

- Concerning grain refining elements: the steel shall contain grain refining elements Al, Nb, V or Ti, either singly or in any combination. When used singly, the steel shall contain the specified minimum content of the element. When Al and Nb are used in combination, the minimum total Al content shall be 0,015% (corresponding to acid soluble content of 0,010%) and the minimum Nb content shall be 0,010%. When Al and V are used in combination, the minimum total Al content shall be 0,015% (corresponding to acid soluble content of 0,010%) and the minimum V content shall be 0,030%. Combinations with other amounts of grain refining elements may be approved. The total content of Nb+V+Ti shall not exceed 0,12%.

- Content of Titanium for thermomechanically controlled-rolled steels: maximum 0,05% Ti for TM steels subjected to approval

Lastly, DNV-GL's marking is presented below:

VL XYY (X = A, D, E or F YY = 27S, 32, 36 or 40)

2.2.3.5 Registro Italiano Navale (HSS)

RINA requirements in Rules for the Classification of Ships (January 2018) in Pt. D of Materials and Welding Ch. 2, Sec.1 is identical to BV. Thus, no further comments are referred.

2.2.3.6 Conclusion (HSS)

DNV-GL and LR rules are more complete, both including strength level 27 grade steels. LR is superior on the quantity classified grades as it includes one more, EH 47 grade, but DNV-GL classifies the materials with more details, resulting in more complete and detailed guidelines. For example, DNV-GL requires titanium content for all the grades, which not only is a grain refiner, also helps the deoxidation and increases the material strength.

2.2.4 Steels for Low Temperature Service (SLTS)

This segment gives specific requirements for carbon-manganese and nickel alloy steels intended for use in the construction of cargo tanks, storage tanks and process pressure vessels for liquefied gases. As the classification societies ensure that the austenitic and duplex steel are capable for use at low design temperature, they should be included as well.

2.2.4.1 Lloyd's Register (SLTS)

According to LR, the chemical composition of carbon-manganese steels shall comply with the requirements of segment *2.2.3.1 Lloyd's Register (HSS)* for grades AH, DH, EH and FH strength levels 27s, 32, 36 and 40, see *Table 2.2.2 Chemical composition (LR)*. Supplementing, LR, in *Rules for the Manufacture, Testing and Certification of Materials (July 2018) Ch. 3, Sec. 6,* indicates that these grades to be designated LT−AH, LT−DH, LT−EH and LT−FH respectively.

In the same section LR specifies the chemical compositions of nickel alloy steels, which are to comply with the appropriate requirements of *Table 2.2.4 Chemical compositions of nickel alloy steels (LR)*.

Table 2.2. 4 Chemical compositions of nickel alloy steels (LR)

Grade of steel	C	Si	Mn	Ni	P	S	Residual elements	Aluminium
1½ Ni	0,18 max.	0,10-0,35	0,30 - 1,50	1,30 - 1,70	0,025 max.	0,020 max.	Cr 0,25 max. Cu 0,35 max. Mo 0,08 max. Total 0,60 max.	Total 0,020% min. Acid soluble 0,015% min
2¼ Ni	0,18 max.		0,30 - 0,80	2,10 - 2,50				
3½ Ni	0,15 max.		0,30 - 0,90	3,20 - 3,80				
5Ni	0,12 max.			4,70 - 5,30				
9Ni	0,10 max.			8,50 - 10,0				

Furthermore, in *Rules for the Manufacture, Testing and Certification of Materials (July 2018) Ch. 3, Sec. 7,* LR indicates that austenitic stainless steels are suitable for applications where the lowest design temperature is not lower than –165°C. In addition any requirement to use duplex stainless steels below 0°C will be subject to special consideration. But, according to LR, duplex stainless steels are suitable for applications where the lowest design temperature is above 0°C. Chemical composition of austenitic and duplex steels that LR classifies is listed in *Table 2.2.5 Chemical composition (LR).*

Table 2.2. 5 Chemical compositions (LR)

Type and grade of steel	Chemical composition % (see Note)									
	C	Si	Mn	P	S	Cr	Ni	Mo	N	Other
Austenitic										
304 L	0,03	1	2	0,45	0,03	17,0-20,0	8,0-13,0	-	0,1	-
304 LN	0,03	1	2	0,45	0,03	17,0-20,0	8,0-12,0	-	0,10-0,22	-
316 L	0,03	1	2	0,45	0,03	16,0-18,5	10,0-15,0	2,0-3,0	0,1	-
316 LN	0,03	1	2	0,45	0,03	16,0-18,5	10,0-14,5	2,0-3,0	0,10-0,22	-
317 L	0,03	1	2	0,45	0,03	18,0-20,0	11,0-15,0	3,0-4,0	0,1	-
317 LN	0,03	1	2	0,45	0,03	18,0-20,0	12,5-15,0	3,0-4,0	0,10-0,22	-
321	0,08	1	2	0,45	0,03	17,0-19,0	9,0-12,0	-	0,1	5 x C ≤ Ti ≤ 0,7
347	0,08	1	2	0,45	0,03	17,0-19,0	9,0-13,0	-	0,1	10 x C ≤ Nb ≤ 1,0
Duplex										
UNS S 31803	0,03	1	2	0,03	0,02	21,0-23,0	4,5-6,5	2,5-3,5	0,08-0,20	-
UNS S 32750	0,03	0,8	1,2	0,035	0,02	24,0-26,0	6,0-8,0	3,0-5,0	0,24-0,32	Cu 0,50 max.
Note All figures are a maximum value except where a range is shown.										

2.2.4.2 American Bureau of Shipping (SLTS)

ABS does not classify low temperature service steels but refers to its own article, *RULES FOR BUILDING AND CLASSING MARINE VESSELS (July 2018)*[6] Pt. 5 Ch. 8 Sec. 6, which is substantially the chapter 6 of the IGC code (Int. Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk)[7]. This chapter sets requirements that a material must meet, depending on the design temperature, in order to be accepted for use in hull construction of such vessel.

2.2.4.3 Bureau Veritas (SLTS)

Bureau Veritas classifies grades of carbon and carbon-manganese steels for low temperature service quite differently than LR, as BV's contents do not comply with the requirements of high strength steels.

The name of the grade, of BV's carbon and carbon-manganese steel grades, consists of two letters and a number, which indicate impact properties at a certain temperature and the ultimate tensile strength respectively. Below follows a paragraph from BV's *Rules on Materials and Welding for the Classification of Marine Units (January 2018)* Ch. 2 Sec. 1 explaining the nomenclature.

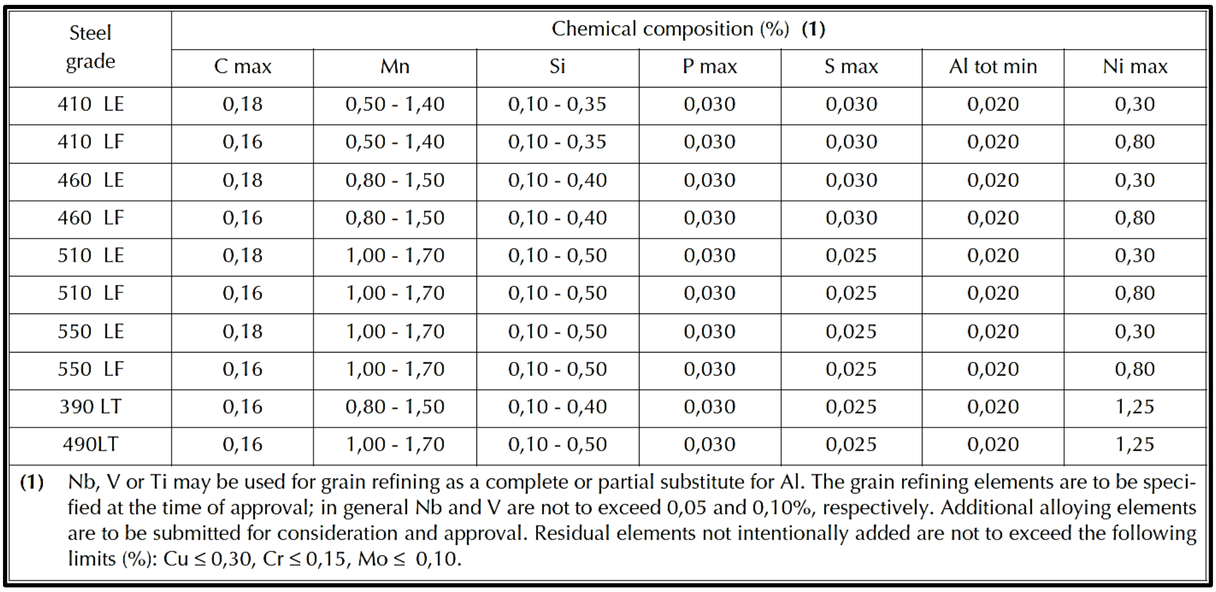
"The carbon and carbon manganese steels are classed into six groups indicated by the minimum ultimate tensile strength R_m (N/mm^2): 390, 410, 460, 490, 510 and 550.

Each group may be further subdivided into three grades, LE, LF or LT, as appropriate, based on the quality level and impact properties.

The letters LE and LF mean impact properties at −40°C and −60°C, respectively. The letters LT mean impact properties at temperature between −55°C and −70°C, depending on the thickness." [3]

The chemical composition on ladle analysis is to comply with the requirements specified in *Table 2.2.6 Chemical composition of carbon and carbon-manganese steels (BV).*

Table 2.2. 6 Chemical composition of carbon and carbon-manganese steels (BV)



Steel grade	Chemical composition (%) (1)						
	C max	Mn	Si	P max	S max	Al tot min	Ni max
410 LE	0,18	0,50 - 1,40	0,10 - 0,35	0,030	0,030	0,020	0,30
410 LF	0,16	0,50 - 1,40	0,10 - 0,35	0,030	0,030	0,020	0,80
460 LE	0,18	0,80 - 1,50	0,10 - 0,40	0,030	0,030	0,020	0,30
460 LF	0,16	0,80 - 1,50	0,10 - 0,40	0,030	0,030	0,020	0,80
510 LE	0,18	1,00 - 1,70	0,10 - 0,50	0,030	0,025	0,020	0,30
510 LF	0,16	1,00 - 1,70	0,10 - 0,50	0,030	0,025	0,020	0,80
550 LE	0,18	1,00 - 1,70	0,10 - 0,50	0,030	0,025	0,020	0,30
550 LF	0,16	1,00 - 1,70	0,10 - 0,50	0,030	0,025	0,020	0,80
390 LT	0,16	0,80 - 1,50	0,10 - 0,40	0,030	0,025	0,020	1,25
490LT	0,16	1,00 - 1,70	0,10 - 0,50	0,030	0,025	0,020	1,25

(1) Nb, V or Ti may be used for grain refining as a complete or partial substitute for Al. The grain refining elements are to be specified at the time of approval; in general Nb and V are not to exceed 0,05 and 0,10%, respectively. Additional alloying elements are to be submitted for consideration and approval. Residual elements not intentionally added are not to exceed the following limits (%): Cu ≤ 0,30, Cr ≤ 0,15, Mo ≤ 0,10.

In terms of nickel steel, BV presents the requirements for the same grades as LR, as given in *Table 2.2.4 Chemical compositions of nickel alloy steels (LR)*, with the following differences:

- Content of Silicon: BV stipulates only the maximum quantity of Si, being 0,35 max. for all the grades, while LR suggest a range 0,10 to 0,35. Setting a lower limit is preferable as Si is a good deoxidizer. Obviously they both agree on the maximum value.
- Content of Phosphorus: BV gives maximum P content of 0,035%, instead of 0,025 that LR does, for all the grades. Higher content of phosphorus could improve machinability and increase strength, but with the cost of increasing brittleness as well.

- Content of Manganese concerning grade 2¼ Ni: BV specifies a range of content of Mn, as LR, but with a little higher upper limit. BV gives 0,30 – 0,90 content of manganese for grade 2¼ Ni. It is reasonable to have a bigger range of manganese content, to balance higher phosphorus content, as manganese not only improves strength, it reduces brittleness.
- Concerning residual elements: The total of residual elements Cr, Cu and Mo are not to exceed 0,50% according to BV, while LR gives a total maximum of 0,60%. Also BV points out that the content of vanadium should not exceed 0,05%, which is not referred in LR's rules.

Lastly, in *Rules on Materials and Welding for the Classification of Marine Units (January 2018)* Ch. 2 Sec. 1, BV establishes austenitic steels as suitable for use both at elevated and low temperatures and duplex steels as generally suitable for design temperature between −20°C and +275°C. Comparing to LR's corresponding rules, BV does not provide a lower limit on the design temperature of austenitic steels and suggests a lower design temperature for duplex steels, −20°C, while LR states the lowest design temperature is above 0°C, see *2.2.4.1 Lloyd's Register (SLTS).*

Requirements on the chemical composition of austenitic and duplex steels that BV suggests are listed in *Table 2.2.7 Chemical composition (BV)*. BV classifies the same austenitic steels as LR, but some discrepancies are presented concerning the element's content, mostly of Ni and N content. Materials classified by BV, having a higher lower limit of Ni content, would present increased durability and in combination with Cr would retain austenite even in lower temperatures.

Also, BV includes the same duplex steel as LR, which present content discrepancies as well, plus grade UNS S 32550 that was missing from LR. In *Table 2.2.7 Chemical composition (BV)* below, the points of deviation from LR are marked as red and the grades that are not included by LR are marked as blue. At this point, it must be highlighted that BV's does not include a column for N and only inducts information of its content in the "Others" (Other elements) column.

Table 2.2. 7 Chemical composition (BV)

Type and grade of steel	Chemical composition % (see Note)								
	C	Si	Mn	P	S	Cr	Ni	Mo	Others
Austenitic									
304 L	0,03	1	2	0,45	0,03	17,0-19,0	9,0-12,0	-	
304 LN	0,03	1	2	0,45	0,03	17,0-19,0	8,5-11,0	-	0,14 ≤ N ≤ 0,22
316 L	0,03	1	2	0,45	0,03	16,0-18,5	10,0-14,0	2,0-3,0	
316 LN	0,03	1	2	0,45	0,03	16,0-18,5	11,0-13,0	2,0-3,0	0,14 ≤ N ≤ 0,22
317 L	0,03	1	2	0,45	0,03	18,0-20,0	14,0-16,0	3,0-4,0	
317 LN	0,03	1	2	0,45	0,03	18,0-20,0	12,5-14,0	3,0-4,0	0,14 ≤ N ≤ 0,22
321	0,08	1	2	0,45	0,03	17,0-19,0	9,0-13,0	-	5 x C ≤ Ti ≤ 0,7
347	0,08	1	2	0,45	0,03	17,0-19,0	9,0-13,0	-	10 x C ≤ Nb ≤ 1,0
Duplex									
UNS S 31803	0,03	0,75	2	0,035	0,01	21,0-23,0	4,5-6,5	2,5-3,0	0,10≤N≤0,22
UNS S 32550	0,03	2,0	0,75	0,035	0,01	24,0-26,0	5,5-7,5	2,7-3,9	1,0 ≤ Cu ≤ 2,0
UNS S 32750	0,03	0,8	2,0	0,035	0,02	24,0-26,0	6,0-8,0	3,0-5,0	Cu 0,50 max.
Note Additional alloying elements are to be submitted for consideration and approval. Residual elements are permitted provided they do not impair the properties, subsequent processing or behaviour in service of the material.									

Comparing LR and BV tables, it is obvious that BV is generally stricter and gives smaller content ranges. The only exception is the Ni content of grade 317 L.

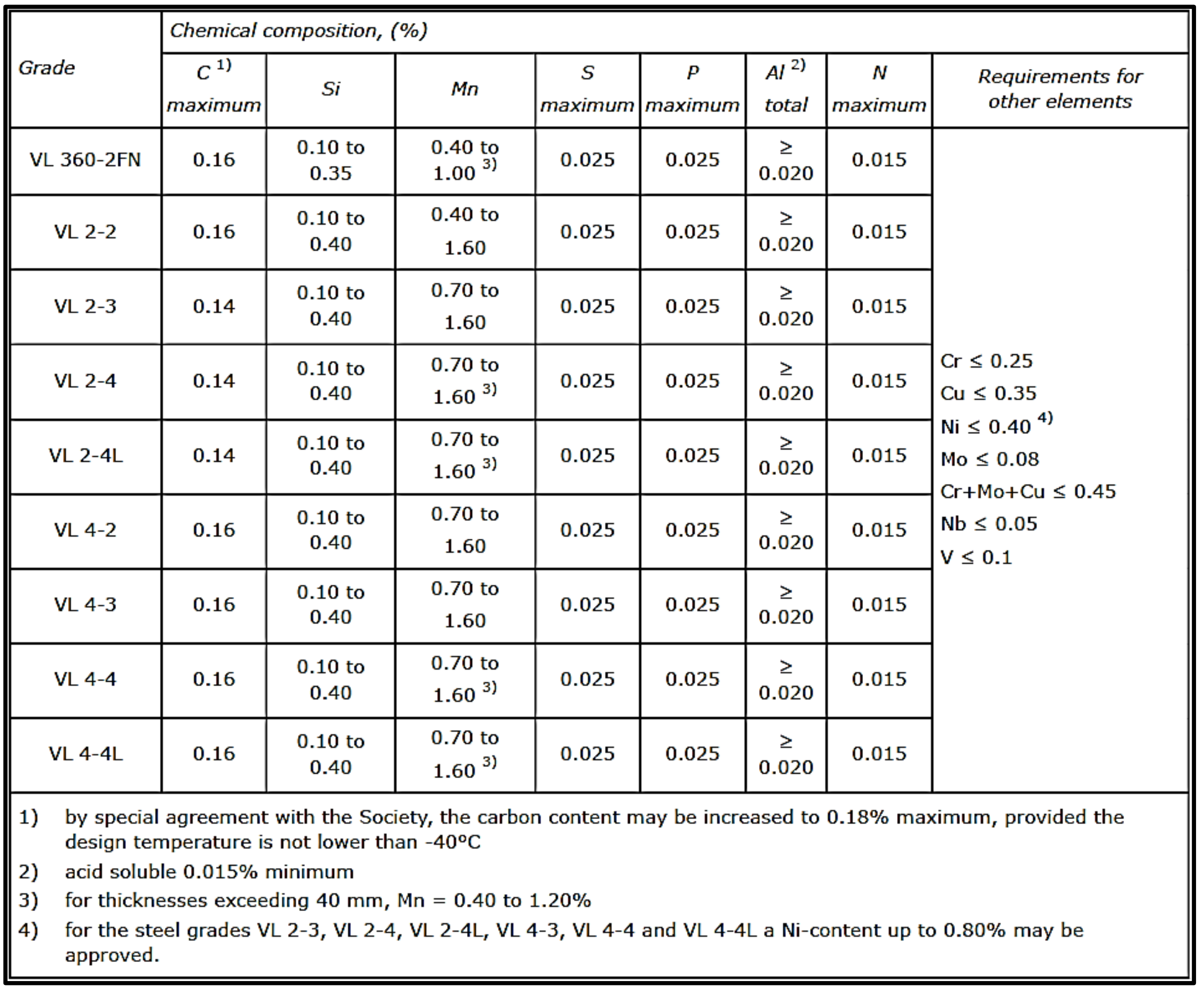
As ABS, BV also refers to IGC code. In case of applications involving the storage and transport of liquefied gases, reference is to be made to BV's Rules for the Classification of Steel Ships (January 2018) Pt D, Ch 9 and the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code)[7] also applies.

2.2.4.4 Det Norske Veritas Germanischer Lloyd – DNV-GL (SLTS)

Rules for classification: Ships (July 2018) Pt.2 Ch.2 Sec.3, by DNV-GL, contains rules on carbon-manganese steels that do not rely on the grades of higher strength steels, but, like BV, DNV-GL classifies distinct grades. Nevertheless BV's and DNV-GL's classified grade does not present similarities.

The chemical composition of the referenced grades shall satisfy the requirements specified in *Table 2.2.8 Chemical composition of carbon-manganese steels for low temperature service (DNV-GL).*

Table 2.2. 8 Chemical composition of carbon-manganese steels for low temperature service (DNV-GL)



Grade	*Chemical composition, (%)*							
	C [1] *maximum*	*Si*	*Mn*	*S* *maximum*	*P* *maximum*	*Al* [2] *total*	*N* *maximum*	*Requirements for other elements*
VL 360-2FN	0.16	0.10 to 0.35	0.40 to 1.00 [3]	0.025	0.025	≥ 0.020	0.015	Cr ≤ 0.25 Cu ≤ 0.35 Ni ≤ 0.40 [4] Mo ≤ 0.08 Cr+Mo+Cu ≤ 0.45 Nb ≤ 0.05 V ≤ 0.1
VL 2-2	0.16	0.10 to 0.40	0.40 to 1.60	0.025	0.025	≥ 0.020	0.015	
VL 2-3	0.14	0.10 to 0.40	0.70 to 1.60	0.025	0.025	≥ 0.020	0.015	
VL 2-4	0.14	0.10 to 0.40	0.70 to 1.60 [3]	0.025	0.025	≥ 0.020	0.015	
VL 2-4L	0.14	0.10 to 0.40	0.70 to 1.60 [3]	0.025	0.025	≥ 0.020	0.015	
VL 4-2	0.16	0.10 to 0.40	0.70 to 1.60	0.025	0.025	≥ 0.020	0.015	
VL 4-3	0.16	0.10 to 0.40	0.70 to 1.60	0.025	0.025	≥ 0.020	0.015	
VL 4-4	0.16	0.10 to 0.40	0.70 to 1.60 [3]	0.025	0.025	≥ 0.020	0.015	
VL 4-4L	0.16	0.10 to 0.40	0.70 to 1.60 [3]	0.025	0.025	≥ 0.020	0.015	

1) by special agreement with the Society, the carbon content may be increased to 0.18% maximum, provided the design temperature is not lower than -40°C
2) acid soluble 0.015% minimum
3) for thicknesses exceeding 40 mm, Mn = 0.40 to 1.20%
4) for the steel grades VL 2-3, VL 2-4, VL 2-4L, VL 4-3, VL 4-4 and VL 4-4L a Ni-content up to 0.80% may be approved.

In the same section DNV-GL gives requirements on the chemical composition of nickel steels and an austenitic manganese alloy steel, VL Mn 400. It's worth noticing that DNV-GL is the only classification society to suggest an austenitic manganese alloy steel grade for low temperature service.

Furthermore, beyond the nickel steel grades that LR includes, DNV-GL sets requirements on two more grades VL 0,5Ni/a and VL 0,5Ni/b. While DNV-GL and LR include common grade on their rules, discrepancies are observed on some of the elements' contents. These discrepancies are considered small, with exception of Mn content, which DNV-GL allow to reach content of 1,70%.

The requirements on the chemical composition are presented in *Table 2.2.9 Chemical composition of nickel alloy steels and austenitic manganese alloy steels for low temperature service (DNV-GL),* where the points of deviation from LR are marked as red and the grades that are not included by LR are marked as blue.

Table 2.2. 9 Chemical composition of nickel alloy steels and austenitic manganese alloy steels for low temperature service (DNV-GL)

Grade	Chemical Composition (%)						
	C Maximum 4)	Si	Mn	P maximum	S maximum	Ni	Al tot
VL 0.5Ni/a 1)	0,14	0,10 - 0,50	0,70 - 1,50	0,025	0,010	0,15 2) - 0,80	≥ 0,020
VL 0.5Ni/b 1)	0,16	0,10 - 0,50	0,85 - 1,70	0,025	0,010	0,15 2) - 0,80	≥ 0,020
VL 1.5Ni	0,14	0,10 - 0,35	0,30 - 1,50	0,025	0,025	1,30 - 1,70	≥ 0,020
VL 2.25Ni	0,13	0,10 - 0,35	0,30 - 1,50	0,025	0,025	2,00 - 2,50	≥ 0,020
VL 3.5Ni	0,12	0,10 - 0,35	0,30 - 0,70	0,025	0,025	3,25 - 3,75	≥ 0,020
VL 5Ni	0,12	0,10 - 0,35	0,30 - 0,80	0,025	0,025	4,70 - 5,30	≥ 0,020
VL 9Ni	0,10	0,10 - 0,35	0,30 - 0,90	0,025	0,025	8,50 - 10,0	≥ 0,020
VL Mn 400 3)	0,35 - 0,55	0,10 - 0,50	22,50 -25,50	0,030	0,010	-	-

1) further compositional requirements:
- Cr ≤ 0,25%
- Mo ≤ 0,08%
- Cu ≤ 0,35%
- Nb ≤ 0,05%
- V ≤ 0,05%
- Cr+Cu+Mo ≤ 0,50%

2) for thicknesses ≥ 40 mm; Ni ≥ 0,30%.

3) further compositional requirements:
- Cr 0,30% to 0,70%
- B ≤ 0,005%
- N ≤ 0,050%

4) except VL Mn 400

In DNV-GL’s referenced section, relevant to low temperature service steels, it is mentioned that requirements for austenitic steels applied for low temperature service are given in the corresponding stainless steels section. Furthermore, in *Rules for classification: Ships (2018) Pt.2 Ch.2 Sec. 4,* DNV-GL states that the austenitic steels may be used for applications where the design temperature is not lower than -165°C, as LR and that the Austenitic-ferritic (duplex) steels may be used for applications where the design temperature is not lower than -46°C, while LR states the lowest design temperature is above 0°C and BV gives -20 °C. Nevertheless DNV-GL classifies similar grades of stainless steels with LR, as given in *Table 2.2.5 Chemical compositions (LR)*, with the following differences:

- Smaller Cr and Ni content ranges of grade VL 304 L: DNV-GL gives Cr : 18,0 to 20 and Ni: 8,0 to 12,0, instead of LR’s respective 17,0-20 and 8,0-13,0
- Not inclusion of Grade 304 LN.
- N content of grades VL 316 LN, VL 317 LN and UNS S 31803: DNV-GL sets a lower content of N limit which is higher than indicated by LR. Thus, for the referenced grades the N content should be between 0,14-0,22, according to DNV-GL

DNV-GL refers also to *Rules for classification: Ships (July 2018) Pt.5 Ch.7 Sec.6,* which also correspond to the IGC code Ch. 6[7].

2.2.4.5 Registro Italiano Navale (SLTS)

RINA’s Rules for the Classification of Ships (January 2018) in Pt. D of Materials and Welding Ch. 2, Sec.1 contains rules and requirements on the same steel grades that Bureau Veritas gives, except grades 390 LT, 490 LT of carbon and carbon-manganese steels and 2¼ Ni of nickel alloy steels, without differentiations on the rest, *see 2.2.4.3 Bureau Veritas (SLTS).*

2.2.4.6 Conclusion (SLTS)

DNV-GL rulebook is the most informative and well summarized as it includes a variety of grades for the surveyor or the shipbuilder to choose from. BV, whose rules are quite close to DNV-GL, sets superior requirements on manganese and carbon-manganese steels, as they contain higher manganese content that should result to stronger materials. Lastly, while LR's rules are quite flexible on chemical composition of the materials, are not as explicitly. For example it is not clear how the manganese steels would be designated as LT, also while LR includes the corresponding to IGC code document in *Rules and Regulations for the Construction and Classification of Ships for the Carriage of Liquefied Gases in Bulk (July 2018)*[8]*,* there is no reference to it as in other classification societies' rulebooks.

2.2.5 "Z" Grade Steels with specified through thickness properties ("Z" Grade)

2.2.5.1 Lloyd's Register ("Z" Grade)

According to LR and *Rules for the Manufacture, Testing and Certification of Materials (July 2018)* Ch. 3, Sec. 8, a "Z" grade material is to comply with the requirements of *2.2.2 Normal Strength Steels (NSS), 2.2.3 Higher Strength Steels, 2.2.4 Steel for Low Service Temperature (SLTS)* and/or other kinds of steel that are not a part of this thesis, along with additional requirements concerning "Z" grade steels.

In terms of chemical composition no further requirements are mentioned by LR, except that the sulphur content of a "Z" grade material is not to exceed 0,008 per cent.

2.2.5.2 American Bureau of Shipping ("Z" Grade)

In *Rules for Materials and Welding (January 2018), Ch.1 Sec.1,* there are no differences presented by ABS compared to LR rules and properties. Thus, no further comments are made.

2.2.5.3 Bureau Veritas ("Z" Grade)

In Rules on *Rules on Materials and Welding for the Classification of Marine Units (January 2018)*Ch. 2 Sec. 1., BV presents no differences nor additions to the impact properties compared to LR *Rules for the Manufacture, Testing and Certification of Materials (January 2018).*

2.2.5.4 Det Norske Veritas Germanischer Lloyd (“Z” Grade)

In *Rules for classification: Ships (July 2018)* Pt.2 Ch.2 Sec.2., DNV-GL presents no differences nor additions to the impact properties compared to *Rules for the Manufacture, Testing and Certification of Materials (July 2018*) by LR.

2.2.5.5 Registro Italiano Navale (“Z” Grade)

RINA in Rules for the Classification of Ships (January 2018) in Pt. D of Materials and Welding Ch. 2, Sec.1 identical to BV. Thus, no further comments are made.

2.2.5.6 Conclusion (“Z” Grade)

Obviously, the classification societies do not present any kind of differences, deficiencies or additions on the matter and can be considered as equally valid.

2.2.6 Aluminum Alloys (AA)

2.2.6.1 Lloyd’s Register (AA)

In this segment requirements will be presented for aluminum alloys plates, bars and sections that find usage in ship and marine constructions. As LR indicates the thickness of plates, sections and bars described by these requirements will be in the range between 3 and 50 mm. The chemical composition of those are presented in *Rules for the Manufacture, Testing and Certification of Materials (July 2018) Ch. 8, Sec. 1,* where grades of the aluminum alloys are imprinted on table. According to LR each aluminum grade shall comply with the requirements of *Table 2.2.10 Chemical composition, percentage (LR).*

Table 2.2. 10 ***Chemical composition, percentage*** **(LR)**

Element	5083	5383	5059	5086	5754	5456	6005–A (see Note 1)	6061 (see Note 1)	6082
Copper	0,10 max.	0,20 max.	0,25 max.	0,10 max.	0,10 max.	0,10 max.	0,30 max.	0,15—0,40	0,10 max.
Magnesium	4,0—4,9	4,0—5,2	5,0—6,0	3,5—4,5	2,6—3,6	4,7—5,5	0,40—0,70	0,80—1,20	0,60—1,20
Silicon	0,40 max	0,25 max.	0,45 max	0,40 max	0,40 max	0,25 max.	0,50—0,90	0,40—0,80	0,70—1,30
Iron	0,40 max	0,25 max.	0,50 max.	0,50 max.	0,40 max	0,40 max	0,35 max.	0,70 max.	0,50 max.
Manganese	0,40—1,00	0,7—1,0	0,6—1,2	0,20—0,70	0,50 max. (see Note 2)	0,50—1,00	0,50 max. (see Note 3)	0,15 max.	0,40—1,00
Zinc	0,25 max.	0,40 max	0,40—0,90	0,25 max.	0,20 max.	0,25 max.	0,20 max.	0,25 max.	0,20 max.
Chromium	0,05—0,25	0,25 max.	0,25 max.	0,05—0,25	0,30 max. (see Note 2)	0,05—0,20	0,30 max. (see Note 3)	0,04—0,35	0,25 max.
Titanium	0,15 max	0,15 max	0,20 max.	0,15 max	0,15 max	0,20 max.	0,10 max.	0,15 max	0,10 max.
Zirconium		0,20 max.	0,05—0,25						
Other Elements:									
each	0,05 max.	0,05 max.	0,05 max.	0,05 max.	0,05 max.	0,05 max.	0,05 max.	0,05 max.	0,05 max.
total	0,15 max.	0,15 max.	0,15 max.	0,15 max.	0,15 max.	0,15 max.	0,15 max.	0,15 max.	0,15 max.

Note 1. These alloys are not normally acceptable for application in direct contact with sea-water.
Note 2. Mn + Cr = 0,10 min., 0,60 max.
Note 3. Mn + Cr = 0,12 min., 0,50 max.

2.2.6.2 American Bureau of Shipping (AA)

ABS does not present any discrepancies on the chemical composition of aluminum alloy grades that LR suggests in *Table 2.2.10 Chemical composition, percentage (LR)*. Although ABS in *Rules for Materials and Welding (January 2018), Ch.5 Sec.3* includes requirements for three more grades. Chemical composition requirements of the additional grades are given on *Table 2.2.11 Chemical composition, percentage (ABS),* below.

Table 2.2. 11 Chemical composition, percentage (ABS)

Element	5052	5454	6063
Copper	0,10 max.	0,10 max.	0,10 max.
Magnesium	2,2 - 2,8	2,4 - 3,0	0,45 - 0,9
Silicon	0,25 max.	0,25 max.	0,20 - 0,6
Iron	0,40 max.	0,40 max.	0,35 max.
Manganese	0,10 max.	0,50 - 1,0	0,10 max.
Zinc	0,10 max.	0,25 max.	0,10 max.
Chromium	0,15-0,35	0,05-0,20	0,10 max.
Titanium	–	0,20 max.	0,10 max.
Zirconium			
Other Elements:			
each	0,05 max.	0,05 max.	0,05 max.
total	0,15 max.	0,15 max.	0,15 max.

2.2.6.3 Bureau Veritas (AA)

Bureau Veritas does not add further requirements on aluminum alloy grades that Lloyd's Register by *Table 2.2.10 Chemical composition, percentage (DNV-GL)* and does not include the three additional grade of ABS'. Thus BV table of *Rules on Materials and Welding for the Classification of Marine Units (January 2018)* Ch. 3 Sec. 2 are not presented in this segment.

2.2.6.4 Det Norske Veritas Germanischer Lloyd – DNV-GL (AA)

The requirements of *Rules for classification: Ships (July 2018) Pt.2 Ch.2 Sec.10,* of DNV-GL, the most complete among the five classification societies concerning aluminum alloy grades. DNV-GL involves on its rules requirements for the grades that LR and ABS does, *see Table 2.2.10 Chemical composition, percentage (LR)* for which chemical composition requirements the three classification societies present no differences, plus two more grades, one of the 5000 and one of the 6000 series. Data for each grade are listed on *Table 2.2.12 Chemical composition, percentage (DNV-GL).*

Table 2.2. 12 Chemical composition, percentage (DNV-GL).

Element	VL 5154A	VL 6060
Copper	0,10 max.	0,10 max.
Magnesium	3,10 - 3,90	0,35 - 0,60
Silicon	0,50 max.	0,30 - 0,60
Iron	0,50 max.	0,10 - 0,30
Manganese	0,50 max.	0,10 max.
Zinc	0,20 max.	0,15 max.
Chromium	0,25 max.	0,05 max.
Titanium	0,20 max.	0,10 max.
Zirconium		
Other Elements:		
each total	0,05 max. 0,15 max.	0,05 max. 0,15 max.

2.2.6.5 Registro Italiano Navale (AA)

RINA Rules for the Classification of Ships (January 2018) in Pt. D of Materials and Welding Ch. 3, Sec.2 is identical to BV's. Thus, no further comments are referred.

2.2.6.6 Conclusion (AA)

The requirements of aluminium alloys set by the five classification societies can be considered equivalent as they do not present differentiations on the chemical composition of the grades. Differences occur on the quantity of the grades that each Society classifies, of which, DNV-GL is superior as it includes all the grades referenced in *2.2.6 Aluminum Alloys.*

Section

2.3 Tensile Tests

2.3.1 Tensile test method

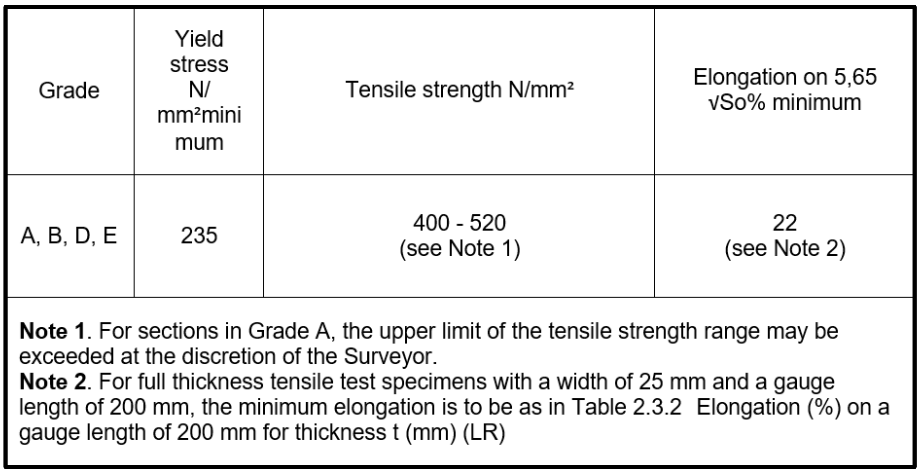
The tensile test method does not have variations amongst the classification societies, as all of them extract information on the method by appropriate Recognized Standards, which are ISO 6892-1[9] and ASTM E8[10]. Both international standards (International Standards Organization- ISO 6892-1:2016 "Metallic materials - Tensile testing, Part 1: Method of test at room temperature" and American Society for Testing and Materials - ASTM E8:2016 "Standard Test Methods for Tension Testing of Metallic Materials") cover tension testing of metallic materials in any form at room temperature and the methods of determination of yield strength, yield point elongation, tensile strength, elongation, and reduction of area.

2.3.2 Normal Strength Steel Rules and Properties (TT: Tensile Test)

2.3.2.1 Lloyd's Register (NSS-TT)

According to LR and *Rules for the Manufacture, Testing and Certification of Materials (July 2018)* Ch.3 Sec. 2 the results of all tensile tests are to comply with the appropriate requirements given in *Table 2.3.1 Mechanical properties for acceptance purposes (LR)*.

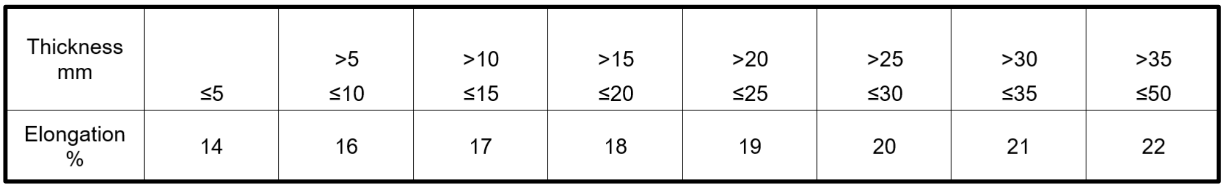
Table 2.3. 1 Mechanical properties for acceptance purposes (LR)



Grade	Yield stress N/ mm²minimum	Tensile strength N/mm²	Elongation on 5,65 √So% minimum
A, B, D, E	235	400 - 520 (see Note 1)	22 (see Note 2)

Note 1. For sections in Grade A, the upper limit of the tensile strength range may be exceeded at the discretion of the Surveyor.
Note 2. For full thickness tensile test specimens with a width of 25 mm and a gauge length of 200 mm, the minimum elongation is to be as in Table 2.3.2 Elongation (%) on a gauge length of 200 mm for thickness t (mm) (LR)

Table 2.3. 2 Elongation (%) on a gauge length of 200 mm for thickness t (mm) (LR)



Thickness mm	≤5	>5 ≤10	>10 ≤15	>15 ≤20	>20 ≤25	>25 ≤30	>30 ≤35	>35 ≤50
Elongation %	14	16	17	18	19	20	21	22

2.3.2.2 American Bureau of Shipping (NSS-TT)

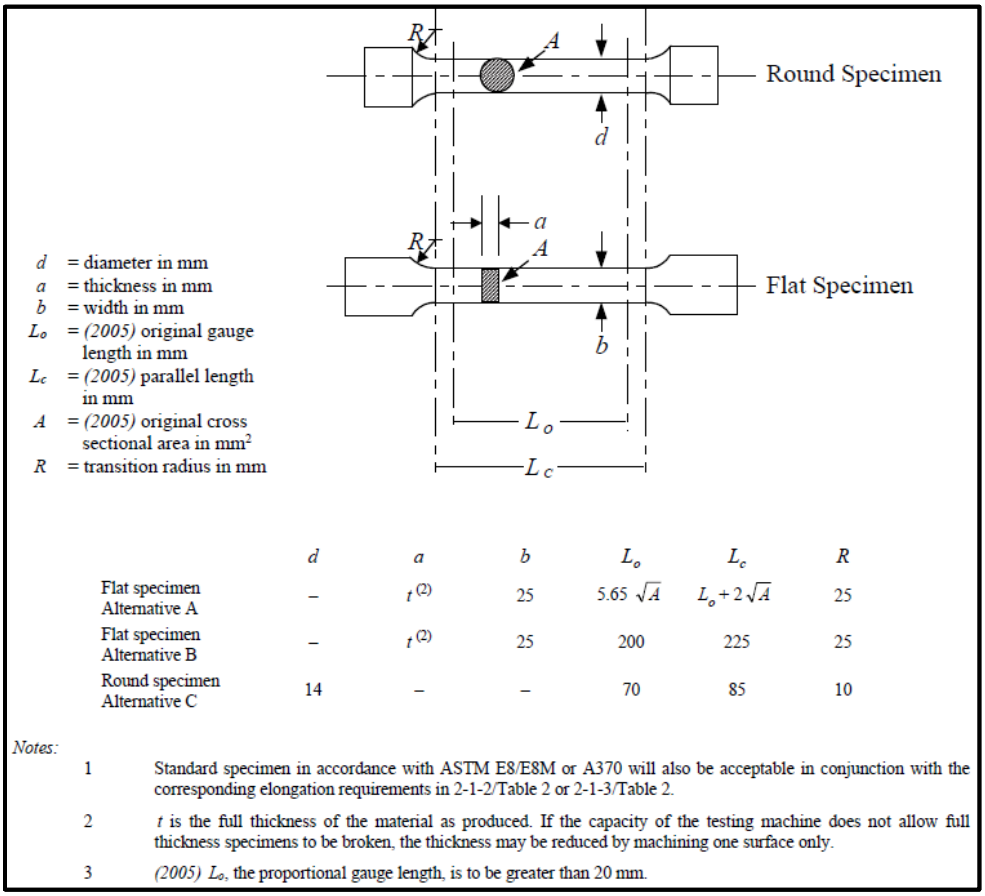
ABS's *Rules for Materials and Welding (January 2018), Ch.1 Sec. 2* does not present differences on the values of the mechanical properties. In the notes, however, ABS adds that minimum elongation for alternative A flat test specimen or alternative C round specimen is to be in accordance to *Table 2.3.1 Tensile properties for acceptance purposes (LR)* and for alternative B flat specimen is to be accordance to *Table 2.3.3 Elongation (%) on a gauge length of 200 mm for thickness t (mm) (ABS)* (figure of specimens and Table 2.3.3 are presented below).

As you see in Table 2.3.3 Elongation (%) on a gauge length of 200 mm for thickness t (mm) (ABS), ABS suggests different limits on the last two columns of the first row, which are marked with red letters. Also ABS differs as shown in the following notes:

- Being specific about the upper limit of the tensile strength of Grade A. For Grade A sections, the upper limit of tensile strength may be 550 N/mm^2.
- Suggesting a lower quality material. Steel ordered to cold flanging quality may have tensile strength range of 380-450N/mm^2 and a yield point of 205N/mm^2 minimum.

Table 2.3. 3 Elongation (%) on a gauge length of 200 mm for thickness t (mm) (ABS)

Thickness mm	≤5	>5 ≤10	>10 ≤15	>15 ≤20	>20 ≤25	>25 ≤30	>30 ≤40	>40 ≤50
Elongation %	14	16	17	18	19	20	21	22



d = diameter in mm
a = thickness in mm
b = width in mm
L_o = *(2005)* original gauge length in mm
L_c = *(2005)* parallel length in mm
A = *(2005)* original cross sectional area in mm^2
R = transition radius in mm

	d	a	b	L_o	L_c	R
Flat specimen Alternative A	–	$t^{(2)}$	25	$5.65\sqrt{A}$	$L_o + 2\sqrt{A}$	25
Flat specimen Alternative B	–	$t^{(2)}$	25	200	225	25
Round specimen Alternative C	14	–	–	70	85	10

Notes:

1 Standard specimen in accordance with ASTM E8/E8M or A370 will also be acceptable in conjunction with the corresponding elongation requirements in 2-1-2/Table 2 or 2-1-3/Table 2.

2 *t* is the full thickness of the material as produced. If the capacity of the testing machine does not allow full thickness specimens to be broken, the thickness may be reduced by machining one surface only.

3 *(2005)* L_o, the proportional gauge length, is to be greater than 20 mm.

Figure 2.3. 1 Standard Tension Test Specimen (ABS)[10]

2.3.2.3 Bureau Veritas (NSS-TT)

Rules on Rules on Materials and Welding for the Classification of Marine Units (January 2018) Ch. 2 Sec.1 of BV provides the same numerical values and amount of notes as LR, but the notes differ on details. Also BV's elongation requirements for full thickness tensile test specimens with a width of 25 mm and a gauge length of 200 mm, the minimum elongation is to be as in *Table 2.3.3 Elongation (%) on a gauge length of 200 mm for thickness t (mm) (ABS).*

- Being specific about the upper limit of the tensile strength of Grade A. For sections in grade A of all thicknesses, the upper limit for the specified tensile stress range may be exceeded up to a maximum of 540 N/mm^2. (Note : 10 N/mm^2 less than ABS's)

2.3.2.4 Det Norske Veritas Germanischer Lloyd – DNV-GL (NSS-TT)

Although DNV-GL's *Rules for classification: Ships (July 2018)* Pt.2 Ch.2 Sec.2 mechanical properties of normal strength steels coincide with the rest, DNV-GL is the only one not to suggest a Grade A steel of a greater tensile strength than 520 N/mm^2. In addition DNV-GL agrees with BV and ABS, on elongation requirements for full thickness tensile test specimens with a width of 25 mm and a gauge length of 200 mm that the minimum elongation is to be as in *Table 2.3.3 Elongation (%) on a gauge length of 200 mm for thickness t (mm) (ABS).*

2.3.2.5 Registro Italiano Navale (NSS-TT)

RINA in Rules for the Classification of Ships (January 2018) in Pt. D of Materials and Welding Ch. 2, Sec.1 is identical to BV. Thus, no further comments are referred.

2.3.2.6 Conclusion (NSS-TT)

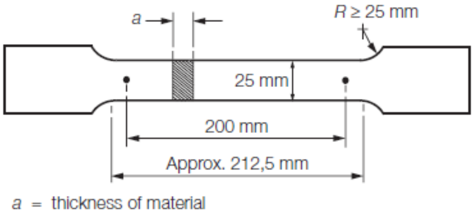
Comparing the tensile properties of normal strength steels that each classification society suggests, significant differences among them could not be found. However, ABS' ability to classify higher (Grade A) and lower (ordered to cold flanging) quality products should be underlined, as it can be quite useful.

2.3.3 Higher Strength Steel Rules and Properties (TT: Tensile Test)

2.3.3.1 Lloyd's Register (HSS-TT)

The results of all tensile tests are given by LR in *Rules for the Manufacture, Testing and Certification of Materials (July 2018)* Ch.3, Sec. 3 and are imprinted in the following *Table 2.3.4 Tensile properties of higher strength steels for acceptance purposes (LR).*

Table 2.3. 4 Tensile properties of higher strength steels for acceptance purposes (LR

Grades (see Note 3)	Yield Stress N/mm^{2}min.	Tensile Strength N/mm^{2}min.	Elongation on 5, 65 √So % min. (see Note 2)	
AH 27S DH 27S EH 27S FH 27S	265	400-530	22	 **Figure 2.3.2** Note 2 Test specimen dimensions for plates, strip and sections
AH32 DH32 EH32 FH32	315	440-570	22	
AH36 DH36 EH36 FH36	355	490-630	21	
AH40 DH40 EH40 FH40	390	510-650	20	
EH47	460	570-720	17	

Note 1. The requirements for products thicker than those detailed in the table are subject to agreement. For greater thicknesses, variations in the requirements may bepermitted or required for particular applications but a reduction of the required impact energy is not allowed.

Note 2. For full thickness tensile test specimens with a width of 25 mm and a gauge length of 200 mm, see Figure 2.3.2 Note 2 Test specimen dimensions for plates, strip and sections, the minimum elongation is to be:

Thickness mm		≤5	<5	<10	<15	<20	<25	<30	<40	<50
			≤10	≤15	≤20	≤25	≤30	≤40	≤50	
Elongation	Strength levels 27S,32	14	16	17	18	19	20	21	22	To be specifically agreed
	Strength level 36	13	15	16	17	18	19	20	21	
	Strength level 40	12	14	15	16	17	18	19	20	

Note 3. Subject to special approval by LR, the minimum tensile strength may be reduced to 470 N/mm^2 , for grades AH36, DH36, EH36 and FH36, in the TM condition when micro-alloying elements Nb, Ti or V are used singly and not in combination and provided the yield to tensile strength ratio does not exceed 0,89. For plates with a thickness ≤12 mm, the yield to tensile strength ratio is to be specially considered.

2.3.3.2 American Bureau of Shipping (HSS-TT)

As it was mentioned in the chemical composition segment *2.2.3.2 American Bureau of Shipping (HSS),* ABS does not include rules on strength level 27 and grade EH47 steels. Another deviation is that ABS suggests different ranges of tensile strength for strength level 32 and 36 steels, as it presented in *Rules for Materials and Welding (January 2018),Ch.1 Sec.3.*. For strength levels 32 and 36 ABS determines tensile strength of 440-590 N/mm^2 and 490-620 N/mm^2 respectively, instead of 440-570N/mm^2 and 490-630 N/mm^2 that LR does. Additional differences are not observed between the two classification societies.

2.3.3.3 Bureau Veritas (HSS-TT)

Bureau Veritas does not include rules on strength level 27 steels, either. In addition, compared to LR, *Rules on Materials and Welding for the Classification of Marine Units (January 2018)* by BV stipulates different upper limit of the tensile strength range for strength level 40 steels, as in, it suggests 660 N/mm^2 rather than 650 N/mm^2 that LR does. Other indications seem to be identical to LR.

2.3.3.4 Det Norske Veritas Germanischer Lloyd (HSS-TT)

DNV-GL, according to *Rules for classification: Ships (July 2018) Pt.2 Ch.2 Sec.2*, totally agrees on the mechanical properties of higher strength steels with LR, except for the upper limit of the tensile strength range for strength level 40 steels, as it is suggested 660 N/mm^2 like BV rather than 650 N/mm^2 that LR does.

2.3.3.5 Registro Italiano Navale (HSS-TT)

RINA indications in Rules for the Classification of Ships (January 2018) in Pt. D of Materials and Welding Ch. 2, Sec.1 are identical to BV. Thus, no further comments are reported.

2.3.3.6 Conclusion (HSS-TT)

Rules and regulations on the tensile properties seem to be quite similar among the five classification societies, as only small discrepancies are observed on the tensile strength of the order of 10-20N/mm^2. Besides this, the guidelines of the five classifications societies should be considered as equally valid for steels of similar grade.

2.3.4 Steels for Low Temperature Service Rules and Properties (TT: Tensile Test)

2.3.4.1 Lloyd’s Register (SLTS-TT)

The results of all tensile tests of steels for low temperature service are stipulated by LR in *Rules for the Manufacture, Testing and Certification of Materials (July 2018)* in Ch.3 Sec. 6. Subsequently they are to comply with the appropriate requirements given in *Table 2.3.5 Mechanical properties for acceptance purposes (LR).* As LR indicates, the ratio between the yield stress and the tensile strength is not to exceed 0,9 for normalised and TM (thermomechanically controlled-rolled) steels or 0,94 for QT steels.

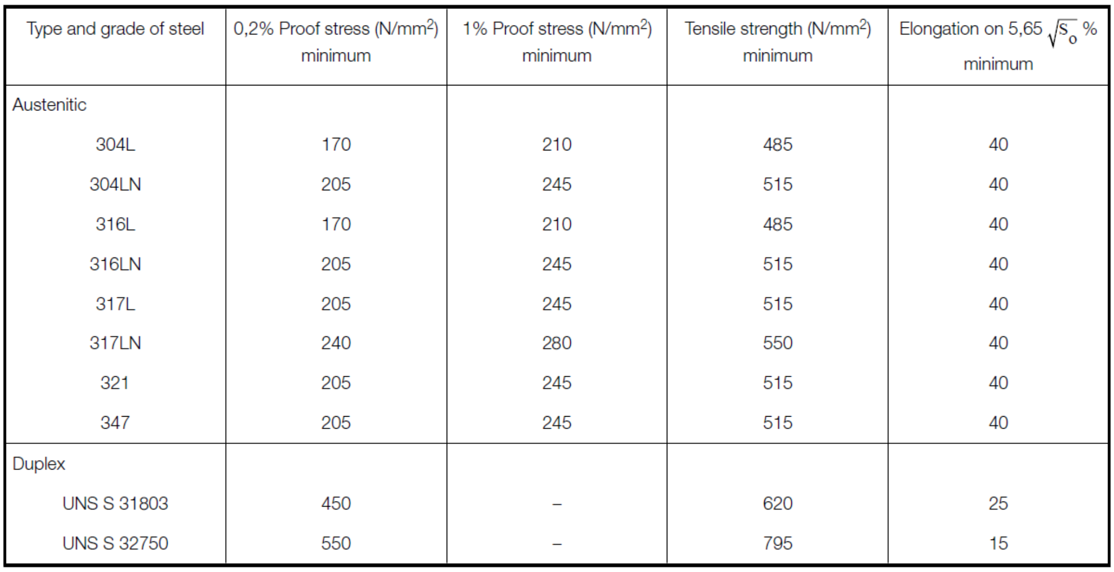
Table 2.3. 5 Mechanical properties for acceptance purposes (LR)

Grades of steel		Yield Stress N/mm²min.	Tensile Strength N/mm²min.	Elongation on 5, 65 √So % min.
LT - AH	27S	265	400 - 530	22
	32	315	440 - 590	22
	36	355	490 - 620	21
	40	390	510 - 650	20
LT - BH	27S	265	400 - 530	22
	32	315	440 - 590	22
	36	355	490 - 620	21
	40	390	510 - 650	20
LT - EH	27S	265	400 - 530	22
	32	315	440 - 590	22
	36	355	490 - 620	21
	40	390	510 - 650	20
LT - FH	27S	265	400 - 530	22
	32	315	440 - 590	22
	36	355	490 - 620	21
	40	390	510 - 650	20
1½ Ni		275	490 - 640	22
2¼ Ni		275	490 - 640	21
3½ Ni		285	450 - 610	21
5Ni		390	540 - 740	21
9Ni		490	640 - 790	18

Note 1. These requirements are applicable to products not exceeding 40 mm in thickness. The requirements for thicker products are subject to agreement.

According to LR austenitic steels and duplex, after special consideration, can be used for low temperature service. Each tensile properties are given in *Rules for the Manufacture, Testing and Certification of Materials (July 2018)* in Ch.3 Sec. 7 and are listed in *Table 2.3.6 Mechanical properties for acceptance purposes (LR).*

Table 2.3. 6 Mechanical properties for acceptance purposes (LR)



Type and grade of steel	0,2% Proof stress (N/mm^2) minimum	1% Proof stress (N/mm^2) minimum	Tensile strength (N/mm^2) minimum	Elongation on 5,65 $\sqrt{S_o}$ % minimum
Austenitic				
304L	170	210	485	40
304LN	205	245	515	40
316L	170	210	485	40
316LN	205	245	515	40
317L	205	245	515	40
317LN	240	280	550	40
321	205	245	515	40
347	205	245	515	40
Duplex				
UNS S 31803	450	–	620	25
UNS S 32750	550	–	795	15

2.3.4.2 American Bureau of Shipping (SLTS-TT)

ABS does not classify low temperature service steels but refers to its own article, *RULES FOR BUILDING AND CLASSING MARINE VESSELS (July 2018)* Pt. 5 Ch. 8 Sec. 6, which is essentially the sixth chapter of the IGC code (Int. Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk). This chapter sets requirements that a material must meet, depending on the design temperature, in order to be accepted for use in hull construction of such vessel.

2.3.4.3 Bureau Veritas (SLTS-TT)

Bureau Veritas stipulates requirements on mechanical properties of steels for low temperature service in *Rules on Materials and Welding for the Classification of Marine Units (January 2018)* Ch. 2 Sec.1. With to regards nickel alloy steels, BV presents no divergences compared to LR requirements, except grade 2¼ Ni where BV suggests minimum elongation of 22 instead of 21.

As it was mentioned in *2.2.4.3 Bureau Veritas (SLTS),* BV classifies distinct carbon and carbon-manganese steel grades from LR, whose tensile properties are meant to comply with the requirement given in *Table 2.3.7 Carbon and carbon manganese steels - Mechanical properties A (BV)* and *Table 2.3.8 Carbon and carbon manganese steels - Mechanical properties B (BV).* It is observed that BV gives yield stress requirements dependent on the thickness of the material, where LR does not present such feature.

Also, the carbon and carbon-manganese steel grades that the two classification societies classify may be distinct, but they present similar yield stress and tensile strength.

Table 2.3. 7 Carbon and carbon manganese steels - Mechanical properties A (BV)

Steel grade	Yield stress ReH (N/mm^2) min. for thickness t (mm)			Tensile strength Rm (N/mm^2)	Elong. A5 (%) min
	t ≤ 16	16 < t ≤ 40	40 < t ≤ 60		
410 LE	265	255	245	410 - 530	23
410 LF	290	280	270	410 - 530	23
460 LE	295	285	270	460 - 580	22
460 LF	320	310	300	460 - 580	22
510 LE	355	345	335	510 - 630	21
510 LF	355	345	335	510 - 630	21
550 LE	390	380	375	550 - 670	20
550 LF	390	380	375	550 - 670	20

Table 2.3. 8 Carbon and carbon manganese steels - Mechanical properties B (BV)

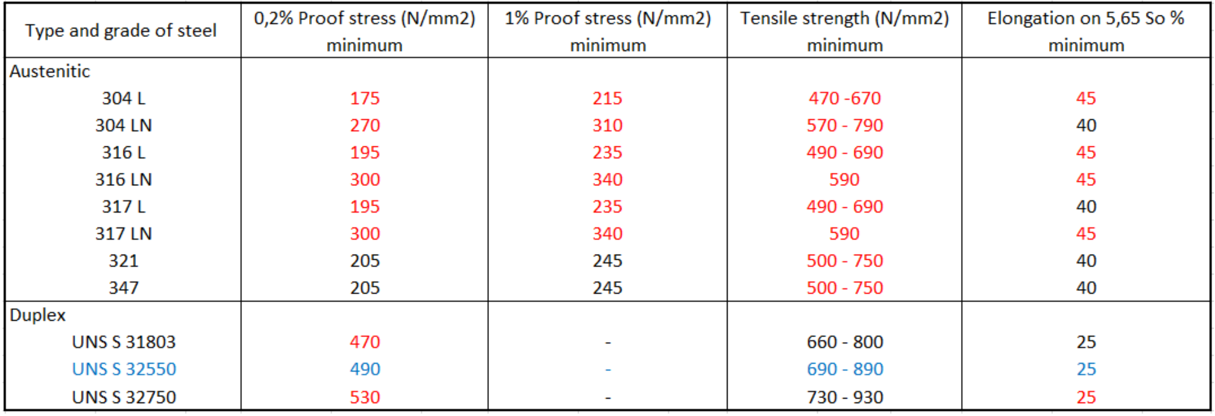
Steel grade	Yield stress ReH (N/mm^2) min. for thickness t (mm)		Tensile strength Rm (N/mm^2)	Elong. A5 (%) min
	t ≤ 16	16 < t ≤ 40		
390 LT	275	265	390 - 510	24
490 LT	355	345	490 - 630	22
Note 1: These requirements are applicable to products with thickness up to 40mm. For thicknesses exceeding 40 mm, the requirements shall be agreed with the Society.				

In terms of austenitic and duplex steels, the two classification societies, BV and LR, may have common grade (BV classifies one grade more that LR, *see 2.2.4.3 Bureau Veritas (SLTS))* but they do not agree on the tensile properties. BV suggests mainly higher minimum values on tensile strength, 0,2% and 1% proof stress.

Furthermore BV does not provide minimum values for tensile strength, as LR, but provides strength ranges. The highest discrepancies occur for 0,2% proof stress of grades 304LN, 316LN and 317LN, where BV gives 270, 300 and 300 N/mm^2 respectively, while LR gives 205, 205 and 240 N/mm^2 and for 1% proof stress of the same grade where BV gives 310, 340 and 340 N/mm^2 respectively, while LR gives 245, 245 and 280 N/mm^2.

The requirements on the tensile properties, suggested by BV, are presented in *Table 2.3.9 Tensile properties (BV),* where the points of deviation from LR are marked as red and the grades that are not included by LR are marked as blue.

Table 2.3. 9 Tensile properties (BV)



Type and grade of steel	0,2% Proof stress (N/mm2) minimum	1% Proof stress (N/mm2) minimum	Tensile strength (N/mm2) minimum	Elongation on 5,65 So % minimum
Austenitic				
304 L	175	215	470 -670	45
304 LN	270	310	570 - 790	40
316 L	195	235	490 - 690	45
316 LN	300	340	590	45
317 L	195	235	490 - 690	40
317 LN	300	340	590	45
321	205	245	500 - 750	40
347	205	245	500 - 750	40
Duplex				
UNS S 31803	470	-	660 - 800	25
UNS S 32550	490	-	690 - 890	25
UNS S 32750	530	-	730 - 930	25

2.3.4.4 Det Norske Veritas Germanischer Lloyd (SLTS-TT)

In *2.2.4.4 Det Norske Veritas Germanischer Lloyd (SLTS),* it was shown that DNV-GL and LR include the same nickel alloy steel grades, beyond the two extra grades that DNV-GL presents, with some discrepancies on the chemical composition.

Similarly, discrepancies are observed concerning the tensile properties on the common grades. The highest is presented on the yield stress of 3½ Ni grade, which is indicated at 285 N/mm^2 by LR and VL 3.5Ni at 355 N/mm^2 and 345 N/mm^2, for thickness $t \leq 30$ and $30 < t \leq 40$ respectively, by DNV-GL.

DNV-GL in *Rules for classification: Ships (July 2018) Pt.2 Ch.2 Sec.3* gives requirements on the mechanical properties of the nickel alloys steels and the austenitic manganese steel, which are given in *Table 2.3.10 Nickel alloy steels and austenitic manganese alloy steels for low temperature service. Mechanical properties (DNV-GL).* In this table, alike BV, DNV-GL gives yield stress requirements depending on the thickness of the material. Also, it is interesting that grade VL 1.5Ni is furtherly subcatecorised to VL 1.5Ni/a and VL 1.5Ni/b, which did not happen with chemical composition requirements. Lastly on the referenced table, the points of deviation from LR are marked with red colour.

Table 2.3. 10 Nickel alloy steels and austenitic manganese alloy steels for low temperature service. Mechanical properties (DNV-GL)

Steel grade	Yield stress ReH (N/mm^2) min. for thickness t (mm)		Tensile strength (N/mm^2)	Elong. A5 (%) min
	t ≤ 30	30 < t ≤ 40		
VL 0.5Ni/a	285	275	420 - 530	24
VL 0.5Ni/b	355	345	490 - 610	22
VL 1.5Ni/a	275	265	470 - 640	22
VL 1.5Ni/b	355	345	490 - 640	22
VL 2.25Ni	305	295	500 - 660	22
VL 3.5Ni	355	345	540 - 690	22
VL 5Ni	390	380	570 - 710	21
VL 9Ni	490	480	640 - 840	19
VL Mn 400	400		800 - 970	22
1) these requirements are applicable to products up to maximum 40 mm thickness. For thicknesses exceeding 40 mm the requirements shall be agreed				

In the same section, *Rules for classification: Ships (July 2018) Pt.2 Ch.2 Sec.3,* DNV-GL specifies, also, the mechanical properties that carbon and carbon-manganese materials are ought to comply with. These are given in *Table 2.3.11 Carbon-manganese steels for low temperature service. Mechanical properties (DNV-GL),* below. Similarly to the previous table, yield stress varies for different thicknesses.

Lastly, DNV-GL carbon and carbon manganese steel grade seem to have a little lower minimum yield stress and tensile strength than the products that LR and BV classify.

Table 2.3. 11 Carbon-manganese steels for low temperature service. Mechanical properties (DNV-GL)

Steel grade	Yield stress ReH (N/mm^2) min. for thickness t (mm)		Tensile strength (N/mm^2)	Elong. A5 (%) min
	t ≤ 16	16 < t ≤ 40		
VL 360-2FN	235	215	360 - 480	26
VL 2-2	265	255	400 - 490	24
VL 2-3	265	255	400 - 490	24
VL 2-4	265	255	400 - 490	24
VL 2-4L	265	255	400 - 490	24
VL 4-2	335	325	490 - 610	21
VL 4-3	335	325	490 - 610	21
VL 4-4	335	325	490 - 610	21
VL 4-4L	335	325	490 - 610	21
1) these requirements are applicable to products up to maximum 40 mm thickness. For thicknesses exceeding 40 mm the requirements shall be agreed				

In the following section, *Rules for classification: Ships (July 2018)* Pt.2 Ch.2 Sec.4, tensile properties of austenitic and duplex steels are reported, which are listed in *Table 2.3.12 Austenitic and duplex stainless steel. Mechanical properties (DNV-GL)*.

DNV-GL requirements present similarities with BV, thus, there a lot of discrepancies with LR, *see 2.3.4.3 Bureau Veritas (SLTS-TT).* DNV completely agrees with BV on the proof stress properties of austenitic steels and with LR on its minimum elongation. The only discrepancy with LR, in terms of duplex steels, is on the tensile strength of grade UNS S 32750, where DNV-GL gives minimum 690 N/mm^2 instead of 795 N/mm^2 and its minimum elongation. On the respective table, the points of deviation from LR are marked with red colour.

Table 2.3. 12 Austenitic and duplex stainless steel. Mechanical properties (DNV-GL)

Type and grade of steel	0,2% Proof stress (N/mm2) minimum	1% Proof stress (N/mm2) minimum	Tensile strength (N/mm2) minimum	Elongation on 5,65 So % minimum
Austenitic				
VL 304 L	175	215	450 - 700	40
VL 316 L	195	235	450 - 700	40
VL 316 LN	300	340	600 - 800	40
VL 317 L	195	235	500 - 700	40
VL 317 LN	300	340	600 - 800	40
VL 321	205	245	500 - 750	40
VL 347	205	245	500 - 750	40
Duplex				
UNS S 31803	450	-	620	25
UNS S 32750	550	-	690	25

2.3.4.5 Registro Italiano Navale (SLTS-TT)

RINA, by *Rules for the Classification of Ships (January 2018*) in Pt. D of Materials and Welding Ch. 2, Sec.1 contains rules and requirements on the same steel grades that Bureau Veritas gives, except for grades 390 LT, 490 LT of carbon and carbon-manganese steels and 2¼ Ni of nickel alloy steels, without differentiations on the rest, *see 2.3.4.3 Bureau Veritas (SLTS-TT).*

2.3.4.6 Conclusion (SLTS-TT)

At this point it is obvious that LR, DNV-GL and BV rules are superior to RINA and ABS. The requirements set by RINA are similar to BV, but do not constitute the same number of grades and ABS does not present additions on the matter. However, it is unclear whether any of the three classification societies has an advantage over the other two.

LR rulebook contains the most grades with compact and clear information, but classifies the least strong austenitic and duplex steels. BV rules are quite easily read and include strong carbon, carbon-manganese and austenitic, duplex stainless steels. Also, the featuring of a variety tensile properties depending on the thickness should prove quite helpful for a shipbuilder. Lastly, DNV-GL may contains the least strong carbon and carbon –manganese steels, but gives class to the biggest variety of nickel steels, while also placing an austenitic manganese steel among them. Furthermore DNV-GL provides different tensile properties' values depending on the thickness as BV and is the only Society, in which the rule section on steels for low temperature service, guides the reader to the relevant section of austenitic steels.

2.3.5 “Z” Grade Steels with specified through thickness properties Rules and Properties (TT: Tensile Test)

2.3.5.1 Lloyd’s Register (“Z” Grade – TT)

Provision is made by LR, in *Rules for the Manufacture, Testing and Certification of Materials (July 2018)* in Ch.3 Sec. 8, for the two quality classes Z25 and Z35. Common areas for Z-grade steels are areas where plates are subjected to significant tensile stress in the through thickness direction. The three through thickness tensile test specimens are to be tested at ambient temperature and for acceptance they are to give a minimum average reduction of area value of not less than a standard value shown in *Table 2.3.13 Reduction of area acceptance values (LR).*

Table 2.3. 13 Reduction of area acceptance values (LR)

Grade	Z25	Z35
Minimum average	25%	35%
Minimum individual	15%	25%

Unless otherwise agreed, through thickness tensile tests are only required for plate materials where the thickness exceeds 15 mm for carbon and alloy steels.

Moreover, as in chemical composition, a “Z” grade material is to comply with the requirements *of 2.3.2 Normal Strength Steels Rules and Properties (TT: Tensile Test), 2.3.3 Higher Strength Steels Rules and Properties (TT: Tensile Test, 2.3.4 Steel for Low Service Temperature Rules and Properties (TT: Tensile Test)* and/or other kinds of steel that are not a part of this thesis, along with additional requirements concerning “Z” grade steels.

2.3.5.2 American Bureau of Shipping (“Z” Grade-TT)

In *Rules for Materials and Welding (January 2018), Ch.1 Sec.1,* there are no differences presented by ABS compared to LR rules and properties. Thus no further comments are included.

2.3.5.3 Bureau Veritas (“Z” Grade-TT)

In *Rules on Materials and Welding for the Classification of Marine Units (January 2018)* Ch. 2 Sec. 1., BV presents no differences nor additions to the impact properties compared to LR and *Rules for the Manufacture, Testing and Certification of Materials (July 2018).*

2.3.5.4 Det Norske Veritas Germanischer Lloyd (“Z” Grade-TT)

In *Rules for classification: Ships (July 2018)* Pt.2 Ch.2 Sec.2., DNV-GL presents no differences nor additions to the impact properties compared to LR and *Rules for the Manufacture, Testing and Certification of Materials* (July 2018).

2.3.5.5 Registro Italiano Navale (“Z” Grade-TT)

RINA requirements given in Rules for the Classification of Ships (January 2018) in Pt. D of Materials and Welding Ch. 2, Sec.1 are identical to BV. Thus no further comments are included.

2.3.5.6 Conclusion (“Z” Grade-TT)

Obviously, the classification societies do not present any kind of differences, deficiencies or additions on the matter and can be considered as equally valid.

2.3.6 Aluminum Alloys Rules and Properties (TT: Tensile Test)

2.3.6.1 Lloyd’s Register (AA-TT)

Lloyd’s Register in *Rules for the Manufacture, Testing and Certification of Materials (July 2018)* in Ch.8 Sec. 1 sets the minimum mechanical properties, provided by tensile tests, of rolled and extruded aluminum alloys, which are listed in *Table 2.3.14 Minimum mechanical properties for acceptance purposes of selected rolled aluminium alloy products (LR)* and *Table 2.3.15 Minimum mechanical properties for acceptance purposes of selected extruded aluminium alloy products (LR),* respectively.

The data of the mechanical characteristics are given in relation with the thickness of the product and temper condition that they are supplied.

The Aluminium 5000 series alloys, capable of being strain hardened, are to be supplied in any of the following temper conditions:

O	annealed
H111	annealed with slight strain hardening
H112	strain hardened from working at elevated temperatures
H116	strain hardened and with specified resistance to exfoliation corrosion for alloys where the magnesium content is 4 per cent or more
H321	strain hardened and stabilised.

The Aluminium 6000 series alloys, capable of being age hardened, are to be supplied in either of the following temper conditions:

T5 hot worked and artificially aged.
T6 solution treated and artificially aged.

Table 2.3. 14 Minimum mechanical properties for acceptance purposes of selected rolled aluminium alloy products (LR)

Alloy and temper condition, see Note 3	Thickness, t, mm	0,2% proof stress R p, N/mm^2	Tensile strength R m N/mm^2	Elongation 4d, %	Elongation on 5, 65 √So 5d,%
5083-O	3 ≤ t ≤ 50 (see Note 2)	125	275-350	16	14
5083-H111	3 ≤ t ≤ 50	125	275-350	16	14
5083-H112	3 ≤ t ≤ 50	125	275	12	10
5083-H116	3 ≤ t ≤ 50	215	305	10	10
5083-H321	3 ≤ t ≤ 50	215-295	305-380	12	10
5086-O	3 ≤ t ≤ 50	100	240-305	16	14
5086-H111	3 ≤ t ≤ 50	100	240-305	16	14
5086-H112	3 ≤ t ≤12,5	125	250	8	-
	12,5 < t ≤ 50	105	240	-	9
5086-H116	3 ≤ t ≤ 50	195	275	10 (see Note 1)	9
5059-O	3 ≤ t ≤ 50	160	330	24	24
5059-H111	3 ≤ t ≤ 50	160	330	24	24
5059-H116	3 ≤ t ≤ 20	270	370	10	10
	20 < t ≤ 50	260	360	10	10
5059-H321	3 ≤ t ≤ 20	270	370	10	10
	20 < t ≤ 50	260	360	10	10
5383-O	3 ≤ t ≤ 50	145	290	17	17
5383-H111	3 ≤ t ≤ 50	145	290	17	17
5754-H111	3 ≤ t ≤ 50	80	190-240	18	17
5383-H116	3 ≤ t ≤ 50	220	305	10	10
5383-H321	3 ≤ t ≤ 50	220	305	10	10
5456-O	3 ≤ t ≤ 6,3	130-205	290-365	16	-
	6,3 ≤ t ≤ 50	125-205	285-360	16	14
5456-H116	3 ≤ t ≤ 30	230	315	10	10
	30 < t ≤ 40	215	305	-	10
	40 < t ≤ 50	200	285	-	10
5456-H321	3 ≤ t ≤12,5	230-315	315-405	12	-
	12,5 ≤ t ≤ 40	215-305	305-385	-	10
	40 < t ≤ 50	200-295	285-370	-	10
5754-O	3 ≤ t ≤ 50	80	190-240	18	17

Note 1. 8% for thickness up to and including 6,3 mm.
Note 2. For application to liquefied natural gas carriers or liquefied natural gas tankers where thicknesses are in excess of 50 mm, the mechanical properties given in this table are, in general, to be complied with.
Note 3. The mechanical properties for the O and H111 tempers are the same for all alloys shown in this Table. However, they are separated in this Table as they are made using different manufacturing processes

Table 2.3. 15 Minimum mechanical properties for acceptance purposes of selected extruded aluminium alloy products (LR)

Alloy and temper condition	Thickness, t, mm	0,2% proof stress R p, N/mm^2	Tensile strength R m N/mm^2	Elongation 4d, %	Elongation on 5, 65 √So 5d,%
5083-O	3 ≤ t ≤ 50	110	275-350	14	12
5083-H111	3 ≤ t ≤ 50	165	275	12	10
5083-H112	3 ≤ t ≤ 50	110	270	12	10
5086-O	3 ≤ t ≤ 50	95	240-315	14	12
5086-H111	3 ≤ t ≤ 50	145	250	12	10
5086-H112	3 ≤ t ≤ 50	95	240	12	10
5059-H112	3 ≤ t ≤ 50	200	330	10	10
5383-O	3 ≤ t ≤ 50	145	290	17	17
5383-H111	3 ≤ t ≤ 50	145	290	17	17
5383-H112	3 ≤ t ≤ 50	190	310	13	13
6005A-T5	3 ≤ t ≤ 50	215	260	9	8
6005A-T6	3 ≤ t ≤ 10	215	260	8	6
	10 < t ≤ 50	200	250	8	6
6061-T6	3 ≤ t ≤ 50	240	260	10	8
6082-T5	3 ≤ t ≤ 50	230	270	8	6
6082-T6	3 ≤ t ≤ 50	250	290	6	-
	5 < t ≤ 50	260	310	10	8
Note 1. The values are applicable for longitudinal and transverse tensile test specimens as well. **Note 2**. The mechanical properties for the O and H111 tempers are the same for all alloys shown in this Table. However, they are separated in this Table as they are made using different manufacturing processes.					

2.3.6.2 American Bureau of Shipping (AA-TT)

American Bureau of Shipping presents a lot of differences compared to LR rules on aluminium tensile properties. First of all ABS indicates different tensile test specimens according to thickness of the material to be tested. A segment from ABS *Rules for Materials and Welding (January 2018), Ch.5 Sec.5* is presented below explaining this division.

" Proportional test specimens with a gauge length: $L_0 = 5.65\sqrt{S_0}$ *can be used or preferably 5d can be used as the gauge length,* L_0*should preferably be greater than 20 mm. The gauge length may be rounded off to the nearest 5 mm provided that the difference between this length and* L_0 *is less than 10% of* L_0.

Flat tensile test specimens shall be used for specified thicknesses up to and including 12,5 mm. The tensile test specimen shall be prepared so that both rolled surfaces are maintained. For thicknesses exceeding 12,5 mm, round tensile test specimens will be used. For thicknesses up to and including 40 mm, the longitudinal axis of the round tensile test specimen shall be located at a distance from the surface equal to half of the thickness. For thicknesses over 40 mm, the longitudinal axis of the round tensile test specimen shall be located at a distance from one of the surfaces equal to one quarter of the thickness." [6]

The dimensions of the test specimens are similar with those in *Figure 2.3.1 Standard Tension Test Specimen (ABS),* see Flat specimen Alternative A and Round specimen Alternative C.

Concerning rolled aluminium alloy products ABS includes grades 5052 and 5454 as it was mentioned in previous sub-section *2.2.6.2 American Bureau of Shipping (AA),* that LR does not. ABS includes all the grades in any temper condition that LR gives but there differentiation that are presented in the next paragraph.

There are discrepancies on the tensile properties of some common grades, between ABS and LR, as they are presented in *Rules for Materials and Welding (January 2018), Ch.5 Sec.5.* While LR gives properties, mostly, in a thickness range of $3 \le t \le 50$, ABS divides this range to smaller ones case by case. In these sub-ranges ABS gives different properties for the same grade, thus, the discrepancies occur when comparing to LR. The alloy temper grades that are falling to this category are the following: 5059-O, 5059-H111, 5083-H112, 5086-H112, 5754-O and 5754-H111.

Another point of deviation concerns 5383-H116 and 5383-H321 alloy temper grades, where LR suggests Rp= 220 N/mm^2 and Rm=305 N/mm^2 for both, while ABS gives Rp=230 N/mm^2 and Rm= 330-400 N/mm^2 respectively. Quite similar to this is the fact that for the tensile strength of aluminum 5456 –H116 LR gives a minimum value and ABS gives a tensile strength range while for aluminum 5456 H-321 the two classification societies reverse their guideline method. Lastly, ABS includes two grades that both societies have, but ABS stipulates tensile properties for a temper condition, on each of the grades, that LR misses. These grade are 5456-H112 and 5083-H128.

Definition on temper condition H128 is given below. ABS data, which differ from LR are listed in *Table 2.3.16 Mechanical Property Limits of Non-Heat-Treatable Sheet and Plate Aluminum Alloys A (ABS)* and *Table 2.3.17 Mechanical Property Limits of Non-Heat-Treatable Sheet and Plate Aluminum Alloys B (ABS).*

The aluminum 5000 series can be supplied in the following temper condition.

H128	Strain hardened with exceptional resistance to corrosion
H32	Work hardened then stabilised by low-temperature heat treatment to quarter hard
H34	Stabilised, Half Hard - A low temperature thermal treatment or heat introduced during manufacture which stabilises the mechanical properties and relieves residual internal stress, usually improves ductility. Only applied to alloys which, unless stabilised, gradually age-soften at room temperature.

Table 2.3. 16 Mechanical Property Limits of Non-Heat-Treatable Sheet and Plate Aluminum Alloys A (ABS)[11]

Alloy and temper condition	Thickness, t, mm (1)	0,2% proof stress R p, N/mm^2	Tensile strength R m N/mm^2	Elongation 4d, %	Elongation on 5, 65 √So 5d,%
5052-O	3 ≤ t ≤6,3	65	170-215	16	-
	6,3≤ t ≤80	65	170-215	18	16
5052-H32 (4)	3 ≤ t ≤6,3	160	215-265	7	-
	6,3≤ t ≤12,5	160	215-265	11	-
	12,5≤ t ≤50	160	215-265	11	10
5052-H34 (4)	3 ≤ t ≤6,3	180	235-285	6	-
	6,3≤ t ≤25	180	235-285	10	9
5052-H112	6,3≤ t ≤12,5	110	190	7	-
	12,5≤ t ≤40	65	170	-	10
	40 ≤ t ≤80	65	170	-	14
5059-O	3 ≤ t ≤20	160	330	24	24
	20 ≤ t ≤40	160	330	-	20
	40 ≤ t ≤50	145	300	-	17
5059-H111	3 ≤ t ≤ 20	160	330	24	24
	20 ≤ t ≤40	160	330	-	20
5083-H112	3 ≤ t ≤40	125	275	12	10
	40 ≤ t ≤50	115	270	-	10
5086-H112	3 ≤ t ≤12,5	125	250	8	-
	12,5≤ t ≤40	105	240	-	9
	40 ≤ t ≤80	95	235	-	12
5454-O	3 ≤ t ≤6,3	85	215-285	16	-
	6,3≤ t ≤80	85	215-285	18	16
5454-H32 (4,5)	3 ≤ t ≤6,3	180	250-305	8	-
	6,3≤ t ≤50	180	250-305	12	10
5454-H34 (4,5)	3 ≤ t ≤4	200	270-325	6	-
	4 ≤ t ≤6,3	200	270-325	6	-
	6.3≤ t ≤25	200	270-325	10	9
5454-H112 (5)	6.3≤ t ≤12,5	125	220	8	-
	12.5≤ t ≤40	85	215	-	9
	40 ≤ t ≤80	85	215	-	13
5456-H112	6,3≤ t ≤40	130	290	12	10
	40.1≤ t ≤80	125	285	-	10
5754-O	3 ≤ t ≤12,5	80	200-270	19	-
	12.6≤ t ≤50	80	190-240	18	17
5754-H111	3 ≤ t ≤12.5	80	200-270	19	-
	12,6≤ t ≤50	80	190-240	18	17

Notes:
1 Type of test specimen used depends on thickness of material.
2 (2011) Values applicable to longitudinal test specimens.
3 (2011) Use of the latest ASTM B209/209M specification may be approved upon application.
4 (2011) For the corresponding H2x temper, the maximum tensile strength and minimum yield strength do not apply.
5 (2013) 5454 is recommended for service applications where exposed to temperatures exceeding 65°C (150°F).
6 (2014) The mechanical properties for the O and H111 tempers are the same. However, they are separated to discourage dual certification as these tempers represent different processing.

Table 2.3. 17 Mechanical Property Limits of Non-Heat-Treatable Sheet and Plate Aluminum Alloys B (ABS)[12]

Alloy and temper condition, see Note 3	Thickness, t, mm	0,2% proof stress R p, N/mm^2	Tensile strength R m N/mm^2	Elongation 4d, %	Elongation on 5, 65 √So 5d,%
5083-H128	4 ≤ t ≤12,5	215	305-385	10	-
	12,5≤ t ≤ 40	215	305-385	-	10
	40 ≤ t ≤ 80	200	285-385	-	10
5086-H116	3 ≤ t ≤ 6,3	195	275-360	8	-
	6.3≤ t ≤50	195	275-360	10	9
5086-H321	3 ≤ t ≤ 6.3	195	275-360	8	-
	6.3≤ t ≤8	195	275-360	9	-
5383-H116	3 ≤ t ≤ 50	230	330-400	10	10
5383-H321	3 ≤ t ≤50	230	330-400	10	10
5456-H116	3 ≤ t ≤12,5	230	315-405	10	-
	12,5≤ t ≤30	230	315-385	-	10
	30 ≤ t ≤40	215	305-385	-	10
	40 ≤ t ≤80	200	285-370	-	10
5456-H321	3 ≤ t ≤4	235	330-405	10	-
	4 ≤ t ≤12.5	230	315-405	12	-
	12,5 ≤ t ≤40	215	305-385	-	10
	40 ≤ t ≤80	200	285-370	-	10

Notes:
1 Type of test specimen used depends on thickness of material.
2 (2011) Values applicable to longitudinal test specimens.
3 (2011) Marine Grade sheet and plate as shown in *Table 2.3.17 Mechanical Property Limits of Non-Heat-Treatable Sheet and Plate Aluminum Alloys B (ABS)*are to be capable of passing an appropriate test for resistance to exfoliation and intergranular corrosion.
4 (2013) Use of the latest ASTM B 928/928M specification may be approved upon application.

Discrepancies occur concerning extruded aluminium products as well. To begin with, ABS does not include properties on the 5000 series for extruded products, only for the 6000 series. Also, ABS gives different elongation for grade 6005A –T5 for thicknesses 3mm ≤ t ≤6.3mm and different tensile strength for grade 6005A –T6 for thicknesses 10 mm ≤ t ≤50 mm. Interestingly ABS provides properties on grade 6082 –T6 for thickness up to 150mm. Lastly ABS includes grade 6063, which LR does not and common grades in specific temper conditions that any other classification does not include. The data of extruded aluminum products are listed on *Table 2.3.18 Mechanical Property Limits of Heat-Treatable Aluminum Alloys for Extruded Products (ABS).*

The aluminum 6000 series can be supplied in the following temper condition.

T451	For sheet and plate that are stress relieved by stretching after solution heat treatment.
T4511	For extruded bars, rods or shapes that are stress relieved by stretching after solution heat treatment.
T651	For sheet and plate that are stress relieved by stretching after solution heat treatment and then artificially aged.
T6511	For extruded bars, rods or shapes that are stress relieved by stretching after solution heat treatment and then artificially aged.

Table 2.3. 18 Mechanical Property Limits of Heat-Treatable Aluminum Alloys for Extruded Products (ABS)[13]

Alloy and temper condition, see Note 3	Thickness, t, mm	0,2% proof stress R p, N/mm^2	Tensile strength R m N/mm^2	Elongation 4d, %	Elongation on 5, 65 √So 5d,%
6005A-T5	3 ≤ t ≤6.3	215	260	7	-
	6.3≤ t ≤50	215	260	9	8
6005A-T6	3 ≤ t ≤10	215	260	8	-
	10 ≤ t ≤50	200	260	8	6
6005A-T61	3 ≤ t ≤6.3	240	260	8	-
	6.4≤ t ≤25	240	260	10	9
6061-T4/T4511 (4),(5)	All	110	180	16	14
6061-T6 (4),(5), -T62 (3) and -T6511 (4),(5)	3 ≤ t ≤6.3	240	260	8	-
	6.3 and over	240	260	10	9
6063-T6, -T62 (3)	3 ≤ t ≤3.2	170	205	8	-
	3.2≤ t ≤25	170	205	10	9
6082-T6, -T6511	3 ≤ t ≤5	250	290	6	-
	5 ≤ t ≤50	260	310	10	8
	50 ≤ t ≤150	260	310	-	8

Notes:
1 Type of test specimen used depends on thickness of material;
2 (2011) Values applicable to long transverse test specimens.
3 (2011) These properties apply to samples of material, which are solution heat treated or solution and precipitation treated from O or F temper by the producer to determine that the material will respond to proper heat treatment. Properties attained by the user, however, may be lower than those listed if the material has been formed or otherwise cold or hot worked, particularly in the annealed temper, prior to solution heat treatment.
4 For stress-relieved tempers, characteristics and properties other than those specified may differ somewhat from the corresponding characteristics and properties of material in the basic temper.
5 Upon artificial aging, T4 and T4511 temper material are to be capable of developing the mechanical properties applicable to the T6 and T6511 tempers, respectively.
6 (2011) Use of the latest ASTM B221/221M specification may be approved upon application.

2.3.6.3 Bureau Veritas (AA-TT)

Bureau Veritas does not present differentiations on aluminum alloy grades properties compared to Lloyd’s Register. Thus, BV respective table of *Rules on Materials and Welding for the Classification of Marine Units (January 2018)* Ch. 3 Sec. 2. Isn’t presented in this section.

2.3.6.4 Det Norske Veritas Germanischer Lloyd (AA-TT)

In Rules *for classification: Ships (July 2018) Pt.2 Ch.2 Sec.10*, by DNV-GL, all grades and tempers examined by LR and ABS are included here, as well. As it was shown in segment 2.2.4.6, DNV-GL includes the most grades of aluminum alloys. However most of the grades that are commonly included by LR and DNV-GL, do not present differences on the tensile properties given by both. The only exception to this is 5086-O and 5086-H111 when produced as rolled, for which DNV-GL suggests Rp = 95N/mm^2 instead of 100N/mm^2.

Considering rolled aluminum alloys, DNV-GL includes grades 5052 and 5454 that ABS does, but, as ABS, classifies them in more thickness ranges, differences occur – also DNV-GL does not include 5052-H112. The rest of the grades that are presented in *Table2.3.19 Mechanical properties for rolled aluminium alloys (DNV-GL)* are included only by DNV-GL.

Table 2.3. 19 Mechanical properties for rolled aluminium alloys (DNV-GL)

Alloy and temper condition	Thickness, t, mm (1)	0,2% proof stress R p, (1) N/mm^2	Tensile strength R m (1) N/mm^2	Elongation (2) 4d, %	Elongation (2) on 5, 65 √So 5d,%
VL 5052-O	t ≤ 50	65	165 - 215	19	18
VL 5052-H32	t ≤ 6	130	210 - 260	10	-
	6 < t ≤ 50	130	210 - 260	12	12
VL 5052-H34	t ≤ 6	150	230 - 280	7	-
	6 < t ≤ 50	150	230 - 280	9	9
VL 5083-H128	4 < t ≤ 8	215	305 - 385	10	-
VL 5086-O	t ≤ 50	95	240 - 305	16	14
VL 5086-H111	t ≤ 50	95	240 - 305	16	14
VL 5454-O	t ≤ 50	85	215 - 285	17	16
VL 5454-H32	t ≤ 6	180	250 - 305	8	-
	6 < t ≤ 50	180	250 - 305	10	9
VL 5454-H34	t ≤ 50	200	270 - 325	8	7
VL 5154A-O	t ≤ 50	85	215 - 275	17	16
VL 5154A-H32	t ≤ 6	180	250 - 305	8	-
	6 < t ≤ 50	180	250 - 305	10	9
VL 5154A-H34	t ≤ 50	200	270 - 325	8	7
VL 5754-H32	t ≤ 50	130	220 - 270	10	9
VL 5754-H34	t ≤ 6	160	240 - 280	8	-
	6 < t ≤ 50	160	240 - 280	10	8

1) specified minimum where one value is given. Specified minimum to maximum value where a range is specified
2) elongation in 4d mm applies for thicknesses up to and including 12,5 mm and in 5d for thicknesses over 12,5 mm.

In terms of extruded aluminium alloy products DNV-GL agrees with LR on the tensile properties on all of LR listed grades. Compared to ABS the only discrepancy lies on the different elongation of grade 6061-T4. On this category DNV-GL is the only one to include the following grades: 6005A-T4, 6060-T4, 6060-T5, 6060-T6, 6061-T5 and 6082-T4. Data of the above are liste on *Table 2.3.20 Mechanical properties for extruded aluminium alloys (DNV-GL)* below.

Table 2.3. 20 Mechanical properties for extruded aluminium alloys (DNV-GL)

Alloy and temper condition	Thickness, t, mm	0,2% proof stress R p, N/mm^2	Tensile strength R m N/mm^2	Elongation (1) 4d, %	Elongation (1) on 5, 65 √So 5d,%
VL-6005A-T4	t ≤ 50	90	180	15	13
VL-6060-T4	t ≤ 50	60	120	16	14
VL-6060-T5	t ≤ 50	100	140	8	6
VL-6060-T6	t ≤ 50	140	170	8	6
VL-6061-T4	t ≤ 50	110	180	15	13
VL-6061-T5	t ≤ 50	205	240	6	7
VL-6063-T4	t ≤ 50	65	130	14	12
VL-6063-T5	t ≤ 50	110	150	8	7
VL-6063-T6	t ≤ 50	170	205	10	9
VL-6082-T4	t ≤ 50	110	205	14	12

1) elongation in 4d applies for thicknesses up to and including 12,5 mm and in 5d for thicknesses over 12,5 mm.

2.3.6.5 Registro Italiano Navale (AA-TT)

RINA requirements in *Rules for the Classification of Ships (January 2018)* in Pt. D of Materials and Welding Ch. 3, Sec.2 are identical to BV. Thus no further comments are reported.

2.3.6.6 Conclusion (AA-TT)

As in chemical composition relevant section, LR, BV and RINA's rules on aluminium alloy tensile properties should be considered equal. This does not apply to ABS and DNV-GL's rules, as they are more analytical, including, not only more grades, also temper conditions of some common grades that the others are missing. Furthermore, both ABS and DNV-GL are more precise on the values they present by dividing thicknesses in to more ranges and correlating them with the appropriate property value.

Section

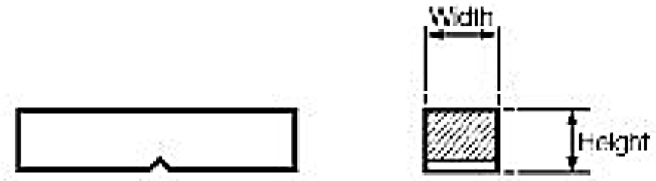
2.4 Impact Tests

2.4.1 Impact test method

The impact test method that is commonly used by all of the classification societies is the Charpy V-notch impact test. The average value of three test specimens shall be determined and meet the specified minimum requirement. One individual value may be below the specified value, provided that it is not less than 70% of the specified minimum. The dimensions of a test specimen, on which dimensions every classification agrees, are shown in *Table 2.4.1 Dimensions and tolerances for Charpy V-notch impact test specimens (LR)*. Also, where standard subsidiary Charpy V-notch test specimens are necessary, the minimum energy values required are to be reduced as follows:

- Specimen 10 x 7,5 mm: 5/6 of tabulated energy.
- Specimen 10 x 5 mm: 2/3 of tabulated energy.

Table 2.4. 1 Dimensions and tolerances for Charpy V-notch impact test specimens (LR)

Dimension	Nominal	Tolerance
Length, in mm	55	±0,60
Height, in mm, *see* Note 1	10	±0,075
Width , in mm, *see* Note 1		
- standard specimen	10	±0,11
- standard subsidiary specimen	7,5	±0,11
- standard subsidiary specimen	5	±0,06
Angle of notch	45°	±2°
Height below notch, in mm	8	±0,075
Root radius, mm	0,25	±0,025
Distance of plane of symmetry of notch from ends of test piece, in mm, *see* Note 1	27,5	±0,42 *see* Note 2
Angle between plane of symmetry of notch and longitudinal axis of test piece	90°	±2°
Angle between adjacent longitudinal faces of test piece	90°	±2°
		
Note 1 The test piece is to have a surface roughness better than Ra 5 μm except for the ends.		
Note 2 For machines with automatic positioning of the test piece the tolerance is to be taken as ±0,165 mm.		

2.4.2 Normal Strength Steels Rules and Properties (IT: Impact Test)

2.4.2.1 Lloyd’s Register (NSS-IT)

In *Rules for the Manufacture, Testing and Certification of Materials (July 2018)* Ch.3 Sec. 2, it is indicated that the average value, of a normal strength steel material, from each set of three impact tests are to comply with the appropriate requirements given in *Table 2.4.2 Impact properties for acceptance purposes (LR).*

Table 2.4. 2 Impact properties for acceptance purposes (LR)

Grade	Charpy V-notch impact test (see Notes 3, 4, 5, 6)		
	Thickness mm	Average energy J minimum	
		Longitudinal	Transverse
A, B, D, E	≤50	27	20
	>50≤70	34	24
	>70≤100	41	27
Impact tests are to be made on the various grades at the following temperatures:	A grade	not required	
	B grade	0°C	
	D grade	-20°C	
	E grade	-40°C	
Note 1: Generally, impact tests are not required when the thickness of the material is less than 6 mm.			

The *Table 2.4.2 Impact properties for acceptance purposes (LR)* is supplemented by the following regulations, which are listed in same section of *Rules for the Manufacture, Testing and Certification of Materials (July 2018).*

- Considering Grade A steel: Charpy V-notch impact tests are not required when the thickness does not exceed 50 mm, or up to 100 mm thick if the material is supplied in either the normalised or thermomechanically controlled-rolled condition and has been fine grain treated. However, the manufacturer should confirm, by way of regular in-house checks, that the material will meet a requirement of 27 J at +20 °C. The results of these checks shall be reported to the Surveyor. The frequency of these checks should as a minimum be every 250 tonnes.
- Considering Grade B steel: Impact tests are not required for Grade B steel of 25 mm or less in thickness. However, the manufacturer is to confirm, by way of regular in-house tests, and on occasional material selected by the Surveyor, that the material meets the requirement in *Table 2.4.2 Impact properties for acceptance purposes (LR)*. The results of the tests are to be reported to the Surveyor. The frequency of the in-house checks are to be, as a minimum, one set of three impact test specimens for every 250 tonnes.

2.4.2.2 American Bureau of Shipping (NSS-IT)

In *Rules for Materials and Welding (January 2018), Ch.1 Sec.2,* there are no differences presented by ABS compared to LR's rules and properties. However two additions can be reported located under ABS' corresponding table.

- Regulating a smaller subsize specimen: For a subsidiary specimen, measured 10 x 2,5 mm, a Charpy- V notch test would return 1/2 of tabulated energy.

- Note for acceptance purposes: ABS clarify that either longitudinal or transverse direction of testing will be acceptable.

2.4.2.3 Bureau Veritas (NSS-IT)

In *Rules on Materials and Welding for the Classification of Marine Units (January 2018)* Ch. 2 Sec. 1., BV presents no differences nor additions to the impact properties compared to LR and *Rules for the Manufacture, Testing and Certification of Materials (July 2018).*

2.4.2.4 Det Norske Veritas Germanischer Lloyd (NSS-IT)

In *Rules for classification: Ships (July 2018)* Pt.2 Ch.2 Sec.2., DNV-GL presents no differences nor additions to the impact properties compared to LR *Rules for the Manufacture, Testing and Certification of Materials (July 2018).*

2.4.2.5 Registro Italiano Navale (NSS-IT)

RINA requirements given in Rules for the Classification of Ships (*January* 2018) in Pt. D of Materials and Welding Ch. 2, Sec.1 are identical to BV. Thus no further comments are referred.

2.4.2.6 Conclusion (NSS-IT)

No differences are presented concerning the impact properties of normal strength steels. As a result, the rules of the five classifications societies should be considered as equally valid for steels of similar grade.

2.4.3 Higher Strength Steels Rules and Properties (IT: Impact Test)

2.4.3.1 Lloyd’s register (HSS-IT)

Higher strength steels classified by LR in *Rules for the Manufacture, Testing and Certification of Materials (July 2018*) in Ch.3 Sec. 3 shall comply with requirements of *Table 2.4.3 Impact properties for acceptance purposes (LR)*.

Table 2.4. 3 Impact properties for acceptance purposes (LR)

Grades	Charpy V-notch impact tests (see Notes 1 and 2)					
	Average energy J minimum					
	t ≤ 50mm		50 < t ≤ 70 mm		70 < t ≤ 100 mm	
	Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse
AH 27S	27	20	34	24	41	27
DH 27S						
EH 27S						
FH 27S						
AH32	31	22	38	26	46	31
DH32						
EH32						
FH32						
AH36	34	24	41	27	50	34
DH36						
EH36						
FH36						
AH40	39	26	46	31	55	37
DH40						
EH40						
FH40						
EH47	-	-	53	35	64 (see Note 1)	42 (see Note 3)

Impact tests are to be made on the various grades at the following temperatures:
AH grades 0°C
DH grades -20°C
EH grades -40°C
FH grades -60°C

Note 1. The requirements for products thicker than those detailed in the table are subject to agreement
Note 2. Generally, impact tests are not required when the thickness of the material is less than 6 mm.
Note 3. The Charpy V-notch impact energy for EH47 in thickness between 85 mm and 100 mm are to be 75J in the longitudinal direction and 50J in the transverse direction

2.4.3.2 American Bureau of Shipping (HSS-IT)

As it was mentioned in the chemical composition segment *2.2.3.2 American Bureau of Shipping (HSS),* ABS does not include rules on strength level 27 and grade EH47 steels. Beyond this, there are no further variation in ABS' *Rules for Materials and Welding (January 2018), Ch.1 Sec.3..*

2.4.3.3 Bureau Veritas (HSS-IT)

Neither Bureau Veritas includes rules on strength level 27 steels or grade EH47. Beyond this *in Rules on Materials and Welding for the Classification of Marine Units (January 2018) Ch*. 2

Sec. 1., BV presents no differences nor additions to the impact properties compared to LR and *Rules for the Manufacture, Testing and Certification of Materials (July 2018).*

2.4.3.4 Det Norske Veritas Germanischer Lloyd (HSS-IT)

In *Rules for classification: Ships (July 2018)* Pt.2 Ch.2 Sec.2., DNV-GL presents no differences nor additions to the impact properties compared to LR and Rules for the Manufacture, Testing and Certification of Materials (July 2018).

2.4.3.5 Registro Italiano Navale (HSS-IT)

RINA requirement given in *Rules for the Classification of Ships (2018)* in Pt. D of Materials and Welding Ch. 2, Sec.1 are identical to BV. Thus no further comments are reported.

2.4.3.6 Conclusion (HSS-IT)

No differences are presented concerning the impact properties of higher strength steels. As a result, the rules of the five classifications societies should be considered as equally valid for steels of similar grade.

2.4.4 Steel for Low Service Temperature Rules and Properties (IT: Impact Test)

2.4.4.1 Lloyd’s Register (SLTS-IT)

The average values of three impact test, for carbon, carbon-manganese and nickel alloy steels, are to comply with the requirements listed in *Table 2.4.4 Impact properties for acceptance purposes (LR),* as it is stated in *Rules for the Manufacture, Testing and Certification of Materials (July 2018)* in Ch.3 Sec. 6..

Table 2.4. 4 Impact properties for acceptance purposes (LR)

Grades of steel		Charpy V-notch impact tests (see Notes 3)	
		Test temp. °C	Impact energy
LT - AH	27S	0	Plates - transverse tests Average energy 27 J min Sections and bars - longitudinal tests Average energy 41 J min
	32		
	36		
	40		
LT - BH	27S	-20	
	32		
	36		
	40		
LT - EH	27S	-40	
	32		
	36		
	40		
LT - FH	27S	-60	
	32		
	36		
	40		
1½ Ni		-65	
2¼ Ni		-70	
3½ Ni		-95	
5Ni		-110	
9Ni		-196	

Note 1. The minimum design temperatures at which plates of different thicknesses in the above grades may be used are given in Figure 2.4.1 Minimum design temperatures for carbon-manganese grades (LR) and Figure 2.4.2 Minimum design temperatures for nickel grades (LR). Consideration will be given to the use of thicknesses greater than those in the Tables or to the use of design temperatures below –165°C.
Note 2. Impact tests are not required when the nominal material thickness is less than 6 mm.

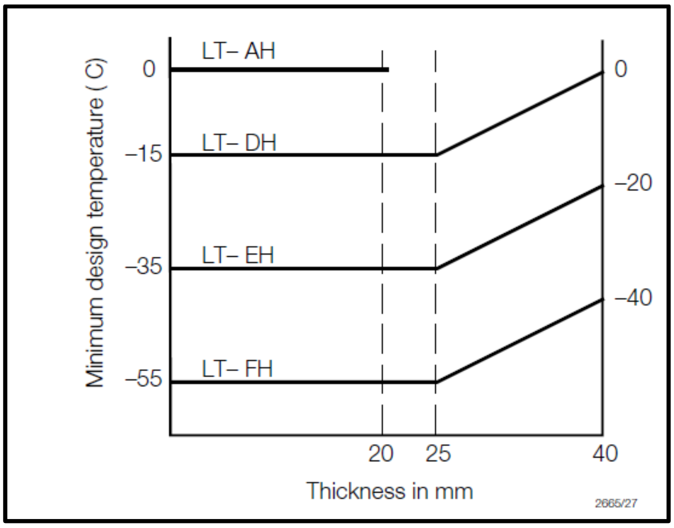


Figure 2.4. 1 Minimum design temperatures for carbon-manganese grades (LR)

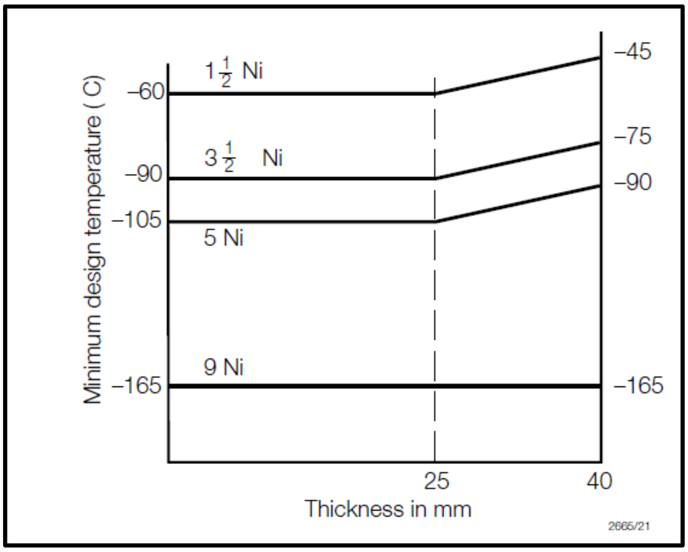


Figure 2.4. 2 Minimum design temperatures for nickel grades (LR)

Concerning austenitic steels, in *Rules for the Manufacture, Testing and Certification of Materials (July 2018)* in Ch.3 Sec. 7, LR states that unless otherwise agreed, impact tests are not required for the austenitic grades of steel given in this Section. As for the duplex grades, one set of three Charpy V-notch impact test specimens machined from the longitudinal direction for each tensile test is to be tested at –20°C. The average energy value of the three specimens is to be not less than 41 Joules.

2.4.4.2 American Bureau of Shipping (SLTS-IT)

ABS does not classify service low temperature steels but refers to its own article, *RULES FOR BUILDING AND CLASSING MARINE VESSELS (July 2018)* Pt. 5 Ch. 8 Sec. 6, which is substantially the chapter 6 of the IGC code (Int. Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk). This chapter sets requirements that a material must meet, depending on the design temperature, in order to be accepted for use in hull construction of such vessel.

2.4.4.3 Bureau Veritas (SLTS-IT)

BV requirements on the impact properties carbon, carbon-manganese and nickel steels, presented in *Rules on Materials and Welding for the Classification of Marine Units (January 2018)* Ch. 2, Sec. 1., are similar to LR but they do not agree completely. Firstly, the two classification societies may classify distinguish grades of carbon and carbon-manganese steels, though the impact properties of those are similar, as grades XXX LE and XXX LF of BV's are tested temperature -40 °C and -60 °C respectively and both have average impact energy 27 J at the transverse and 41 J at the longitudinal direction, like the corresponding LT-EH and LT-FH grades, as designated by LR and show in *Table 2.4.4 Impact properties for acceptance purposes (LR).*

However the grades 390 LT and 490 LT are presented separately as its impact test temperature varies with thickness. Nickel alloy grades' impact properties presented similarly, while LR gives only one test temperatures for each grade. Nevertheless BV does not provide the minimum design temperature as LR.

Nickel alloy grades and grades 390 LT and 490 impact requirements are listed in *Table 2.4.5 Nickel, carbon and carbon manganese steels – Impact properties (BV).*

Table 2.4. 5 Nickel, carbon and carbon manganese steels - Impact properties (BV)

Steel grade	Average impact energy (J) min.			
	Thickness (mm)	Temp (°C)	KVT	KVL
390 LT	t ≤ 25	-55	27	41
	25 < t ≤ 30	-60		
	30 < t ≤ 35	-65		
	35 < t ≤ 40	-70		
490 LT	t ≤ 25	-55	27	41
	25 < t ≤ 30	-60		
	30 < t ≤ 35	-65		
	35 < t ≤ 40	-70		
1,5 Ni	t ≤ 25	-65	27	41
	25 < t ≤ 30	-70		
	30 < t ≤ 35	-75		
	35 < t ≤ 40	-80		
2.25 Ni	t ≤ 25	-70	27	41
	25 < t ≤ 30	-75		
	30 < t ≤ 35	-80		
	35 < t ≤ 40	-85		
3,5 Ni	t ≤ 25	-95	27	41
	25 < t ≤ 30	-100		
	30 < t ≤ 35	-105		
	35 < t ≤ 40	-110		
5,0 Ni	t ≤ 25	-110	27	41
	25 < t ≤ 30	-115		
	30 < t ≤ 35	-120		
	35 < t ≤ 40	-125		
9,0 Ni	t ≤ 40	− 196	27	41

Note 1: These requirements are applicable to products with thickness up to 40mm. For thicknesses exceeding 40 mm, the requirements shall be agreed with the Society.

As for austenitic steels BV, in contrast with LR, considers impact tests necessary. The same applies for duplex steels. Both impact properties are listed in *Table 2.4.6 Austenitic and duplex steels. Impact properties (BV).*

Table 2.4. 6 Austenitic and duplex steels. Impact properties (BV).

Type and grade of steel	Average impact energy (J) min.	
	KVL	KVT
Austenitic	at −196°C	at −196°C
304 L 304 LN 316 L 316 LN 317 L 317 LN 321 347	41	27
Duplex	at −20°C	at −20°C
UNS S 31803 UNS S 32550 UNS S 32750	41	27

2.4.4.4 Det Norske Veritas Germanischer Lloyd (SLTS-IT)

Similar to BV, DNV-GL in *Rules for classification: Ships (July 2018)* Pt.2 Ch.2 Sec. 3, determines the impact properties of carbon manganese and nickel steels at an impact test temperature that varies with thickness. Carbon manganese steels' properties shall comply with the requirements of *Table 2.4.7 Carbon-manganese steels for low temperature service. Impact properties (DNV-GL).* DNV-GL does provide minimum design temperature the materials as LR.

In terms of nickel alloy steels, DNV-GL completely agrees with BV, see *Table 2.4.5 Nickel, carbon and carbon manganese steels - Impact properties (BV),* and its data are not repeated on this segment. In addition DNV-GL suggests the same design temperature for nickel steels as LR, *see Figure 2.4.2 Minimum design temperatures for nickel grades (LR).* Although impact properties of grades VL 0.5Ni/a, VL 0.5Ni/b and the austenitic manganese VL Mn 400 will be listed in *Table 2.4.8 Nickel alloy steels and austenitic manganese alloy steels. Impact properties (DNV-GL),* as they're not part of LR or BV regulations.

Table 2.4. 7 Carbon-manganese steels for low temperature service. Impact properties (DNV-GL)

Steel grade	Charpy V-notch impact energy, minimum average 2)				Min. design temperature, (°C)
	Thickness (mm)	Test Temp (°C) 3, 4, 5)	Transverse (J)	Longitudinal (J)	
VL 360-2FN	t ≤ 25	-20	27	41	-15
	25 < t ≤ 30	-25			
	30 < t ≤ 35	-30			
	35 < t ≤ 40	-35			
VL 2-2	t ≤ 25	-20	27	41	-15
	25 < t ≤ 30	-25			
	30 < t ≤ 35	-30			
	35 < t ≤ 40	-35			
VL 2-3	t ≤ 25	-40	27	41	-35
	25 < t ≤ 30	-45			
	30 < t ≤ 35	-50			
	35 < t ≤ 40	-55			
VL 2-4	t ≤ 25	-55	27	41	-50
	25 < t ≤ 30	-60			
	30 < t ≤ 35	-65			
	35 < t ≤ 40	-70			
VL 2-4L	t ≤ 25	-60	27	41	-55
	25 < t ≤ 30	-65			
	30 < t ≤ 35	-70			
	35 < t ≤ 40	-75			
VL 4-2	t ≤ 25	-20	27	41	-15
	25 < t ≤ 30	-25			
	30 < t ≤ 35	-30			
	35 < t ≤ 40	-35			
VL 4-3	t ≤ 25	-40	27	41	-35
	25 < t ≤ 30	-45			
	30 < t ≤ 35	-50			
	35 < t ≤ 40	-55			
VL 4-4	t ≤ 25	-55	27	41	-50
	25 < t ≤ 30	-60			
	30 < t ≤ 35	-65			
	35 < t ≤ 40	-70			
VL 4-4L	t ≤ 25	-60	27	41	-55
	25 < t ≤ 30	-65			
	30 < t ≤ 35	-70			
	35 < t ≤ 40	-75			

1) these requirements are applicable to products up to maximum 40 mm thickness. For thicknesses exceeding 40 mm the requirements shall be agreed

2) the specified impact toughness requirements also apply in the heat affected zone of welded connections and it is recommended that the steel is ordered with sufficient margin

3) materials for tanks or parts of tanks completely thermally stress relieved after welding may for all thicknesses t ≤ 40 mm be tested at a temperature 5°C below the minimum design temperature

4) materials for liquefied gas carriers

5) for thickness 25 < t ≤ 40 mm the impact test temperature shall be stamped on the products and stated in the certificate.

Table 2.4. 8 Nickel alloy steels and austenitic manganese alloy steels. Impact properties (DNV-GL)

Steel grade	Charpy V-notch impact energy, minimum average 2)				Min. design temperature, (°C)
	Thickness (mm)	Test Temp (°C)	Transverse (J)	Longitudinal (J)	
VL 0.5Ni/a	t ≤ 25 25 < t ≤ 30 30 < t ≤ 35 35 < t ≤ 40	-60 -65 -70 -75	27	41	-55
VL 0.5Ni/b	t ≤ 25 25 < t ≤ 30 30 < t ≤ 35 35 < t ≤ 40	-60 -65 -70 -75	27	41	-55
VL Mn 400	t ≤ 40	-196	27	41	-165

1) these requirements are applicable to products up to maximum 40 mm thickness. For thicknesses exceeding 40 mm the requirements shall be agreed
2) the specified impact toughness requirements also apply in the heat affected zone of welded connections and it is recommended that the steel is ordered with sufficient margin
3) materials for tanks or parts of tanks completely thermally stress relieved after welding may for all thicknesses t ≤ 40 mm be tested at a temperature 5°C below the minimum design temperature
4) materials for liquefied gas carriers
5) for thickness 25 < t ≤ 40 mm the impact test temperature shall be stamped on the products and stated in the certificate.

Lastly, DNV-GL presents no differences from BV on the impact properties of austenitic and duplex steels.*see Table 2.4.6 Austenitic and duplex steels. Impact properties (BV)*. To remind grade 304L and UNS S 32550 are not part of DNV-GL rules and regulations.

2.4.4.5 Registro Italiano Navale (SLTS-IT)

RINA's Rules for the Classification of Ships (*January* 2018) in Pt. D of Materials and Welding Ch. 2, Sec.1 contains rules and requirements on the same steel grades that Bureau Veritas gives, except grades 390 LT, 490 LT of carbon and carbon-manganese steels and 2¼ Ni of nickel alloy steels, without differentiations on the rest, *see 2.4.4.3 Bureau Veritas (SLTS-IT).*

2.4.4.6 Conclusion (SLTS-IT)

On this matter, Lloyd's Register is appeared as more informative than BV or RINA, as it provides minimum design temperatures for nickel and carbon-manganese steels. Meanwhile BV and RINA are more thorough by adding different test temperatures that vary with thickness, for nickel alloy and carbon-manganese steels and by considering the impact test for austenitic steels as necessary. DNV-GL, however, combines both these elements and its list should be considered superior as more complete.

2.4.5 “Z” Grade Steels with specified through thickness properties Rules and Properties (IT: Impact Test)

2.4.5.1 Lloyd’s Register (“Z” Grade-IT)

A “Z” grade material is to comply with the requirements *of 2.4.2 Normal Strength Steels Rules and Properties (IT: Impact Test), 2.4.3 Higher Strength Steels Rules and Properties (IT: Impact Test), 2.4.4 Steel for Low Service Temperature Rules and Properties (IT: Impact Test)* and/or other kinds of steel that are not a part of this thesis, along with additional requirements concerning “Z” grade steels.

No further requirements are indicated by LR concerning the impact properties of “Z” grade steels.

2.4.5.2 American Bureau of Shipping (“Z” Grade-IT)

In *Rules for Materials and Welding (January 2018),Ch.1 Sec.1,* there are no differences presented by ABS compared to LR rules and properties. Thus, no further comments are reported.

2.4.5.3 Bureau Veritas (“Z” Grade-IT)

In *Rules on Materials and Welding for the Classification of Marine Units (January 2018)* Ch. 2 Sec. 1., BV presents no differences nor additions to the impact properties compared to LR and *Rules for the Manufacture, Testing and Certification of Materials (July 2018).*

2.4.5.4 Det Norske Veritas Germanischer Lloyd (“Z” Grade-IT)

In Rules for classification: Ships (July 2018) Pt.2 Ch.2 Sec.2., DNV-GL presents no differences nor additions to the impact properties compared to LR and *Rules for the Manufacture, Testing and Certification of Materials (July 2018).*

2.4.5.5 Registro Italiano Navale (“Z” Grade-IT)

RINA requirements given in Rules for the Classification of Ships (*January* 2018) in Pt. D of Materials and Welding Ch. 2, Sec.1 are identical to BV’s. Thus, no further comments are reported.

2.4.5.6 Conclusion (“Z” Grade-IT)

Obviously, the classification societies do not present any kind of differences, deficiencies or additions on the matter and can be considered as equally valid.

2.4.6 Aluminum Alloys Rules and Properties (IT: Impact Test)

2.4.6.1 General (AA-IT)

No requirements are set by any classification society for aluminium impact testing. This is reasonable as one of the goals of a Charpy-V notch test is to determine whether the materials are ductile or brittle in the presence of the notch, while aluminium is ductile and remains so even in lower temperatures.

Section

2.5 Other Testing Procedures for Metallic Materials

2.5.1 Bend Testing Procedure (BT: Bend Test)

2.5.1.1 Lloyd’s Register (BT)

According to *Rules for the Manufacture, Testing and Certification of Materials (July 2018)* Ch. 2, Sec. 7 a test specimen shall be of rectangular cross-section with dimensions as defined in *Figure 2.5.1 Bend test specimen (LR),* while the edges on the tension side of bend samples are to be rounded to a radius of 1 to 2 mm.

Specifically, for plates, sections and strip the dimensions shall be full thickness and width 30 mm. Where the rolled thickness exceeds 25 mm the compression face may be reduced to 25 mm.

Also, butt weld face and root bend test specimens are to be 30 mm in width and of the full plate thickness. Where the thickness exceeds 12mm, two side bend test specimens may be tested in place of the face and root specimens specified. The side bend specimens should be 10 mm minimum thickness. The upper and lower surfaces of the weld are to be filed, ground or machined flush with the surface of the plate.

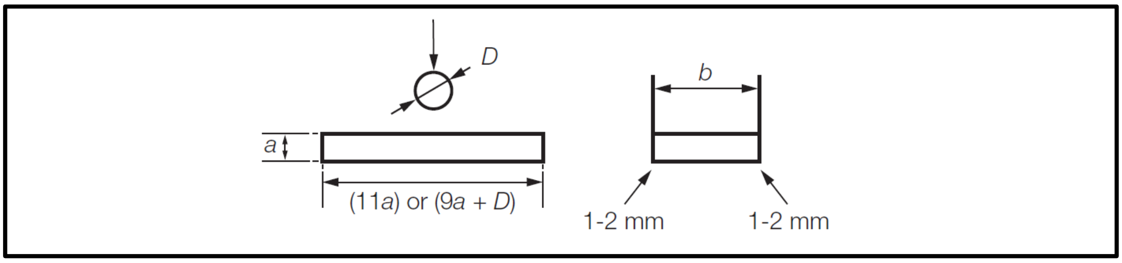


Figure 2.5. 1 Bend test specimen (LR)

The testing procedure is described also by LR in the same section, as a bend sample that is plastically deformed by plunging a mandrel between two fixed points as shown in *Figure 2.5.2 Bend test (LR).* Especially for alumimium welds, LR proposes a guided weld test to ensure even deformation, as in *Figure 2.5.3 Guide bend test (LR).* LR also suggests that bend tests are to be conducted at ambient temperature at the highest convenient rate of bending (but not impact).

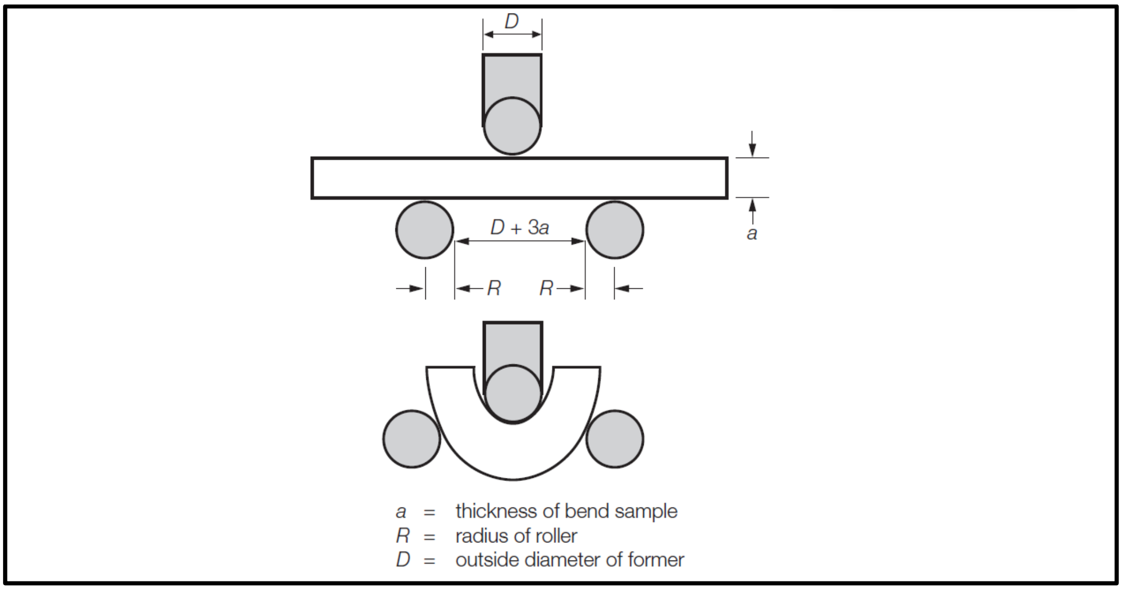


Figure 2.5. 2 Bend test (LR)

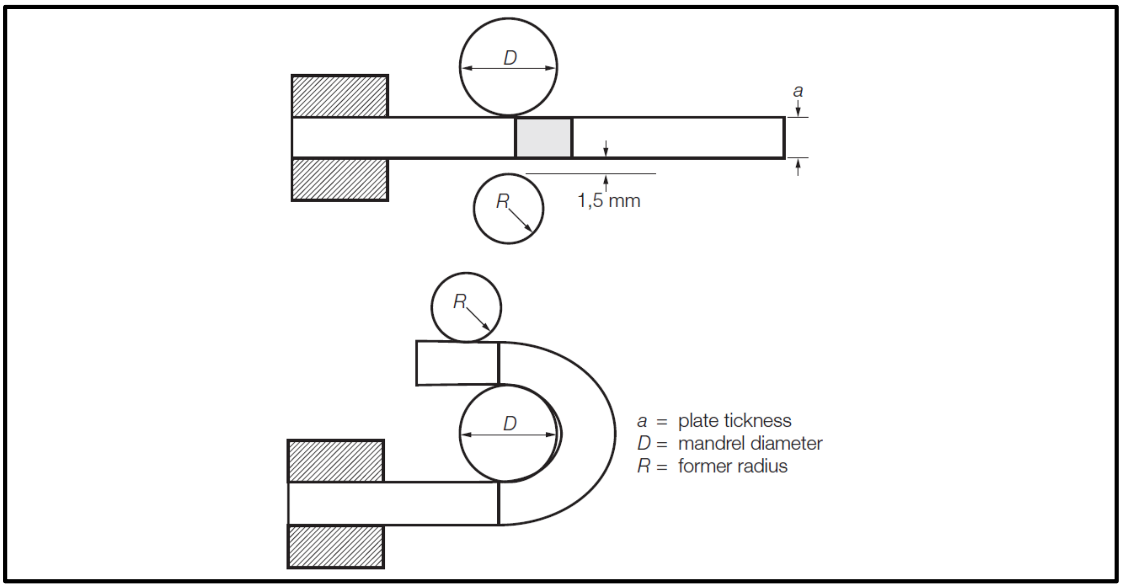


Figure 2.5. 3 Guide bend test (LR)

2.5.1.2 American Bureau of Shipping (BT)

ABS does not make provisions considering the bend testing procedure of materials for hull construction in *Rules for Materials and Welding (January 2018).*

2.5.1.3 Bureau Veritas (BT)

In *Rules on Materials and Welding for the Classification of Marine Units (January 2018)* Ch. 1 Sec. 2, BV includes rules on the bend test specimens that are almost similar to LR respective ones.

Small divergences are observed concerning butt weld face and root bend test specimens. In terms of transverse testing, BV indicates that if the thickness is greater than 25 mm, it may be reduced to 25 mm by machining on the compression side of the bend specimen, while LR suggested full plate thickness. Also, for transverse side bend test on butt welds, BV adds that if the thickness of welded plates is equal or greater than 40mm, the side bend test specimen may be subdivided, each part being at least 20mm wide. Lastly, BV recommends that test specimens for longitudinal face and root bend test on butt welds are to be in accordance with an appropriate recognised standard.

As per the testing procedure BV just refers that is to be performed by applying a continuous mechanical compressive action on one of the surfaces of the test specimen.

2.5.1.4 Det Norske Veritas Germanischer Lloyd (BT)

DNV-GL regulations on bend testing combine BV and LR indications on the subject. As, in *Rules for classification: Ship (July 2018) Pt.2 Ch.1 Sec.3*, DNV- GL completely agrees with BV notes on butt weld face and root test specimens (*see 2.5.1.3 Bureau Veritas (BT))* and with LR on general test specimen dimensions and test methods (*see 2.5.1.1 Lloyd's Register (BT)*). A small but important difference with LR is that DNV-GL recommends guided bend test (or wrap around test) generally for low strength materials (e.g. by DNV-GL aluminum alloys) and not just aluminium welds.

As an addition to the previous guidelines, DNV-GL indicates the size/diameter of the mandrel depending on specified minimum yield stress and elongation of the material as follows:

> *"Unless otherwise detailed in the respective rules or standard, the mandrel diameter shall be 4 × a (four times specimen thickness) for materials with SMYS < 550 MPa, and 5 × a for materials with SMYS ≥ 550 MPa.*
>
> *For materials with specified elongation < 20% the mandrel diameter calculated in accordance with ISO 15614-1 is accepted as an alternative.*
>
> *The bending angle shall be 180°."* [4]

2.5.1.5 Registro Italiano Navale (BT)

RINA requirements in Rules for the Classification of Ships (*January* 2018) in Pt. D of Materials and Welding Ch. 2, Sec.1 and Ch.5 Sec. 2 are identical to BV. Thus, no further comments are reported.

2.5.1.6 Conclusion (BT)

LR rules are the most well-presented, providing explanatory figures of the test and including information about various matters of bend testing. BV and RINA are more explicit and thorough, especially in terms of butt weld root and face tests. DNV-GL provides the most complete rules and regulation on bent testing procedure, as it was mentioned in the relevant subsection, as it combines all of the aforementioned attributes.

2.5.2 Embrittlement Tests (ET: Embrittlement Tests)

2.5.2.1 Lloyd’s Register (ET)

In *Rules for the Manufacture, Testing and Certification of Materials (July 2018)* Ch. 2, Sec. 5, LR states regulations on three tests, which are temper embrittlement test, strain age embrittlement test and hydrogen embrittlement test.

Conducting the first one, the material to be tested is to be split in half and to be heat treated. Half of the material is to be water quenched and the other half is to be cooled from the tempering temperature to 300°C at a rate not exceeding 10°C per minute.

Impact tests in accordance with *Ch. 1, Sec. 4 Impact tests* are to be made on the material in each condition at temperatures over a range wide enough to establish the upper and lower shelf energies and temperatures, tests being made at no less than three intermediate temperatures.

A set of three specimens is to be tested at each temperature. The results are to be plotted separately for each condition, in the form illustrated in *Figure 2.5.4 Idealized transition curve (LR)*. In addition, the test temperatures, proportions of crystallinity and absorbed energies for all the specimens tested are to be reported. The transition temperature for each condition is to be taken as the mid-temperature of the fracture transition zone. The difference between the two transition temperatures is to be reported.

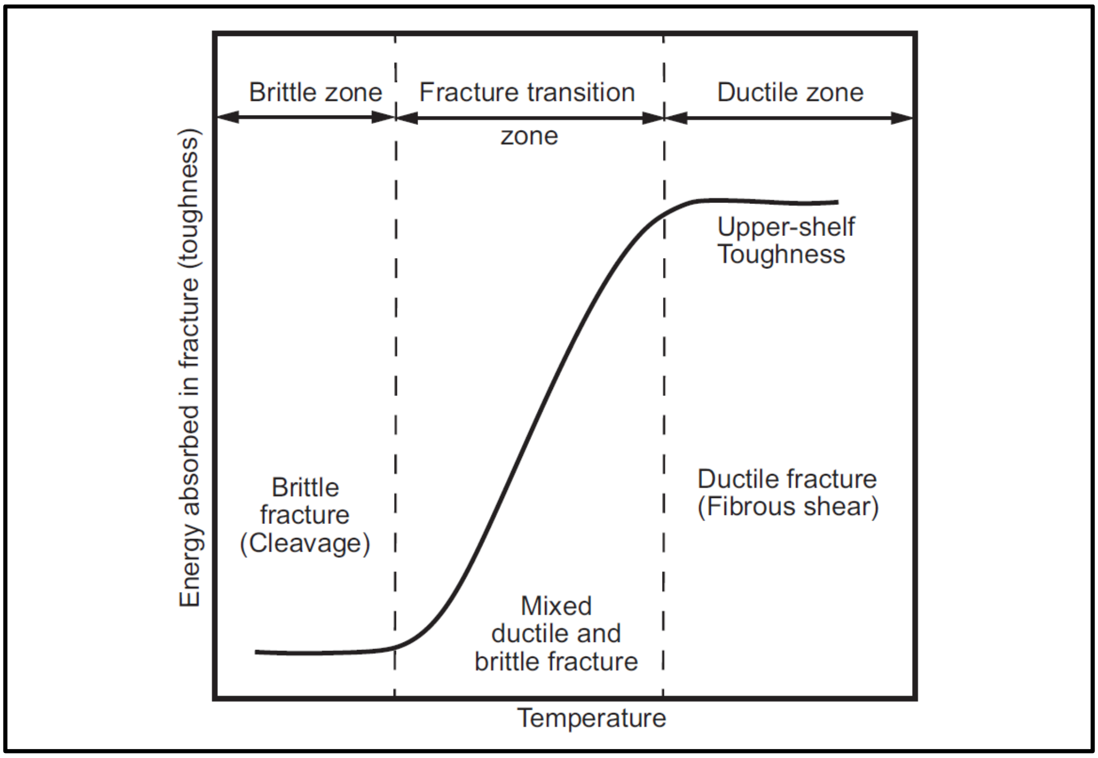


Figure 2.5. 4 Idealized transition curve (LR)

In strain age embrittlement test, according to LR, the test material is to be heat treated in accordance with the specification and then subjected to five per cent (5%) strain. The test material is then to be heated to 250°C and held for one hour. Subsequently the procedure described in the previous two paragraphs shall be followed.

Hydrogen embrittlement test also requires two specimens to be tested. The specimens are to be of a diameter of 20 mm. Where this is not practicable a diameter of 14 mm may be accepted. One specimen is to be tested within a maximum of 3 hours after machining. Where the specimen diameter is 14 mm, the time limit is 1,5 hours. Alternatively, the specimen may be cooled to –60°C immediately after machining and kept at that temperature for a maximum period of 5 days before being tested. The other specimen is to be tested after baking at 250°C for 4 hours. Where the specimen diameter is 14 mm the baking time is to be 2 hours.

A strain rate not exceeding 0,0003 s^{-1} is to be used during the entire test, until fracture occurs. Tensile strength, elongation and reduction of area are to be reported. Lastly the ratio Z1/Z2 is to be reported, where Z1 is the reduction in area without baking and Z2 the reduction in area after baking.

2.5.2.2 American Bureau of Shipping (ET)

ABS does not make stipulations on embrittlement test of materials for hull construction in *Rules for Materials and Welding (January 2018).*

2.5.2.3 Bureau Veritas (ET)

Bureau Veritas, in *Rules on Materials and Welding for the Classification of Marine Units (January 2018) Ch. 1 Sec. 2,* includes only the strain age embrittlement test and its description is a little different than the one that LR proposes.

BV indicates that the material, that the test specimens are to be obtained from, is to be deformed, generally by compression (in special cases, deformation under tension may be permitted) until the required shortening (or elongation) (usually 3%, 5% or 10%) is attained. Then the material is to be heat treated in a furnace at 250°C for 1/2h unless otherwise agreed. Lastly the test specimen is to be Charpy impact tested and broken at the specified temperature.

BV also notes that when the deformation is reached by lateral compression, the procedure of artificial aging described above may be applied directly to the individual test specimens.

2.5.2.4 Det Norske Veritas Germanischer Lloyd (ET)

DNV-GL does not make provisions on embrittlement test of materials for hull construction in *Rules for classification: Ship (July 2018) Pt.2.*

2.5.2.5 Registro Italiano Navale (ET)

RINA requirement *Rules for the Classification of Ships (January 2018) in Pt. D of Materials and Welding* Ch. 2, Sec.1 are identical to BV. Thus, no further comments are reported.

2.5.2.6 Conclusion (ET)

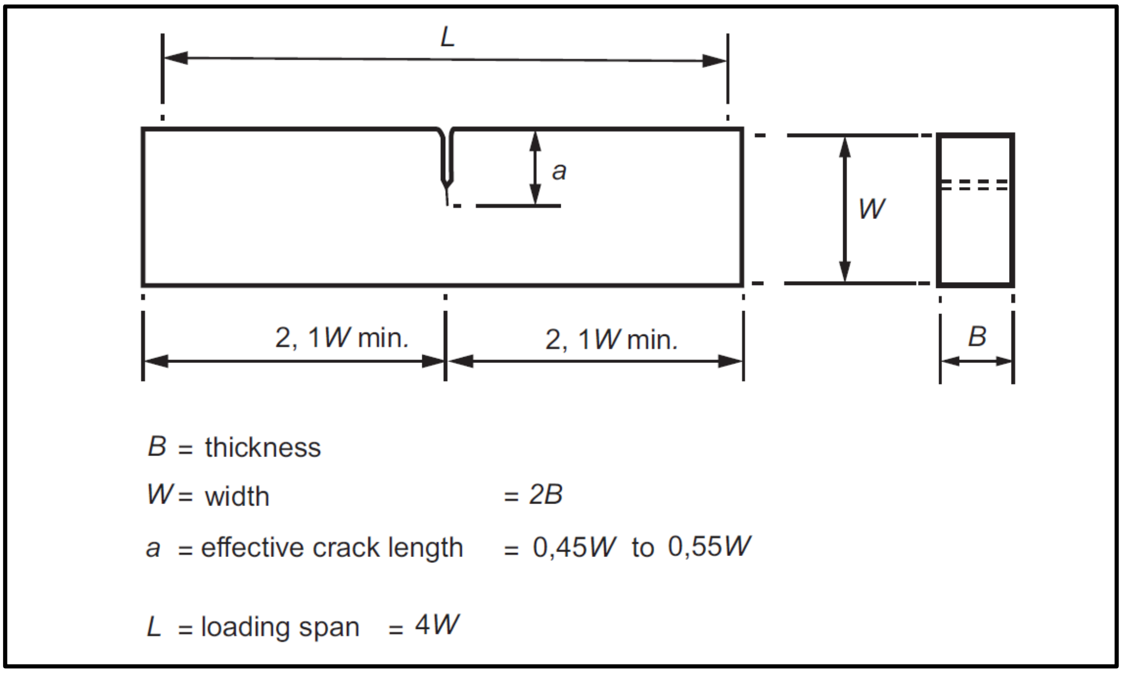
Only LR, BV and RINA includes regulation on embrittlement test. Among them, clearly, LR indications are superior to the other as it includes two embrittlement tests, which are also presented in detail.

2.5.3 Crack Tip Opening Displacement Tests (CTOD)

2.5.3.1 Lloyd's Register (CTOD)

Rules and regulations on CTOD tests are given by LR in *Rules for the Manufacture, Testing and Certification of Materials (July 2018)* Ch. 2, Sec. 6, where indications on test specimens and procedure are presented.

According to LR, unless agreed otherwise, tests are to be made on specimens of the full section thickness and which conform to a nationally agreed standard. The dimensions of the test specimen are given in *Figure 2.5.5 Outline dimensions of the preferred specimen (LR),* normally rectangular and are to be tested in three point bending. LR provides also a subsidiary guideline that may be used after agreement as in *Figure 2.5.6 Outline dimensions of the subsidiary specimen (LR).*



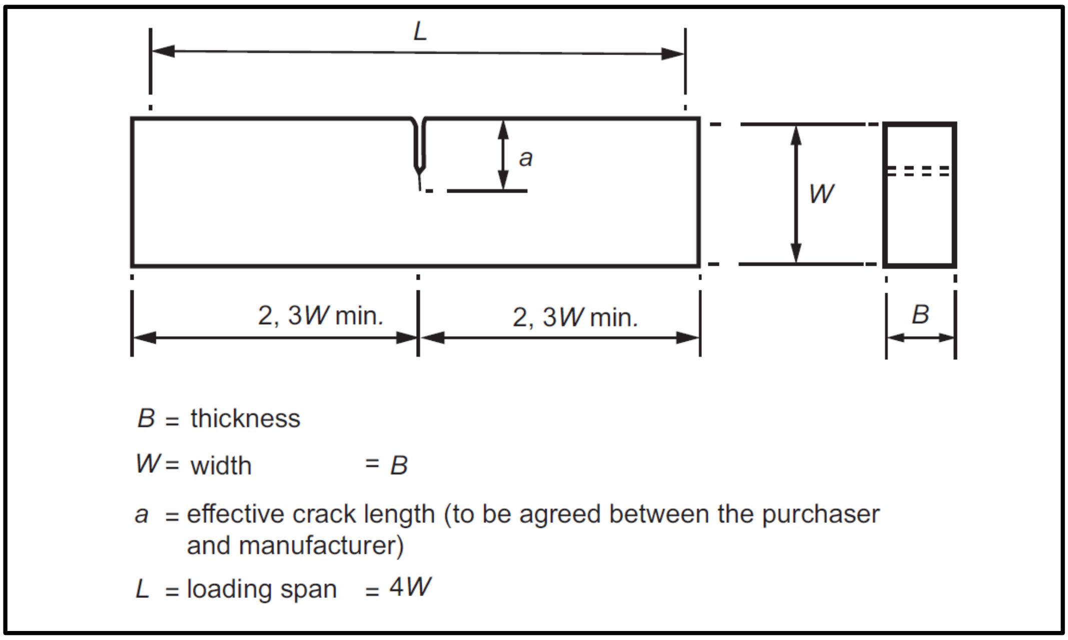
B = thickness

W = width = $2B$

a = effective crack length = $0{,}45W$ to $0{,}55W$

L = loading span = $4W$

Figure 2.5. 5 Outline dimensions of the preferred specimen (LR)



B = thickness

W = width = B

a = effective crack length (to be agreed between the purchaser and manufacturer)

L = loading span = $4W$

Figure 2.5. 6 Outline dimensions of the subsidiary specimen (LR)

In each case the notch is to be positioned at the centre of the loading span; its root radius is not to exceed 0,10 mm. The notch is to be extended by the generation of a fatigue crack to give an effective crack length of the dimension a. For this purpose, the fatigue stress ratio, R1, is to be within the range 0 to 0,1 and the fatigue intensity is not to exceed $0{,}63\sigma_{\gamma}B^{1/2}$ where σ_{γ} is the 0,2 per cent proof stress at the test temperature.

LR state that a CTOD test is to take place at recognized test houses with a nationally accepted standard, providing also additional indications concerning welds and supplementary comments on the testing procedure as presented below:

> *"Unless otherwise agreed, all tests on unwelded wrought material are to be made on specimens taken transverse to the principal working direction and are to be through thickness notched.*
>
> *Where tests are made on weld material, the fatigue crack should be arranged to sample the maximum amount of unrefined weld metal.*
>
> *Where tests are made on the Heat Affected Zone (H.A.Z.) of a weld, a K or single bevel weld preparation is recommended. The region of lowest fracture toughness in the Heat Affected Zone should be identified for the particular steel and weld procedure by means of preliminary tests. The fatigue crack is to be accurately positioned to sample as high a proportion of this critical region as possible and after testing has been completed, the specimen is to be sectioned to check that this has been achieved. Sufficient tests should be made to ensure that the critical region has been sampled in at least three specimens.*
>
> *At least three valid tests are to be made for each material condition. Invalid tests are to be disregarded and the tests repeated.*
>
> *Local pre-compression of the test specimen ahead of the notch is acceptable in order to provide an acceptably even fatigue crack front.*
>
> *The temperature of the test piece is to be measured to within ±2°C over the range minus 196°C to +200°C and to within ±5°C outside this range. The temperature should be measured at a point on the specimen not farther than 2 mm away from the crack tip."* [1]

2.5.3.2 American Bureau of Shipping (CTOD)

American Bureau of Shipping is does not have particular regulations as per CTOD in *Rules for the Classification of Ships (January 2018) in Pt. D of Materials and Welding.* Generally for fracture toughness testing, as in Ch.1 Sec. 1, ABS suggests that tests are to be carried out as per BS 7448 Parts 1[14] & 2/ASTM E1820[15] specification or any other recognized standard.

2.5.3.3 Bureau Veritas (CTOD)

Similarly to ABS, BV plainly states that unless otherwise agreed, the test is to be performed on test specimens of full thickness according to appropriate national or international standards like BS 7448 Part 1:1991[14] and ASTM E 1290[16]. A slight difference is that BV in *Rules on Materials and Welding for the Classification of Marine Units (January 2018) Ch. 1 Sec. 2* refers to it uniquely for CTOD and not generally for fracture testing.

2.5.3.4 Det Norske Veritas - Germanischer Lloyd (CTOD)

DNV-GL does not make provision for CTOD tests, but in *Rules for classification: Ship (July 2018)* Pt.2 Ch.1 Sec. 3 includes a subsection dedicate to fracture mechanics testing, indicating test to be carried out according to ISO 12135 (for base material) [17] and ISO 15653 (for welded joints) using 3-point bend specimens (SENB) [18], or another recognized standard as agreed with the Society.

The referenced ISOs may not regulate the CTOD test, however DNV-GL states that test may be required for the base material or for a welded connection. For base metal at least three valid CTOD tests shall be obtained. For welded plates for each required crack tip position at least three valid CTOD tests shall be obtained. The test results report shall contain the information as given in ISO 12135 (paragraph 8 Test report) and in ISO 15653 (paragraph 13 Test report), the force (F) - notch opening displacement (V) records and photographs for the fractured surfaces on which the crack lengths are measured.

2.5.3.5 Registro Italiano Navale (CTOD)

RINA requirements in *Rules for the Classification of Ships (January 2018) in Pt. D of Materials and Welding* Ch. 2, Sec.1 are identical to BV. Thus, no further comments are reported.

2.5.3.6 Conclusion (CTOD)

While most of the classification societies suggest appropriate recognized standards, LR is the only one to set requirements itself (dimensions, indications on the procedure, specifications for welds) to ensure the normality and validity of the crack tip displacement tests.

2.5.4 Hardness Testing Procedure (HT: Hardness Test)

2.5.4.1 Lloyd's Register (HT)

Hardness testing is to be carried out according to ISO 6506-1[19], ISO 6507[20], which are correspond to Brinell and Vickers tests respectively or equivalent for the type of hardness test, as stated by LR in *Rules for the Manufacture, Testing and Certification of Materials (July 2018)* Ch. 2, Sec. 8.

2.5.4.2 American Bureau of Shipping (HT)

While in *Rules for Materials and Welding (January 2018),Ch.1 Sec.2* the hardness test method is not regulated, ABS suggest Brinell and Rockwell test for forgings and anchor chains, which do not constitute part of this thesis.

2.5.4.3 Bureau Veritas (HT)

BV does not make provisions considering the bend testing procedure of materials for hull construction in *Rules on Materials and Welding for the Classification of Marine Units (January 2018)* Ch. 1 Sec. 2 (2018*).*

2.5.4.4 Det Norske Veritas - Germanischer Lloyd (HT)

Similarly to LR, DNV-GL in *Rules for classification: Ships (July 2018)* Pt.2 Ch.1. Sec. 3 (2018) suggests where hardness test is required, the test to be performed in accordance with a recognized standard as the following:

— ISO 6506 Brinell hardness test

— ISO 6507 Vickers hardness test

— ISO 6508[21] Rockwell hardness test.

DNV-GL also, cautionary states that a hardness test is in principle not considered to be a substitute for tensile test.

2.5.4.5 Registro Italiano Navale (HT)

RINA does not make provisions considering the bend testing procedure of materials for hull construction in *Rules for the Classification of Ships (January 2018) in Pt. D of Materials and Welding* Ch. 1 Sec. 2 (2018*).*

2.5.4.6 Conclusion (HT)

Except RINA and BV, the classification societies suggest similar and standard ISO tests. Only LR and DNV-GL dedicate a subsection in their guidelines to hardness tests and to refer to relevant ISOs.

2.5.5 Corrosion Test and Procedure (CT: Corrosion Test)

2.5.5.1 Lloyd's Register (CT)

Provisions made by LR on corrosion test, in *Rules for the Manufacture, Testing and Certification of Materials (July 2018)* Ch. 2, Sec. 9, concern two separate tests, intergranular corrosion test and pitting corrosion test.

As per intergranular test, the procedure described by LR as follows:

"For all products other than pipes, the material for the test specimens is to be taken adjacent to that for the tensile test and is to be machined to suitable dimensions for either a round or rectangular section bend test. The diameter or thickness is to be not more than 12 mm, and the total surface area is to be between 1500 mm^2 and 3500 mm^2.

Specimens are to be heated to a temperature of 700 ± 10 °C for 30 minutes, followed by rapid cooling in water. They are then to be placed on a bed of copper turnings (50 g per litre of test solution) and immersed for 15 to 24 hours in a boiling solution of the following composition:

- *100 g of hydrated copper sulphate granules* ($CuSO_4 . 5H_2O$)
- *184 g (100 ml) sulphuric acid (density 1,84 g/ml) added dropwise to distilled water to make 1 litre of solution.*

Precautions are to be taken during boiling to prevent concentration of the solution by evaporation.

After immersion, the test specimens are to be bent, at ambient temperature, through 90° over a former with a diameter equal to twice the diameter or thickness of the test specimen.

After bending, the test specimens are to be free from cracks on the outer, convex surface." [1]

(Note: Comments on pipes have been exclude as they are not part of this thesis)

Subsequently, the pitting corrosion test procedure is described by LR in the relevant section as follows:

"The material for the test specimens is to be taken adjacent to that for the tensile test and is to be machined to a round or rectangular test piece of thickness approximately 6 mm with total surface area between 1500 mm^2 and 3500 mm^2. Any deformed material at the edges is to be removed.

All surfaces of the specimen are to be polished to a uniform finish using 120 grit abrasive paper. Sharp edges are to be removed and, after polishing, the specimen should be thoroughly washed and dried.

The dimensions of the surface are to be measured in order to calculate the exposed area.

The specimen is to be weighed to an accuracy of 0,001g or greater.

For the corrosive media 100g of reagent grade ferric chloride, $FeCl_3.6H_2O$, is dissolved in 900ml of de-ionised water and filtered to remove insoluble particles.

At least 250ml of ferric chloride solution is to be added to a glass test container. The container is to be placed in a water bath and allowed to reach the required test temperature. The bath temperature shall be monitored and recorded in order to ensure that the temperature is satisfactorily maintained throughout the test. Once the test temperature has been achieved, the test piece is to be placed in a glass cradle and lowered into the solution.

A glass cover is to be placed over the vessel to allow the test piece to remain undisturbed throughout the duration of the test. The standard duration of the test is 72 hours.

At the end of the test, the specimen is to be removed from the solution. It shall be rinsed with water, scrubbed with a nylon bristle brush under running water to remove corrosion products, and then dried.

The surface of the specimen is to be thoroughly inspected to a magnification of x20 and the specimen is weighed to an accuracy of 0,001 g or better.

The results obtained shall be recorded and these shall include the weight loss expressed as g/m2 and a description of the surface appearance, noting any evidence of pitting corrosion.

Unless otherwise agreed, the acceptance criteria for the test are that there shall be no evidence of pitting at x20 magnification and that the maximum weight loss shall be 0,8 g/m^2." [1]

Requirements on corrosion resistance ability of aluminium products are set LR in Ch. 8, Sec. 1 of the previous referenced Article. Specifically, for Rolled 5xxx alloys of type 5083, 5383, 5059, 5086 and 5456 in the H116 and H321 tempers intended for use in marine hull construction or in marine applications where frequent direct contact with seawater is expected are to be corrosion tested with respect to exfoliation and intergranular corrosion resistance. In addition, the procedure described by LR below, is to be followed in order of material approval:

"The manufacturers have to establish the relationship between microstructure and resistance to corrosion when the above alloys are approved. A reference photomicrograph taken at 500x, under the conditions specified in ASTM B928[12] *Section 9.4.1, is to be established for each of the alloy tempers and thickness ranges relevant. The reference photographs are to be taken from samples which have exhibited no evidence of exfoliation corrosion at a pitting ration of PB or better, when subjected to the test described in ASTM G66 (ASSET)*[22]*. The samples are also to have exhibited resistance to intergranular corrosion at a mass loss not greater than 15 mg/cm^2, when subjected to the test described in ASTM G67 (NAMLT)*[23]*. Upon satisfactory establishment of the relationship between microstructure and resistance to corrosion, the master photomicrographs and the results of the corrosion tests are to be submitted to the Society for approval.*

The manufacturer is responsible to maintain the production practices unchanged after approval of the reference micrographs.

Other test methods may also be accepted at the discretion of the Society." [1]

As per aluminium, when the products have been tested with satisfactory results, the mark "M" is to be added after the temper condition

2.5.5.2 American Bureau of Shipping (CT)

In *Rules for Materials and Welding (January 2018)* ABS does not include rule on corrosion test methods. However, in Appendix 8 of *Rules for Materials and Welding (2018),* ABS states that it may give approval for steel with enhanced corrosion resistance properties. A manufacturer has to submit to ABS a request for approval, which is to include the following:

i) Corrosion test plan and details of equipment and test environments.
ii) Technical data related to product assessment criteria for confirming corrosion resistance
iii) The technical background explaining how the variation in added and controlled elements improves corrosion resistance.
iv) The grades, the brand name and maximum thickness of steel with enhanced corrosion resistance properties to be approved. ABS' designations for steels with enhanced corrosion resistance properties are given in *Table 2.5.1 Designations for Steels with Enhanced Corrosion Resistance Properties (ABS).*
v) The welding processes and the brand name of the welding consumables to be used for approval.

Table2.5. 1 Designations for Steels with Enhanced Corrosion Resistance Properties (ABS)

Type of Steel	*Location where Steel is Effective*	*Enhanced Corrosion Resistance Properties Designation*
Rolled steel for hull	For strength deck, ullage space.	RCU
	For inner bottom	RCB
	For both strength deck and inner bottom plating	RCW

ABS also includes requirement on the corrosion resistance of aluminium and demands a certain procedure for material approval, both in the same manner as LR, *see 2.5.5.1 Lloyd's Register (CT).*

2.5.5.3 Bureau Veritas (CT)

BV does not directly regulates corrosion test, but proposes appropriate international standards for various products in *Rules on Materials and Welding for the Classification of Marine Units (January 2018)*.

In Ch. 1, Sec. 2 of the referenced article, stipulations are made for normal and higher strength corrosion resistant steels for cargo oil tanks. Such steels comply with the requirement of normal and higher strength steels and are designated as in *Table 2.5.1 Designations for Steels with Enhanced Corrosion Resistance Properties (ABS).* The suffix is given to any steel grade which has been tested according to the present Article and to the corrosion testing procedure defined in the Appendix of the Annex to Performance Standard for Alternative Means of Corrosion Protection for Cargo Oil Tanks of Crude Oil Tankers MSC.289(87)[24].

In the same section, considering kind of steel, pipes and forgings, which may not be part of this thesis, BV proposes ASTM A262[25], for various corrosion tests such as intergranular corrosion test, nitric acid test etc.

Requirements on corrosion resistance ability of aluminium products are set BV in Ch. 3, Sec. 2 in exact similar way to LR, *see 2.5.5.1 Lloyd's Register (CT).*

2.5.5.4 Det Norske Veritas - Germanischer Lloyd (CT)

When intercrystalline corrosion test on a steel is required, according to *Rules for classification: Ship (July 2018)* Ch. 2 Sec. 3, the test shall be carried out according to ISO 3651-2[26] (ferritic, austenitic and ferritic-austenitic stainless steel), ASTM A262, Practice E, Copper – Copper Sulphate - Sulphuric Acid Test (austenitic stainless steel), or to another recognised standard. Also, in case requirements for pitting or crevice corrosion resistance are specified, appropriate corrosion tests should be carried out in accordance with an agreed standard, e.g. ASTM G48 method A[27]

In terms of aluminum products, DNV-GL requirements are similar to LR, *see 2.5.5.1 Lloyd's Register (CT),* except the fact that DNV-GL does not define a designation mark.

2.5.5.5 Registro Italiano Navale (CT)

RINA requirement in *Rules for the Classification of Ships (January 2018) in Pt. D of Materials and Welding* are identical to BV. Thus, no further comments are reported.

2.5.5.6 Conclusion (CT)

While the rules on corrosion testing present a lot of similarities among the five classification societies, LR rules and regulations stand out as they include analytical description of the testing procedures (intergranular and pitting corrosion tests), being immediately informative. Besides that, the rules of the five classification societies should be considered equally reliable as they all suggest appropriate International Standards.

2.5.6 Drop Weight Testing Procedure (DW: Drop-weight)

2.5.6.1 Lloyd’s Register (DW)

LR does not involve any requirements or indication on drop-weight testing in *Rules for the Manufacture, Testing and Certification of Materials (July 2018).*

2.5.6.2 American Bureau of Shipping (DW)

While ABS does not dedicate any reference to the matter on relevant testing section, in *Rules for Materials and Welding (January 2018),* considering specified material, such as low temperature materials, suggest ASTM E208[28] when drop-weight testing is required.

2.5.6.3 Bureau Veritas (DW)

When the NDT (nil ductility transition) temperature is to be determined, BV suggests drop weight test according to ASTM Standard E 208, in *Rules on Materials and Welding for the Classification of Marine Units (January 2018)* Ch.1 Sec.2. The NDT is the maximum temperature where the drop weight test specimen breaks when tested according to the provisions of the standard.

BV sets requirements also on the dimension of the drop weight test specimens as follows (thickness by width by length, in mm^3):

- type P1: 25 x 90 x 360
- type P2: 19 x 50 x 130
- type P3: 16 x 50 x 130

2.5.6.4 Det Norske Veritas - Germanischer Lloyd (DW)

Similarly to BV, in *Rules for classification: Ship (July 2018)* Ch. 1 Sec. 3, DNV-GL suggests ASTM E208 for drop-weight testing and includes similar requirements on test specimens’ dimensions.

Furthermore, DNV-GL gives the flexibility of testing specimens of lower thickness than the three referenced types, *see 2.5.6.3 Bureau Veritas (DW),* by adding the following:

> *“When drop weight test is required for material thicknesses below 16 mm down to and including 12 mm, a test specimen machined down to 12 mm thickness shall be used. For material thicknesses below 12 mm down to and including 10 mm, the thickness of the test specimen shall be that of the material. Other dimensions and requirements for test specimen with thickness below 16 mm shall be as for test specimen no. 3 above, except that a stop distance of 2,3 mm shall be used.”* [4]

2.5.6.5 Registro Italiano Navale (DW)

RINA requirements in *Rules for the Classification of Ships (January 2018) in Pt. D of Materials and Welding* are identical to BV. Thus, no further comments are reported.

2.5.6.6 Conclusion (DW)

With LR standing aside, all the other classification societies are equally valid suggesting the same international standards on drop weight testing.

2.5.7 Determination of Grain Size (DGZ)

2.5.7.1 Lloyd's Register (DGZ)

Determination of grain size in not a part of LR's *Rules for the Manufacture, Testing and Certification of Materials (July 2018).*

2.5.7.2 American Bureau of Shipping (DGZ)

While in *Rules for Materials and Welding (January 2018),* ABS does not include a passage dedicated to the determination of grain size, in ordinary and higher strength steels relevant sections here ABS suggest ASTM E112[29] in order to determine that a fine grain practice has been achieved

2.5.7.3 Bureau Veritas (DGZ)

Bureau Veritas does not presents either an exclusive segment on determination of grain size in *Rules on Materials and Welding for the Classification of Marine Units (January 2018)* . However, in Ch.1 Sec.2, among other test, ASTM E 112 58 T Standards is suggested for the evaluation of the primary austenitic grain size. For fine grained steels, the "fine grain" condition is considered satisfied when the grain size is 5 or finer according to BV. Also, other recognized standards may be accepted by agreement with BV.

2.5.7.4 Det Norske Veritas - Germanischer Lloyd (DGZ)

DNV-GL is the only one to refer explicitly to the determination of grain size in *Rules for classification: Ship (July 2018)* Ch. 1 Sec. 3, which is the relevant test method segment. However, like the rest, DNV-GL recommends ASTM E112 where the austenitic grain size specification is required, or other recognized standards.

2.5.7.5 Registro Italiano Navale (DGZ)

RINA requirement in *Rules for the Classification of Ships (January 2018) in Pt. D of Materials and Welding* are identical to BV. Thus, no further comments are reported.

2.5.7.6 Conclusion (DGZ)

LR standing aside, all the other classification societies are equally valid suggesting the same international standards on determination of grain size.

Chapter

3 Composite Materials (Fibre Reinforced Plastics)

Section

3.1 Introduction

3.1.1 Scope

Composite materials are defined as materials consisting of two or more components, which combine to achieve specific properties and characteristics, which none of the participating components alone can achieve.

The composites are characterized by the coexistence of at least two macroscopically distinct components, one of which, designated as a the reinforcing material, gives improved, mainly mechanically related, properties to the composite material. The second component, called the matrix, is usually low density and its involvement in the material ensures maximum utilization of the reinforcement properties.[30]

At this Chapter, rules on the properties of raw materials (reinforcements, resins, core materials) will be explored as well as those of laminates. Each raw material will be examined separately quoting rules of the five classification societies. Rules contained in *Hull in Composite Materials and Plywood, Material Approval, Design Principles, Construction and Survey (November 2018)*[31] by Bureau Veritas are quoted first, as they seem more complete, followed with supplements of the other societies.

Section

3.2 Reinforcements

3.2.1 General

Mainly the reinforcing material is used in the shape of continuous fibres and less often as discontinuous fibres. These fibres are arranged into fabrics or “rovings” in order to be used and handled.

The reinforcing fibers, while capable of carrying only tensile loads in non-resin yarn form, contribute to the bulk of the tensile, compressive, flexural and shear stiffness and durability of a fibrous multilayer material. So, in this section the most important rules on the mechanical characteristics of the five classification societies are presented.

3.2.2 Bureau Veritas (R)

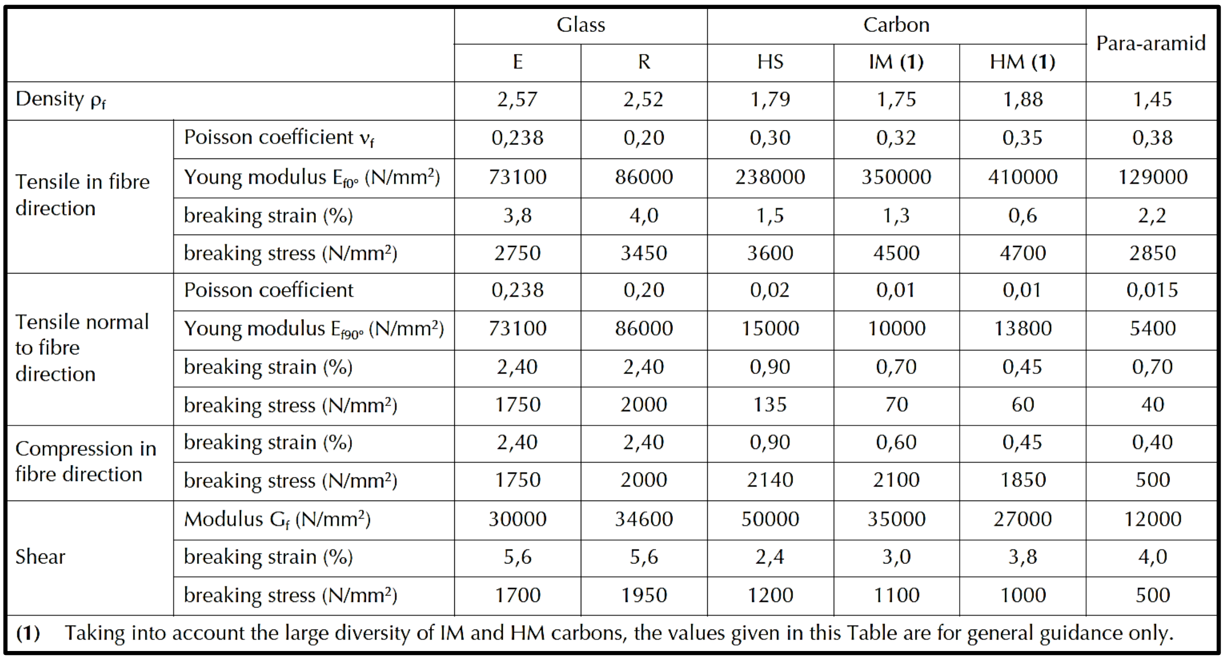
The mechanical characteristics of fibres, as raw materials, are given by the classification society of ***Bureau Veritas*** in *Hull in Composite Materials and Plywood, Material Approval, Design Principles, Construction and Survey* (November 2018) Sec. 4. This section contains requirements for glass (E and R types), carbon (HS: High Strength, IM: Intermediate Modulus, HM: High Modulus) and para-aramid fibres. Minimum values of the mechanical characteristics are presented by the rule **3.2.4** of the previous referenced section:

3.2.4 Mechanical characteristics of fibre types

As a general rule, the mechanical characteristics of fibres to be taken into account for laminate calculations are to be submitted by the manufacturer and/or are given by mechanical tests. The minimum mechanical characteristics are given in Tab 2, for information.

The data of BV's above rule of "Tab 2" can be found in the following *Table 3.2.1 Mechanical properties of fibres (BV)*.

Table 3.2. 1 Mechanical properties of fibres (BV)



		Glass		Carbon			Para-aramid
		E	R	HS	IM **(1)**	HM **(1)**	
Density ρ_f		2,57	2,52	1,79	1,75	1,88	1,45
Tensile in fibre direction	Poisson coefficient ν_f	0,238	0,20	0,30	0,32	0,35	0,38
	Young modulus $E_{f0°}$ (N/mm^2)	73100	86000	238000	350000	410000	129000
	breaking strain (%)	3,8	4,0	1,5	1,3	0,6	2,2
	breaking stress (N/mm^2)	2750	3450	3600	4500	4700	2850
Tensile normal to fibre direction	Poisson coefficient	0,238	0,20	0,02	0,01	0,01	0,015
	Young modulus $E_{f90°}$ (N/mm^2)	73100	86000	15000	10000	13800	5400
	breaking strain (%)	2,40	2,40	0,90	0,70	0,45	0,70
	breaking stress (N/mm^2)	1750	2000	135	70	60	40
Compression in fibre direction	breaking strain (%)	2,40	2,40	0,90	0,60	0,45	0,40
	breaking stress (N/mm^2)	1750	2000	2140	2100	1850	500
Shear	Modulus G_f (N/mm^2)	30000	34600	50000	35000	27000	12000
	breaking strain (%)	5,6	5,6	2,4	3,0	3,8	4,0
	breaking stress (N/mm^2)	1700	1950	1200	1100	1000	500

(1) Taking into account the large diversity of IM and HM carbons, the values given in this Table are for general guidance only.

(HS: High Strength, IM: Intermediate Modulus, HM: High Modulus)

3.2.3 American Bureau of Shipping (R)

ABS' *Rules for Materials and Welding (2018)* Ch. 6 Sec. 1 does not provide rules on the mechanical characteristics of reinforcements, nor does it requires data for their approval.

3.2.4 Det Norske Veritas - Germanischer Lloyd (R)

DNV-GL like BV includes rules for glass, carbon and aramid reinforcements’ properties and declared properties to be determined for approval purposes by *Table 3.2.2 Glass fibre reinforcements (DNV-GL)*, *Table 3.2.3 Physical requirements for carbon fibre reinforcements (DNV-GL)* and *Table 3.2.5 Requirements for aramid reinforcements (DNV-GL)* respectively.

However in DNV – GL’s *Rules for classification: Ships (October 2015)* Pt. 2, Ch. 3, Sec. 2 requirements for the fibre products are not given in numerical values, but ISO-tests are suggested for the determination of the properties. Only one table concerning carbon fibre yarns corresponds to tensile strength, tensile modulus and elongation with values and the corresponding ISO-standard and is presented in *Table 3.2.4 Tensile testing of carbon fibre yarns (DNV-GL).*

Intrestingly that most of the ISO tests that DNV-GL suggests, could be applied on various forms of reinforcement products, such as continuous-filament yarn, staple fibre yarn, rovings, chopped strands mats, fabrics etc.

Table 3.2. 2 Glass fibre reinforcements (DNV-GL) [32, 33, 34, 35,36,37]

Property	*Test method 1)*	*Acceptance criteria*
Moisture content 2)	ISO 3344	Maximum 0.2% on delivery
Loss on ignition 2)	ISO 1887	The manufacturer’s nominal value. Tolerance limits for the various materials are subject to approval in each separate case
Linear density (tex)	ISO 1889	The arithmetic mean ± 2 standard deviation shall be within the manufacturer's value ± 10%
Average diameter (μm)	ISO 1888	mean
Tensile strength of impregnated rovings	ISO 9163	manufacturer’s specified minimum value
Mass per unit area 2)	ISO 3374	The arithmetic mean ± 2 standard deviation shall be within the manufacturer's value ± 10%

1) other standards may be used if agreed upon with the Society prior to testing
2) unless otherwise agreed, these parameters shall be tested and documented in W certificate

Table 3.2. 3 Physical requirements for carbon fibre reinforcements (DNV-GL) [32, 34, 37, 38]

Property 1)	*Test method 2)*	*Acceptance criteria*
Moisture content	ISO 3344	manufacturer’s specified value
Size content	ISO 10548	manufacturer’s specified value
Linear density of the yarn	ISO 1889	Manufacturer‘s nominal value ± 5%
Weight per unit area of the fabric	ISO 3374	Manufacturer’s nominal value ± 10% - fabrics, weaves, etc.

1) unless otherwise agreed, these parameters shall be tested and documented in W certificate
2) other standards may be used if agreed upon with the Society prior to testing

Table 3.2. 4 Tensile testing of carbon fibre yarns (DNV-GL) [39]

Fibre type	*Test method 1)*	*Acceptance criteria*		
HT	ISO 10618	Tensile strength	MPa	3000
		Tensile modulus		235000
		Elongation	%	1.4
HM		Tensile strength	MPa	2000
		Tensile modulus		350000
		Elongation	%	0.4
1) other standards may be agreed upon with the Society prior to testing				

(HT: High Tensile Strength, HM: High Modulus)

Table 3.2. 5 Requirements for aramid reinforcements (DNV-GL)[32, 40]

Property 1)	*Test method 2)*	*Acceptance criteria*
Moisture content	ISO 3344	manufacturer's specified value
Mass per unit area	ISO 4605	mean ± 2 sdev, within manufacturer's nominal value ±10%
1) unless otherwise agreed, these parameters shall be tested and documented in W certificate 2) other standards may be used if agreed upon with the Society prior to testing		

3.2.5 Lloyd's Register (R)

LR is lacking rules about the properties of fibre reinforcements, but on *Rules for the Manufacture, Testing and Certification of Materials (July 2018)* Ch. 14 Sec. 2 it dictates the requirements data to be provided on the society for materials approval and/or inspection purposes with the rule **2.4.1**:

2.4.1 *The following data is to be provided, where applicable, for each type of reinforcement:*

(a) Reinforcement type.

(b) Fibre type for each direction.

(c) Fibre tex value.

(d) Fibre finish and/or treatment.

(e) Yarn count in each direction.

(f) Width of manufactured reinforcement.

(g) Weight per unit area of manufactured reinforcement.

(h) Weight per linear metre of manufactured reinforcement.

(i) Compatibility (e.g. suitable for polyesters, epoxides, etc.)

(j) Constructional stitching – details of yarn, specific gravity, type, frequency and direction.

(k) Weave type.

(l) Binder type and content.

(m) Density of the fibre material.[1]

3.2.6 Registro Italiano Navale (R)

RINA *Rules for the Classification of Pleasure Yachts (January 2019)*[41] Pt. D, Ch. 6, Sec. 2 deals with the subject in the same fashion as LR. The corresponding rule is the 4.1.1 of the referenced section:

4.1.1 The following data are to be provided, where applicable, according to the type of reinforcement, for each type of reinforcement:

a) Reinforcement type

b) Diameter and length of fibres

c) Type of dressing and bonding for fibre treatment

d) Linear mass or mass per area

e) Moisture content

f) Solubility in styrene

g) Content of combustible materials

h) Compatibility (e.g. suitable for polyesters, epoxides, etc.)

i) Tensile strength

j) Resistance to temperature

k) Surface treatment, in particular against oxidation.[41]

3.2.7 Conclusion (R)

Among the five classification societies DNV-GL seem to be more complete and explicit as they are including, not only the requirements to be provided for every distinct type of reinforcement, as do LR and RINA, but also specifies the exact ISO tests to be performed. Although, Bureau Veritas' provisions on minimum values is quite useful, DNV-GL rules should be considered superior.

Section

3.3 Resins

3.3.1 General

If the fibers contribute to the high mechanical strength of the compound, the matrix ensures it. The mechanical stresses exerted on the composite material are transferred through the matrix to the fibers. In addition, the spread of cracks, which start from broken fibers, is stopped by the matrix material. Resin is the material that most often used for matrix purposes.

Resins mainly are distinguished in two categories, thermoplastic and thermosetting resins and in this section the most significant mechanical characteristics of them are going to be examined, as given by the five classification societies.

3.3.2 Bureau Veritas (Res.)

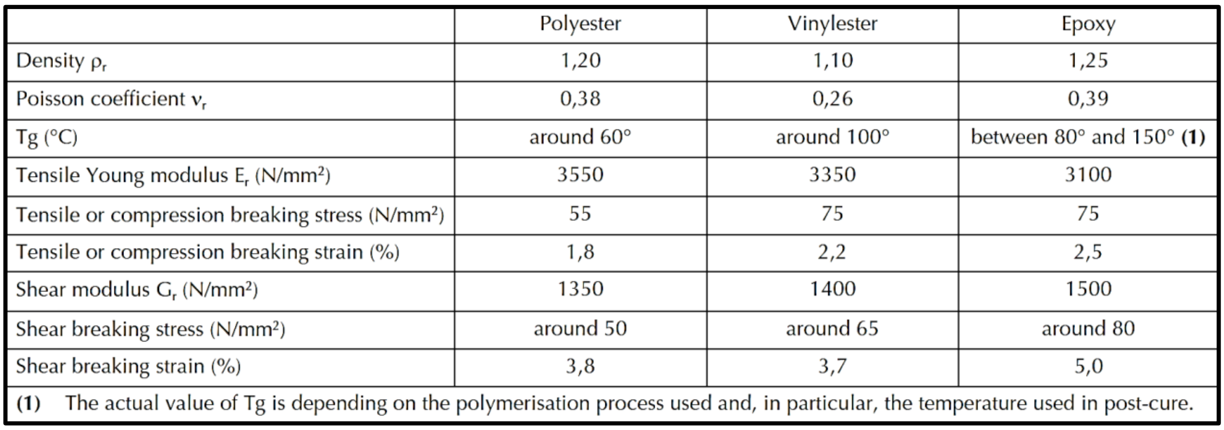
Bureau Veritas guidelines concern only systems of thermosetting resins, polyester, vinylester and epoxy resin systems. Mechanical characteristics of them can be found in *Hull in Composite Materials and Plywood, Material Approval, Design Principles, Construction and Survey* (November 2018) Sec. 4 under guideline numbers 2.3.1 and 2.3.2:

2.3 Resin mechanical characteristics

2.3.1 General
As a general rule, the resin mechanical characteristics to be taken into account for laminate calculation are to be given by the manufacturer and/or by mechanical tests.
2.3.2 *The minimum mechanical characteristics are given in Tab 1, for information.*[31]

The data of BV's above rule of "Tab 1" can be found on the following *Table 3.3.1 Mechanical characteristics of resins (BV)*.

Table 3.3. 1 Mechanical characteristics of resins (BV).



	Polyester	Vinylester	Epoxy
Density ρ_r	1,20	1,10	1,25
Poisson coefficient ν_r	0,38	0,26	0,39
Tg (°C)	around 60°	around 100°	between 80° and 150° **(1)**
Tensile Young modulus E_r (N/mm²)	3550	3350	3100
Tensile or compression breaking stress (N/mm²)	55	75	75
Tensile or compression breaking strain (%)	1,8	2,2	2,5
Shear modulus G_r (N/mm²)	1350	1400	1500
Shear breaking stress (N/mm²)	around 50	around 65	around 80
Shear breaking strain (%)	3,8	3,7	5,0
(1) The actual value of Tg is depending on the polymerisation process used and, in particular, the temperature used in post-cure.			

The rest of the classification societies use more analytical tables which usually correspond to the property measured with values and the suitable National or International Test.

3.3.3 America Bureau of Shipping (Res.)

ABS, besides vinylester, polyester and epoxy resins, acknowledges gel coats and phenolic resins, noting that the latter have superior properties for fire resistance, but minimum values for the mechanical characteristics of resins are not presented. Instead ABS indicates data of properties to be provided for any type of resin in *Materials and Welding (2018)* Ch. 6 Sec. 1 with the following rule:

1.11 Resin Properties

The properties of a resin are to be for the final form of the resin actually used in production with all additives and fillers included. The amount of silicon dioxide or other material added to provide thixotropy is to be the minimum necessary to resist flowing or draining. The following liquid and cured condition properties of resins are to be provided for the gel coat resin and laminating resin, and if different, for the skin coat:

- *Liquid Properties (at 25°C)*

Monomer Content %

Viscosity – Brookfield (Spindle No. & RPM) CPS

Thixotropic Index, Minimum

Specific Gravity

Flash Point, Closed Cup

Fillers (type and amount)

- *Cure Characteristics (at 25°C)*

Gel Time, Minutes (indicate initiator (catalyst) and activator (promoter) and %)

Gel to Peak, Minutes

Peak Exotherm

- *Cured Properties for Resin Clear Casting*

Barcol Hardness

Heat Deflection Temperature

Tensile Strength and Tensile Modulus

Tensile Elongation at Break, %

Flexural Strength & Modulus

Volume Shrinkage

Water Absorption

- *Chemical analysis and shelf life.*

For polyester resins, the tensile elongation at break is generally not to be less than 1.0% for laminating resins and is to be generally not less than 2.0% for gel coat resins. Elongation of other resins will be specifically considered.[1]

3.3.4 Det Norske Veritas - Germanischer Lloyd (Res.)

Similarly to BV, in DNV-GL guidelines for polyester, vinyl ester and epoxy resins can be found. It is worth noticing that polyester and vinyl ester share a common segment in *Rules for classification: Ships (October 2015)* Pt. 2, Ch. 3, Sec. 2, while guidelines for epoxy resins systems are in the following one.

DNV-GL, already, sets requirements that concern the manufacturer’s quality control, as its incompliance can affect the final product, with *Table 3.3.2 Manufacturer’s quality control for polyester and vinyl ester in liquid condition (DNV-GL)* and *Table 3.3.3 Manufacturer's quality control for epoxy resins (DNV-GL).*

Table 3.3. 2 Manufacturer's quality control for polyester and vinyl ester in liquid condition (DNV-GL)[42, 43, 44, 45, 46]

Control on	*Test method* 1)	*Acceptance criteria*
Density	ISO 1675	msv
Viscosity 2)	ISO 2555 3)	msv ±250 mPas
Monomer content	ISO 3251	msv ± 2%
Mineral content 2)	DIN 16945, item 4.10	msv ± 1%
Gel time 4)	ISO 2535	For curing time at room temperature: < 60 minutes: msv ± 5 minutes 60 to 120 minutes: msv ± 10 minutes >120 minutes: msv ± 15 minutes

1) other standards may be used if agreed upon with the Society prior to testing
2) unless otherwise agreed, these parameters shall be tested and documented in W certificate
3) for polyester and vinyl ester, the following parameters shall be used; Viscometer type A, rotational frequency 10, temperature 23°C. Viscosity can be accepted with msv ± 20%
4) specify activator and initiator and % of each

Table 3.3. 3 Manufacturer's quality control for epoxy resins (DNV-GL)[47, 48, 49, 45, 50]

Control on 2)	*Test method* 3)	*Acceptance criteria*
Epoxy equivalent	ISO 3001	msv (g/mol)
Viscosity	ISO 3219	msv (mPas) ± 20%
Density	ISO 1675	msv (g/cm^3)
Gel Time (temperature increase)	DIN16945,section 6.26.3, DIN EN ISO 2535	msv

1) the table is relevant for both epoxy resin (A component) and curing agent (B component) in liquid condition, separately, for the basic epoxy resin system and each of any variants, ref. ISO 3673-1, Table 1
2) unless otherwise agreed, all parameters shall be tested and documented in W certificate
3) other standards may be used if agreed upon with the Society prior to testing

Another point of deviation from BV is that DNV-GL, besides the minimum value of a property, refers to the International Standard document of the test method, as you can see in *Table 3.3.4 Polyester and vinyl ester products, cured not reinforced resin (DNV-GL)* and *Table 3.3.6 Testing of mechanical properties of the cured epoxy system (DNV-GL)*, which correspond with rule 5.1.7 and 6.3.1, of the referenced section, respectively. Also, in terms of polyester and vinyl ester resins, DNV-GL includes two grades of products and sets requirements of grade 1 polyester base gelcoats and topcoats in *Table 3.3.5 Properties of gelcoat / topcoat (DNV-GL).*

5.1.7 *Requirements for cured resin are given in Table 11* (**see Table 3.3.4 Polyester and vinyl ester products, cured not reinforced resin (DNV-GL)** of this document). *Comment: unless anything else is specified by the manufacturer, the following curing procedure shall be used:*

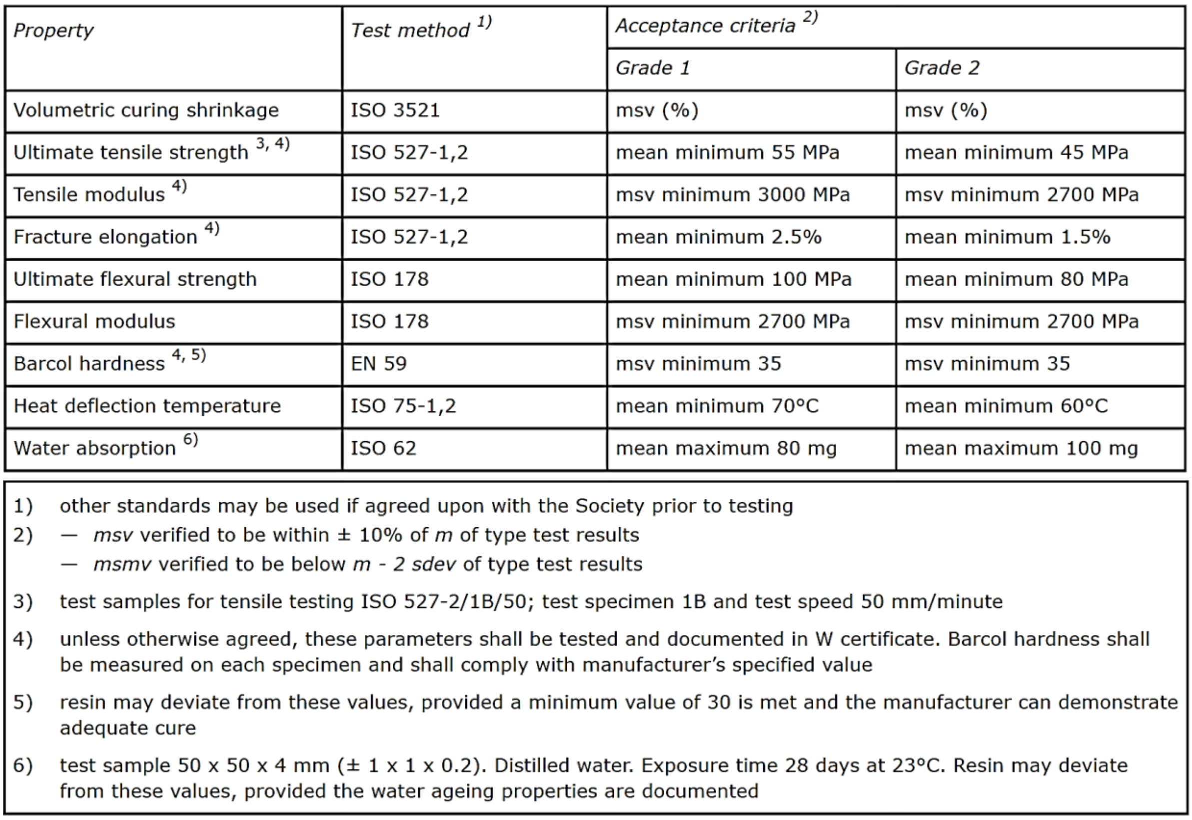
— standard MEKP (active oxygen 9.0 - 9.2%)

— curing: 24 hours at 23°C

— post curing: 24 hours at 50°C.

Curing systems requiring high temperature may be approved after special consideration.[4]

Table 3.3. 4 Polyester and vinyl ester products, cured not reinforced resin (DNV-GL)[44, 51, 52, 53, 54,55]



Property	*Test method* 1)	*Acceptance criteria* 2)	
		Grade 1	*Grade 2*
Volumetric curing shrinkage	ISO 3521	msv (%)	msv (%)
Ultimate tensile strength 3, 4)	ISO 527-1,2	mean minimum 55 MPa	mean minimum 45 MPa
Tensile modulus 4)	ISO 527-1,2	msv minimum 3000 MPa	msv minimum 2700 MPa
Fracture elongation 4)	ISO 527-1,2	mean minimum 2.5%	mean minimum 1.5%
Ultimate flexural strength	ISO 178	mean minimum 100 MPa	mean minimum 80 MPa
Flexural modulus	ISO 178	msv minimum 2700 MPa	msv minimum 2700 MPa
Barcol hardness 4, 5)	EN 59	msv minimum 35	msv minimum 35
Heat deflection temperature	ISO 75-1,2	mean minimum 70°C	mean minimum 60°C
Water absorption 6)	ISO 62	mean maximum 80 mg	mean maximum 100 mg

1) other standards may be used if agreed upon with the Society prior to testing

2) — *msv* verified to be within ± 10% of *m* of type test results
   — *msmv* verified to be below *m - 2 sdev* of type test results

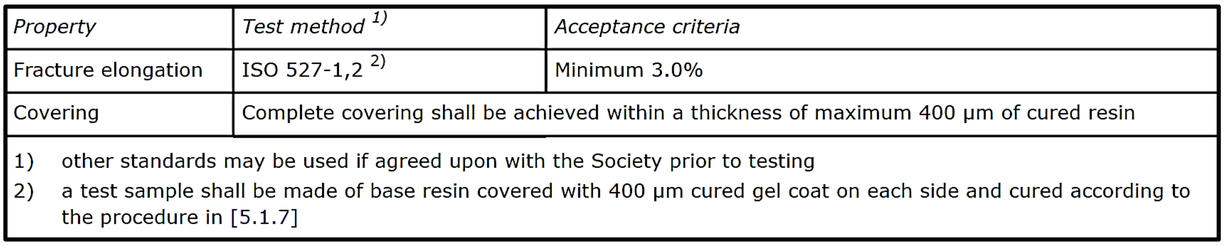
3) test samples for tensile testing ISO 527-2/1B/50; test specimen 1B and test speed 50 mm/minute

4) unless otherwise agreed, these parameters shall be tested and documented in W certificate. Barcol hardness shall be measured on each specimen and shall comply with manufacturer's specified value

5) resin may deviate from these values, provided a minimum value of 30 is met and the manufacturer can demonstrate adequate cure

6) test sample 50 x 50 x 4 mm (± 1 x 1 x 0.2). Distilled water. Exposure time 28 days at 23°C. Resin may deviate from these values, provided the water ageing properties are documented

Table 3.3. 5 Properties of gelcoat / topcoat (DNV-GL)[51]



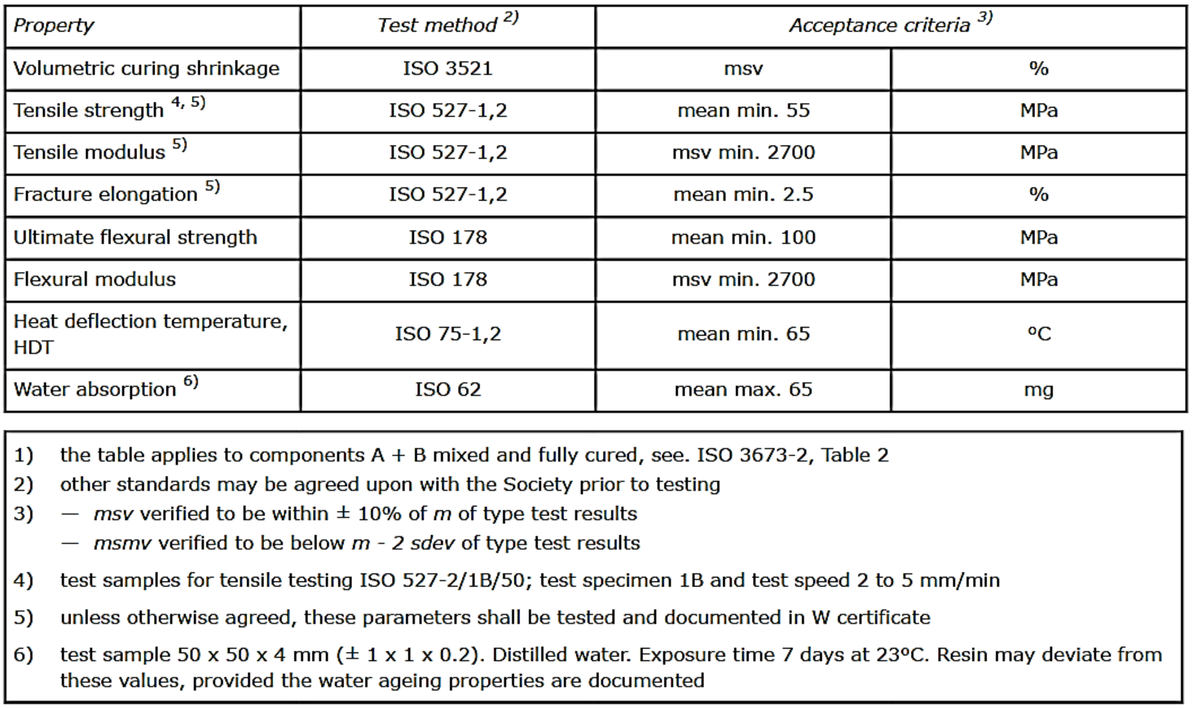
Property	*Test method* 1)	*Acceptance criteria*
Fracture elongation	ISO 527-1,2 2)	Minimum 3.0%
Covering	Complete covering shall be achieved within a thickness of maximum 400 μm of cured resin	

1) other standards may be used if agreed upon with the Society prior to testing

2) a test sample shall be made of base resin covered with 400 μm cured gel coat on each side and cured according to the procedure in [5.1.7]

6.3.1 *Requirements for cured resin are given in Table 16* (**see Table 3.3.6 Testing of mechanical properties of the cured epoxy system (DNV-GL)** of this document). *Unless otherwise agreed, the curing time and temperature shall be:*
— 7 days at 23°C (normally considered to be full curing)
— curing procedures requiring higher temperature or longer time for full curing may be approved upon special consideration
— the manufacturer shall specify a curing procedure giving properties that can realistically be achieved at a production site.[4]

Table 3.3. 6 Testing of mechanical properties of the cured epoxy system (DNV-GL)[44, 51, 52, 54, 55]



Property	*Test method* 2)	*Acceptance criteria* 3)	
Volumetric curing shrinkage	ISO 3521	msv	%
Tensile strength 4, 5)	ISO 527-1,2	mean min. 55	MPa
Tensile modulus 5)	ISO 527-1,2	msv min. 2700	MPa
Fracture elongation 5)	ISO 527-1,2	mean min. 2.5	%
Ultimate flexural strength	ISO 178	mean min. 100	MPa
Flexural modulus	ISO 178	msv min. 2700	MPa
Heat deflection temperature, HDT	ISO 75-1,2	mean min. 65	°C
Water absorption 6)	ISO 62	mean max. 65	mg

1) the table applies to components A + B mixed and fully cured, see. ISO 3673-2, Table 2
2) other standards may be agreed upon with the Society prior to testing
3) — *msv* verified to be within ± 10% of *m* of type test results
   — *msmv* verified to be below *m - 2 sdev* of type test results
4) test samples for tensile testing ISO 527-2/1B/50; test specimen 1B and test speed 2 to 5 mm/min
5) unless otherwise agreed, these parameters shall be tested and documented in W certificate
6) test sample 50 x 50 x 4 mm (± 1 x 1 x 0.2). Distilled water. Exposure time 7 days at 23°C. Resin may deviate from these values, provided the water ageing properties are documented

As regards polyester and vinyl ester resins containing other substances, DNV-GL proposes a delamination test, in order for this quality to be acceptable, with *Table 3.3.7 Interlaminar strength of LSE resins, double cantilever beam test (DNV-GL)* and the rule 5.1.8 of the previous references section:

5.1.8 *Resins containing waxes or other substances (like DCPD resins or blends of DCPD), which might lower external adhesive capacity shall be subjected to the delamination test according to Table 12* (**see Table 3.3.7 Interlaminar strength of LSE resins, double cantilever beam test (DNV-GL)** *of this document).*

Preparation of test piece:

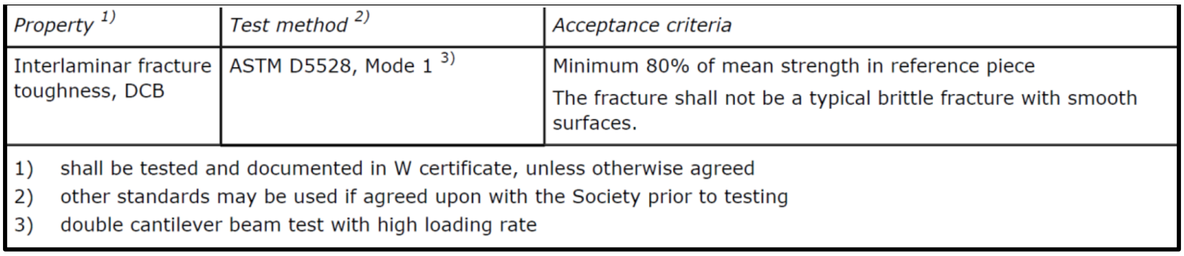
1) a primary laminate consisting of five (5) layers of 450 g/m^2 emulsion/powder bounded mat with excess polyester in the upper surface. Curing procedure: 48 h at 23°C. The laminate surface shall not be covered

2) a secondary laminate consisting of five (5) layers of 450 g/m^2 emulsion/powder bounded mat is built on the first without any form of upper surface treatment. Curing procedure as selected in [5.1.7]. The fibre weight fraction shall be 50% ± 5%.

Preparation of reference piece:

1) *a laminate consisting of ten (10) layers of 450 g/m^2 emulsion/powder bounded mat. Curing procedure as selected in [5.1.7].*[4]

Table 3.3. 7 Interlaminar strength of LSE resins, double cantilever beam test (DNV-GL)[56]



Property [1)]	*Test method* [2)]	*Acceptance criteria*
Interlaminar fracture toughness, DCB	ASTM D5528, Mode 1 [3)]	Minimum 80% of mean strength in reference piece The fracture shall not be a typical brittle fracture with smooth surfaces.

1) shall be tested and documented in W certificate, unless otherwise agreed
2) other standards may be used if agreed upon with the Society prior to testing
3) double cantilever beam test with high loading rate

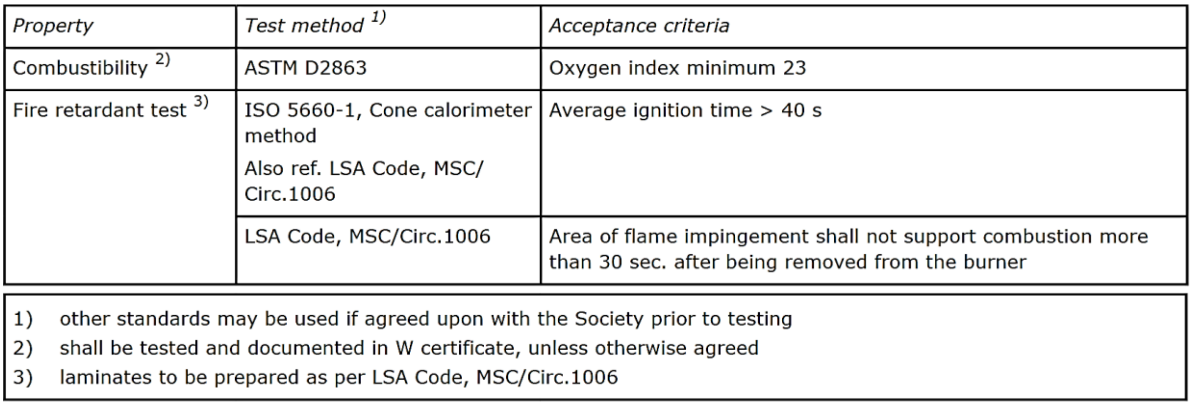
Further expanding on resins, DNV-GL adds requirements for fire retardant material that are also missing from BV. DNV-GL suggests that under circumstances polyester, vinyl ester and epoxy resins can be approved as fire retardant resins.

As in *Rules for classification: Ships (October 2015)* Pt. 2, Ch. 3, Sec. 2, polyester and vinyl ester ought to comply with the requirements of grade 2, *Table 3.3.2 Manufacturer's quality control for polyester and vinyl ester in liquid condition (DNV-GL), Table 3.3.7 Interlaminar strength of LSE resins, double cantilever beam test (DNV-GL)* and *Table 3.3.8 Combustibility testing of fire retardant resins (DNV-GL)* and as for epoxy resins, they shall comply with *Table 3.3.3 Manufacturer's quality control for epoxy resins (DNV-GL), Table 3.3.6 Testing of mechanical properties of the cured epoxy system (DNV-GL)* and *Table 3.3.9 Testing of fire retardant epoxy system (solid material) (DNV-GL).* Also, all of them should be in compliance with the following:

The hull and canopy material shall be flame tested to determine its fire-retarding characteristics by placing a test specimen in a flame. After removal from the flame the burning time and burning distance shall be measured and shall be to the satisfaction of the administration (IMO Res. A.689(17) Part 1, 6.2.1) [4]

Lastly, DNV-GL states for the polyester and vinyl ester products that fire retardant gel-coat and topcoat shall be produced of base resin that fulfils the requirements of fire retardant resins and shall be able to withstand long term exposure to weathering without any visible signs of crazing, outwash of matter or significant colour change.

Table 3.3. 8 Combustibility testing of fire retardant resins (DNV-GL)[57, 58, 59]



Property	*Test method* [1)]	*Acceptance criteria*
Combustibility [2)]	ASTM D2863	Oxygen index minimum 23
Fire retardant test [3)]	ISO 5660-1, Cone calorimeter method Also ref. LSA Code, MSC/ Circ.1006	Average ignition time > 40 s
	LSA Code, MSC/Circ.1006	Area of flame impingement shall not support combustion more than 30 sec. after being removed from the burner

1) other standards may be used if agreed upon with the Society prior to testing
2) shall be tested and documented in W certificate, unless otherwise agreed
3) laminates to be prepared as per LSA Code, MSC/Circ.1006

Table 3.3. 9 Testing of fire retardant epoxy system (solid material) (DNV-GL) [57, 58, 59]

Property	*Test method*	*Acceptance criteria*
Combustibility 1)	ASTM D2863 or equivalent standard	Oxygen index min. 23
Fire retardant test 2)	ISO 5660-1, Cone calorimeter method Also ref. LSA Code, MSC/Circ.1006	Average ignition time > 40 s
	LSA Code, MSC/Circ.1006	Area of flame impingement shall not support combustion more than 30 s after being removed from the burner

1) unless otherwise agreed, this parameters shall be tested and documented in W certificate
2) laminates to be prepared as per LSA Code, MSC/Circ. 1006

3.3.5 Lloyd's Register (Res.)

In *Rules for the Manufacture, Testing and Certification of Materials (July 2018)* Ch. 14 Sec. 2, LR rules on thermoplastic polymers, which are not part of BV, ABS or DNV-GL rules, can be found along with thermosetting resins. In addition LR does not suggest rules and tests based on the resin systems, but generally for thermoplastic and thermosetting resins. In the latter phenolic resins and gel coats are included, also guideline **2.3.5** of the referenced section corresponds to DNV-GL rule **5.1.8** that was discussed on Ch. 2 sub-section ***3.3.4** Det Norske Veritas - Germanischer Lloyd (Res.)* of this document.

Firstly, LR indicates data and requirements, to be provided for approval with guidelines of segments **2.2** and **2.3** of the referenced section for thermoplastic polymers and thermosetting resins respectively. The guidelines of this sort are presented below:

2.2 Thermoplastic polymers

2.2.1 *The following data is to be provided by the manufacturer for each thermoplastic polymer:*

(a) Melting point.

(b) Melt flow index.

(c) Density.

(d) Bulk density.

(e) Filler content, where applicable.

(f) Pigment content, where applicable.

(g) Colour.[1]

2.2.2 *Samples for testing are to be prepared by moulding or extrusion under the polymer manufacturer's recommended conditions.*[1]

2.2.3 *The following tests are to be carried out on these samples:*

(a) Tensile stress at yield and break.

(b) Modulus of elasticity in tension.

(c) Tensile strain at yield and break.

(d) Compressive stress at yield and break.

(e) Compressive modulus.

(f) Temperature of deflection under load.

(g) Determination of water absorption.[1]

2.3 Thermosetting resins

2.3.1 *The data listed in Table 14.2.1 Data requirements for thermosetting resins (**see** **Table 3.3.10 Data requirements for thermosetting resins (LR)** of this document) is to be provided by the manufacturer for each thermosetting resin.*[1]

2.3.2 *Cast samples are to be prepared in accordance with the manufacturer's recommendations and are to be cured and post-cured in a manner consistent with the intended use. The curing system used and the ratio of curing agent (or catalyst) to resin are to be recorded. Where post-cure conditions equivalent to ambient-cure conditions apply, see Ch 14, 3.2 Preparation of test samples 3.2.2 and Ch 14, 3.2 Preparation of test samples 3.2.3 (**these segments are not presented on this document**).*[1]

2.3.3 *The following are to be determined using these samples:*

(a) Tensile strength (stress at maximum load) and stress at break.

(b) Tensile strain at maximum load.

(c) Tensile secant modulus at 0,5 per cent and 0,25 per cent strain respectively.

(d) Temperature of deflection under load.

(e) Barcol hardness.

(f) Determination of water absorption.

(g) Volume shrinkage after cure.

(h) Specific gravity of cast resin.[1]

2.3.4 *In addition, for gel coat resins the stress at break and modulus of elasticity in flexure are to be determined.*[1]

2.3.5 *Where resins which have been modified by the addition of waxes or polymers, for example 'low styrene emission or air inhibited' materials, it is to be confirmed that the use of such resins will not result in poor interlaminar adhesion when interruptions to the laminating process occur. The test procedure is to be as follows:*

(a) A conventional room temperature curing catalyst/ accelerator system is to be used with the resin for laminate preparation.

(b) A laminate of 25 to 35 per cent glass content in mass is to be prepared using two plies of 450 g/m2 chopped strand mat.

The laminate is to be prepared at ambient temperature (18° to 21°C). The laminate is to be allowed to stand for a minimum of four days but no longer than 6 days at ambient temperature.

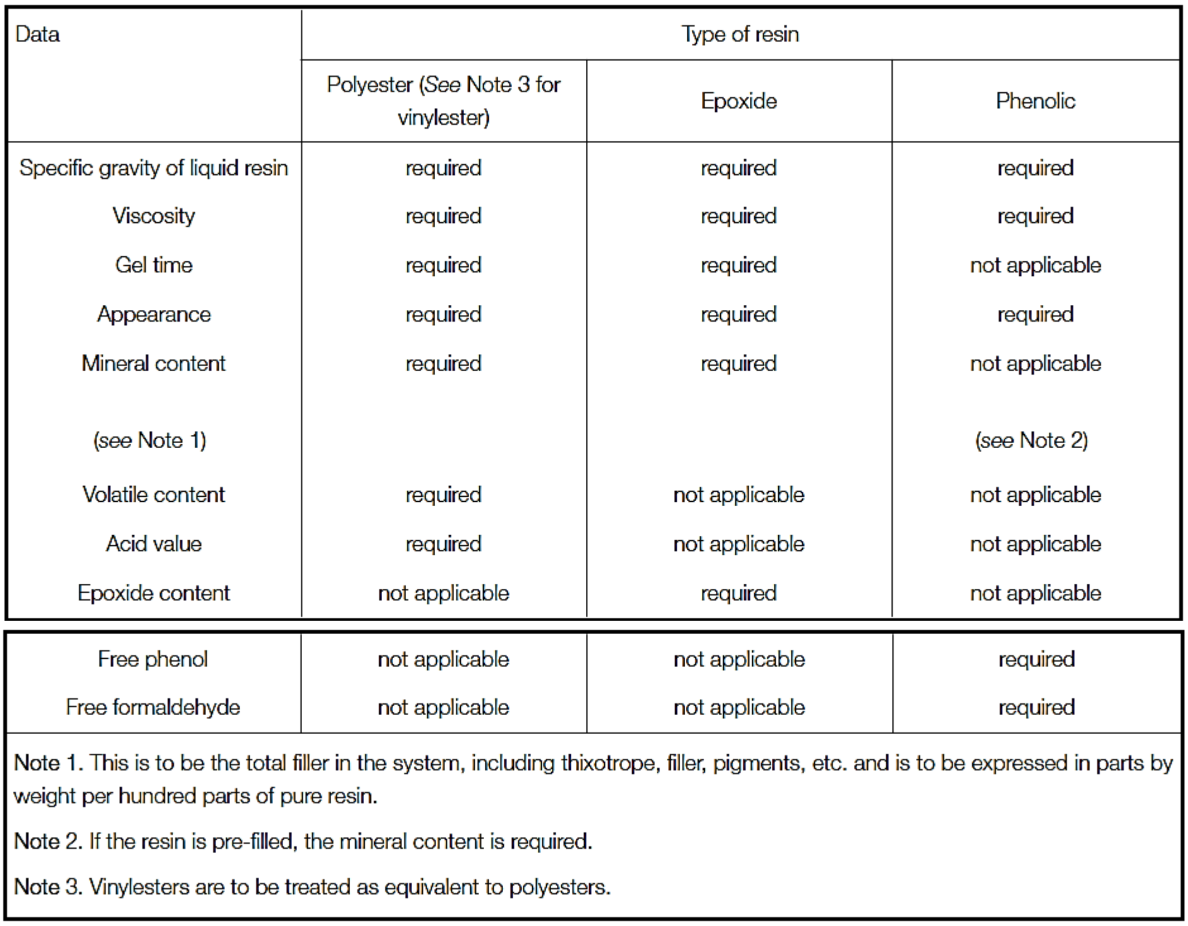
(c) A further two plies of 450 g/m2 chopped strand mat are to be laminated onto the exposed surface and cured at ambient temperature for 24 hours. The finished laminate is then to be post-cured at 40°C for 16 hours. The finished laminate is to have a glass content of 25 to 35 per cent.

(d) After cooling, the apparent interlaminar shear strength of the laminate is to be determined in accordance with ISO 14130; the minimum value is given in Ch 14, 5.11 Minimum tested requirements for material approval 5.11.4. Before testing the samples shall be conditioned at 23°C and relative humidity of 50 per cent for a period of 88 hours before testing.

(e) If the tests are undertaken at the resin manufacturer's own laboratory, the individual test values are to be reported and the broken test specimens retained for examination by LR.

Alternative test procedures will be considered with prior agreement.[1]

Table 3.3. 10 Data requirements for thermosetting resins (LR)



Data	Type of resin		
	Polyester (*See* Note 3 for vinylester)	Epoxide	Phenolic
Specific gravity of liquid resin	required	required	required
Viscosity	required	required	required
Gel time	required	required	not applicable
Appearance	required	required	required
Mineral content (*see* Note 1)	required	required	not applicable (*see* Note 2)
Volatile content	required	not applicable	not applicable
Acid value	required	not applicable	not applicable
Epoxide content	not applicable	required	not applicable
Free phenol	not applicable	not applicable	required
Free formaldehyde	not applicable	not applicable	required

Note 1. This is to be the total filler in the system, including thixotrope, filler, pigments, etc. and is to be expressed in parts by weight per hundred parts of pure resin.

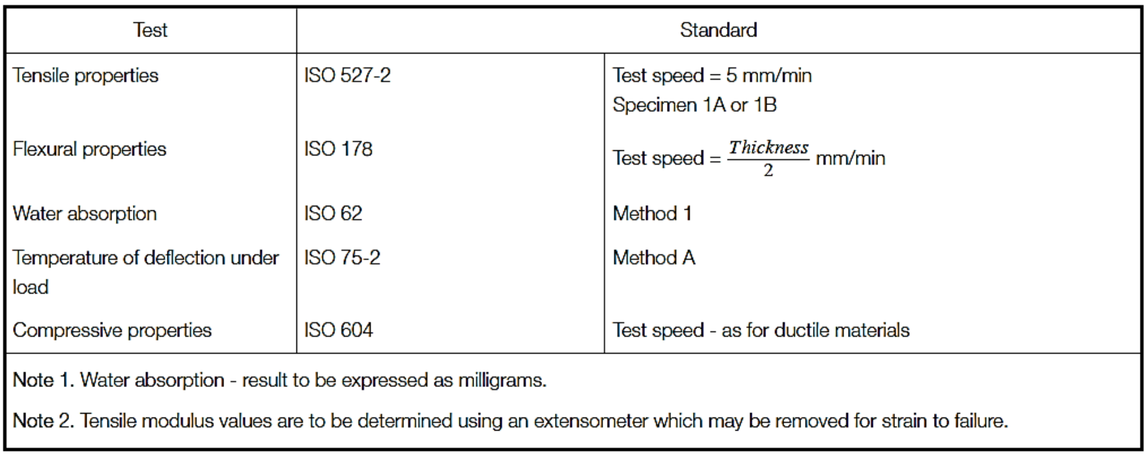
Note 2. If the resin is pre-filled, the mineral content is required.

Note 3. Vinylesters are to be treated as equivalent to polyesters.

Alike DNV-GL, LR, in *Rules for the Manufacture, Testing and Certification of Materials (July 2018) Ch. 14, Sec. 3,* correlates the resin data requirements to be provided with the appropriate International Standard. The two classification societies suggest similar tests, albeit with the differentiation that LR indicates test on compressive properties and DNV-GL test on volumetric curing shrinkage. Also on Ch. 14, sec. 5 LR provides minimum values of the properties.

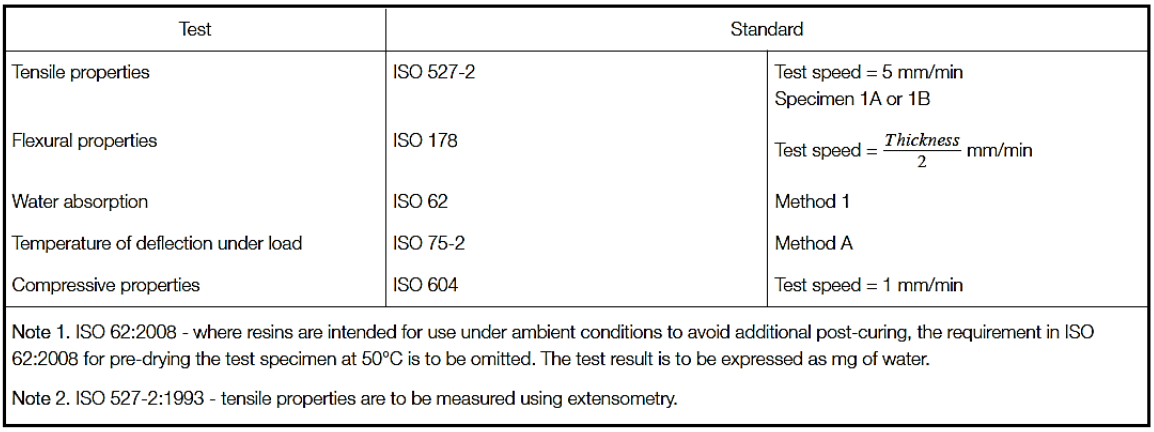
Concerning thermoplastic and thermosetting resins, test methods for each material are presented on *Table 3.3.11 Tests for unreinforced thermoplastic resins (LR)* and *Table 3.3.12 Tests for unreinforced thermosetting resins (LR)* respectively. Thermosetting resins when tested accordingly, *Table 3.3.13 Gel coat resins, minimum property values (LR)* for gel coats and *Table 3.3.14 Laminating resins, minimum property values (LR)* for laminating resins provide their minimum property values.

Table 3.3. 11 Tests for unreinforced thermoplastic resins (LR)[51, 52, 55, 54, 60]



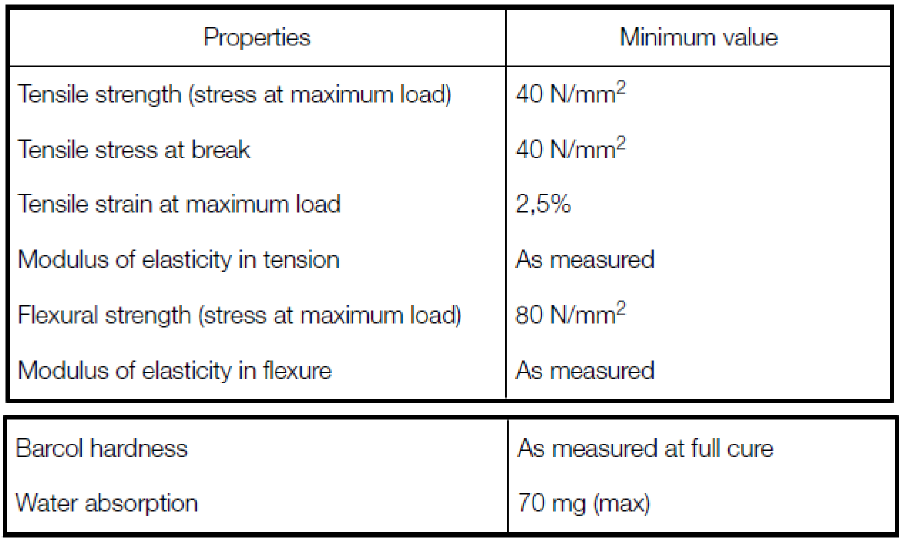
Test	Standard	
Tensile properties	ISO 527-2	Test speed = 5 mm/min Specimen 1A or 1B
Flexural properties	ISO 178	Test speed = $\frac{Thickness}{2}$ mm/min
Water absorption	ISO 62	Method 1
Temperature of deflection under load	ISO 75-2	Method A
Compressive properties	ISO 604	Test speed - as for ductile materials
Note 1. Water absorption - result to be expressed as milligrams. Note 2. Tensile modulus values are to be determined using an extensometer which may be removed for strain to failure.		

Table 3.3. 12 Tests for unreinforced thermosetting resins (LR) [51, 52, 55, 54, 60]



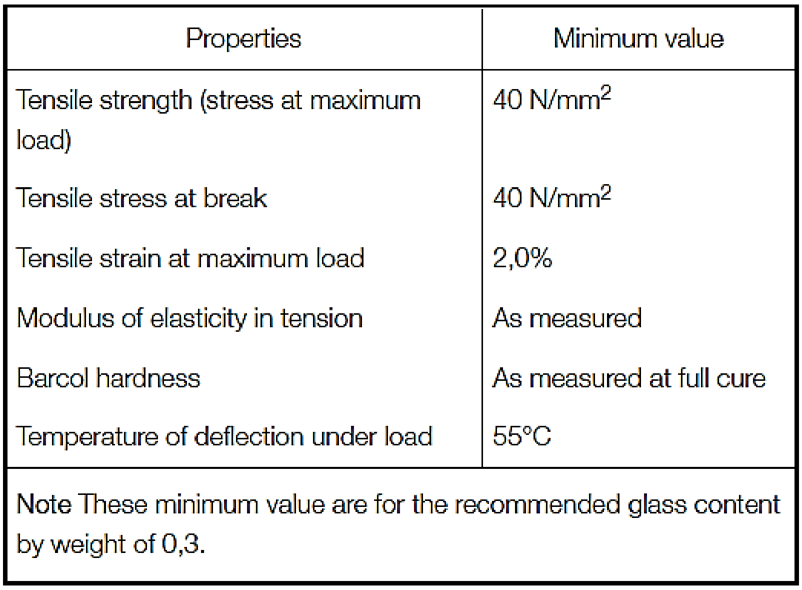
Test	Standard	
Tensile properties	ISO 527-2	Test speed = 5 mm/min Specimen 1A or 1B
Flexural properties	ISO 178	Test speed = $\frac{Thickness}{2}$ mm/min
Water absorption	ISO 62	Method 1
Temperature of deflection under load	ISO 75-2	Method A
Compressive properties	ISO 604	Test speed = 1 mm/min
Note 1. ISO 62:2008 - where resins are intended for use under ambient conditions to avoid additional post-curing, the requirement in ISO 62:2008 for pre-drying the test specimen at 50°C is to be omitted. The test result is to be expressed as mg of water. Note 2. ISO 527-2:1993 - tensile properties are to be measured using extensometry.		

Table 3.3. 13 Gel coat resins, minimum property values (LR)



Properties	Minimum value
Tensile strength (stress at maximum load)	40 N/mm^2
Tensile stress at break	40 N/mm^2
Tensile strain at maximum load	2,5%
Modulus of elasticity in tension	As measured
Flexural strength (stress at maximum load)	80 N/mm^2
Modulus of elasticity in flexure	As measured
Barcol hardness	As measured at full cure
Water absorption	70 mg (max)

Table 3.3. 14 Laminating resins, minimum property values (LR) for laminating resins (LR)



Properties	Minimum value
Tensile strength (stress at maximum load)	40 N/mm^2
Tensile stress at break	40 N/mm^2
Tensile strain at maximum load	2,0%
Modulus of elasticity in tension	As measured
Barcol hardness	As measured at full cure
Temperature of deflection under load	55°C
Note These minimum value are for the recommended glass content by weight of 0,3.	

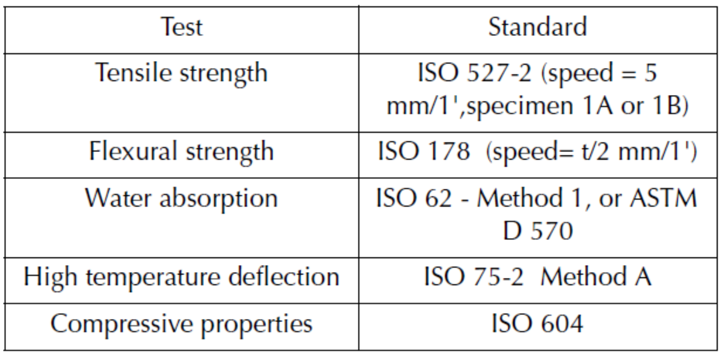
3.3.6 Registro Italiano Navale (Res.)

RINA guidelines on resins has similar structure and guidelines as with Lloyd's Register. The present section points out only the discrepancies and similarities between the two.

The data of thermoplastic polymers and thermosetting resins required by RINA for approval are exactly the same as LR and are presented in *Rules for the Classification of Pleasure Yachts (January 2019)* Pt. D, Ch. 6, Sec. 2. The only difference is the rule **2.3.5** of LR about resins which have been modified by the addition of waxes or polymers, which RINA does not include and is presented in the previous sub section *3.3.5 Lloyd's Resister (Res.).*

With regards to tests for unreinforced thermoplastic resins and cast thermosetting resins, while LR presents them in a separate table with specific notation for each material, RINA in *Rules for the Classification of Pleasure Yachts (January 2019)* Pt. D, Ch. 6, Sec. 3 give a common table without further notes. As indicated by *Table 3.3.15 Test standards on for unreinforced thermoplastic resins and cast thermosetting resins (RINA)* RINA suggests the exact same ISO tests adding ASTM alternates.

Table 3.3. 15 Test standards on for unreinforced thermoplastic resins and cast thermosetting resins (RINA) [51, 52, 55, 54, 61]



Test	Standard
Tensile strength	ISO 527-2 (speed = 5 mm/1',specimen 1A or 1B)
Flexural strength	ISO 178 (speed= t/2 mm/1')
Water absorption	ISO 62 - Method 1, or ASTM D 570
High temperature deflection	ISO 75-2 Method A
Compressive properties	ISO 604

In Rules for the Classification of Pleasure Yachts (January 2019) Pt. D, Ch. 6, Sec. 3, RINA gives minimum property values on gel coat and laminating resins. On this occasion RINA does not completely agree with LR, as there are some discrepancies on the properties and on the corresponding values. However they agree on the minimum tensile strength of the material. Data of RINA are presented on *Table 3.3.16 Minimum property values of gel coat resins (RINA)* and *Table 3.3.17 Minimum property values of laminating resins (RINA)* below.

Table 3.3. 16 Minimum property values of gel coat resins (RINA)

Properties	Standard
Tensile strength	40 N/mm^2
Tensile strain	>3,0%
Flexural strength	80 N/mm^2
Water absoption	<60 mg
High temperature deflection	>60 °C

Table 3.3. 17 Minimum property values of laminating resins (RINA)

Properties	Standard
Tensile strength	40 N/mm^2
Tensile strain	>2,5%
Flexural strength	70 N/mm^2
Water absoption	<60 mg
High temperature deflection	>60 °C

3.3.7 Conclusion (Res.)

LR and RINA guidelines on resins, which are quite similar, seem to be the most complete, being the only ones to provide rules on thermoplastic resins. However, DNV-GL wide and analytical indications on thermosetting resin, as by regulating various grades and fire retardant materials, should be underlined. ABS rules are a few and minimum property values, set by BV, may be quite useful but are insufficient in contrast to the amount of information that the other classification societies provide.

Section

3.4 Core Materials

3.4.1 General

The aim of a core material in a laminate is to increase the laminate stiffness by increasing its thickness. The core material acts similar to the web of a beam, and so is basically subject to shear forces.

3.4.2 Bureau Veritas (CM)

Bureau Veritas provides the most complete guidelines considering core materials as it includes ones for foam cores, wooden cores and honeycombs. The most common are PVC (PolyVinyl Chloride) and PUR (polyurethane) foams and balsa wood cores. However, BV includes guidelines also for SAN (Styrene Acrylo Nitrile), PMI (Polymethacrylimide) foams and Red Cedar cores.

In *Hull in Composite Materials and Plywood, Material Approval, Design Principles, Construction and Survey* (November 2018) Sec. 4, tables are given with the mechanical characteristics of the above materials. The related guidelines of the referenced section are presented below. Such rules are **4.2.2** on generally on foam cores, **4.3.2** on balsa wood, **4.3.3** on red cedar and **4.4.2** meta-aramid honeycombs.

4.2.2 Mechanical characteristics of foam cores

As a general rule, mechanical characteristics of the foam cores to be taken into account for sandwich calculations are to be given by the manufacturer and/or are given by mechanical tests. Standard mechanical characteristics of different types of foam cores in relation to their density are given in Tab 3 ***(See* Table 3.4.1 Foams (BV) of this document)** *, for information only.* [31]

Table 3.4. 1 Foams (BV)

Foam type	Density (kg/m³)	Modulus			Poisson coefficient ν_{12} , ν_{21}	Breaking stresses		
		Tensile E_1 , E_2 (N/mm²)	Compression E_3 (N/mm²)	Shear G_{12} , G_{13} , G_{23} (N/mm²)		Tensile σ_1, σ_2 (N/mm²)	Compression σ_1, σ_2 (N/mm²)	Shear τ_{12} , τ_{13} , τ_{23} (N/mm²) (1)
Linear PVC	50	21	18	8	0,36	0,7	0,3	0,3
	60	29	28	11	0,31	0,9	0,4	0,5
	70	37	38	14	0,27	1,1	0,6	0,7
	80	44	49	18	0,25	1,3	0,7	0,8
	90	52	59	21	0,24	1,4	0,9	1,0
	100	59	69	24	0,23	1,6	1,0	1,2
	110	67	79	27	0,22	1,8	1,2	1,3
	130	82	99	34	0,21	2,2	1,5	1,7
	140	89	109	37	0,21	2,4	1,6	1,9
Cross linked PVC	50	37	40	18	0,02	1,0	0,6	0,6
	60	47	51	22	0,05	1,4	0,8	0,8
	70	57	63	27	0,07	1,8	1,1	1,0
	80	67	75	31	0,08	2,2	1,4	1,1
	90	78	88	36	0,09	2,5	1,7	1,3
	100	88	102	40	0,10	2,9	1,9	1,5
	110	98	116	44	0,11	3,3	2,2	1,6
	130	118	145	53	0,12	3,9	2,8	2,0
	140	129	161	57	0,12	4,3	3,0	2,2
	170	159	209	71	0,13	5,2	3,8	2,7
	190	180	243	79	0,13	5,8	4,4	3,0
	200	190	260	84	0,13	6,1	4,7	3,2
	250	241	352	105	0,14	7,4	6,0	4,1
SAN	50	52	29	13	0,11	0,9	0,4	0,7
	60	65	37	16	0,18	1,2	0,5	0,8
	70	78	44	18	0,20	1,5	0,6	0,9
	80	92	50	21	0,19	1,7	0,8	1,0
	90	107	55	23	0,17	1,9	0,9	1,1
	100	122	60	26	0,15	2,0	1,1	1,2
	110	137	64	29	0,12	2,2	1,2	1,3
	130	168	71	34	0,06	2,5	1,6	1,5
	140	184	74	36	0,03	2,6	1,8	1,6
	170	234	83	43	0,03	2,9	2,4	1,9
	190	268	88	48	0,03	3,1	2,8	2,1
	200	285	90	51	0,03	3,1	3,0	2,1
PMI	50	54	59	21	0,40	1,9	0,8	0,8
	60	69	76	24	0,60	2,1	1,1	1,0
	70	84	94	28	0,60	2,3	1,5	1,2
	80	101	112	33	0,70	2,6	1,9	1,5
	90	119	132	39	0,70	2,9	2,3	1,8
	100	137	152	45	0,70	3,2	2,7	2,1
	110	155	173	52	0,60	3,6	3,2	2,4
	130	195	217	71	0,50	4,5	4,2	3,1
	140	215	239	83	0,40	5,0	4,8	3,5
	170	280	311	131	0,20	6,8	6,7	4,7

(1) τ_{13} and τ_{23} are identical to, respectively, τ_{IL2} and τ_{IL1} .

Note 1: The values given in this Table are for general guidance only.

4.3.2 Balsa

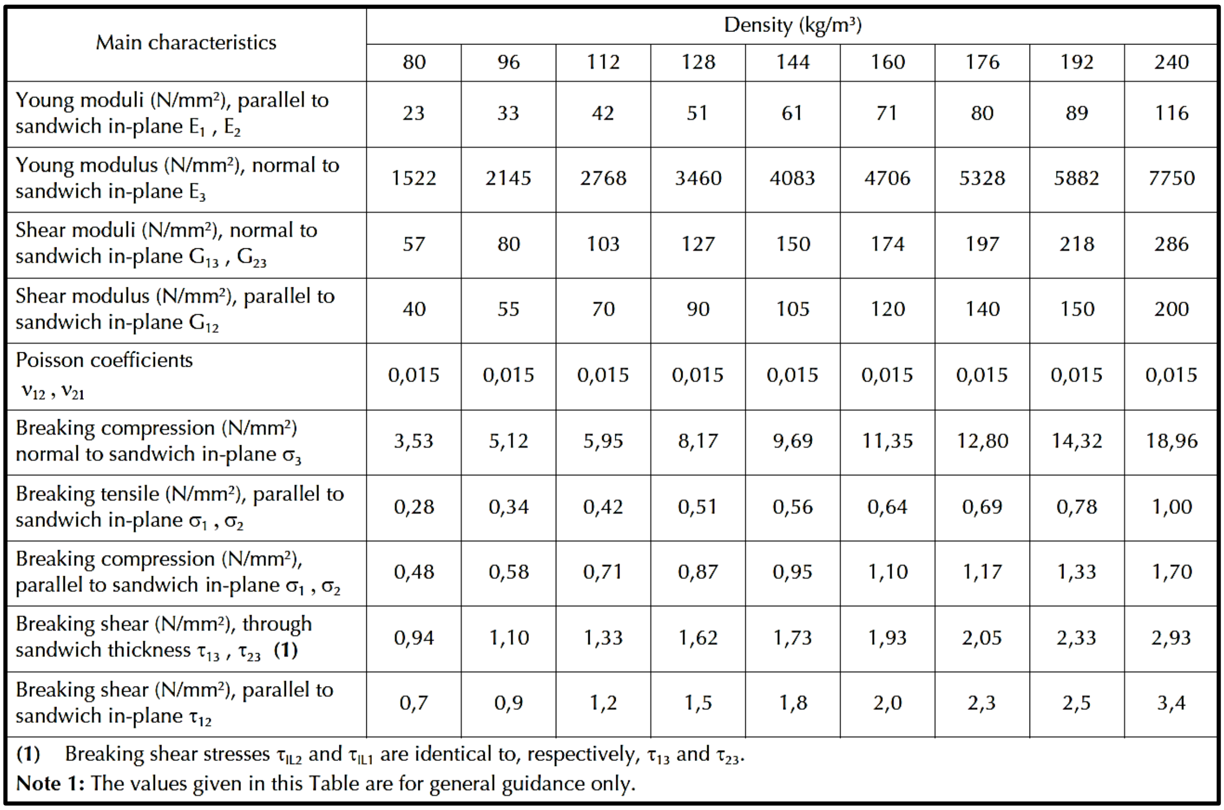
The main mechanical characteristics of balsa are:

- *high compression and shear strength*
- *high stability where heated.*

Balsa is available in a large range of densities and thicknesses. Where balsa with high density and thickness is used, the grain may be transversely solicited by the global sandwich bending.

Standard mechanical characteristics of balsa core materials, in relation to their density, are given in Tab 4 ***(See* Table 3.4.2 Balsa (BV) of this document)** *for information.*[31]

Table 3.4. 2 Balsa (BV)



Main characteristics	Density (kg/m³)								
	80	96	112	128	144	160	176	192	240
Young moduli (N/mm²), parallel to sandwich in-plane E_1 , E_2	23	33	42	51	61	71	80	89	116
Young modulus (N/mm²), normal to sandwich in-plane E_3	1522	2145	2768	3460	4083	4706	5328	5882	7750
Shear moduli (N/mm²), normal to sandwich in-plane G_{13} , G_{23}	57	80	103	127	150	174	197	218	286
Shear modulus (N/mm²), parallel to sandwich in-plane G_{12}	40	55	70	90	105	120	140	150	200
Poisson coefficients ν_{12} , ν_{21}	0,015	0,015	0,015	0,015	0,015	0,015	0,015	0,015	0,015
Breaking compression (N/mm²) normal to sandwich in-plane σ_3	3,53	5,12	5,95	8,17	9,69	11,35	12,80	14,32	18,96
Breaking tensile (N/mm²), parallel to sandwich in-plane σ_1 , σ_2	0,28	0,34	0,42	0,51	0,56	0,64	0,69	0,78	1,00
Breaking compression (N/mm²), parallel to sandwich in-plane σ_1 , σ_2	0,48	0,58	0,71	0,87	0,95	1,10	1,17	1,33	1,70
Breaking shear (N/mm²), through sandwich thickness τ_{13} , τ_{23} **(1)**	0,94	1,10	1,33	1,62	1,73	1,93	2,05	2,33	2,93
Breaking shear (N/mm²), parallel to sandwich in-plane τ_{12}	0,7	0,9	1,2	1,5	1,8	2,0	2,3	2,5	3,4

(1) Breaking shear stresses τ_{IL2} and τ_{IL1} are identical to, respectively, τ_{13} and τ_{23}.

Note 1: The values given in this Table are for general guidance only.

4.3.3 Red cedar

Red cedar is generally used in typical construction, named "strip planking". With its wood grain running parallel to the sandwich plane, the cedar is also participating to bending stress located perpendicular to the cedar grain where its resistance is weaker.

The main mechanical characteristics of different types of red cedar are given in Tab 5
***(See* Table 3.4.3 Red Cedar (BV) of this document)**, *for information.* [31]

Table 3.4. 3 Red Cedar (BV)

Main characteristics	Density (kg/m³)		
	0,33	0,40	0,46
Young modulus (N/mm²), parallel to grain E_1	7160	8730	10000
Young moduli (N/mm²), perpendicular to grain E_2 , E_3	310	440	560
Shear modulus (N/mm²) G_{12}	620	710	775
Shear modulus (N/mm²) G_{23}	110	160	200
Shear modulus (N/mm²) G_{13}	580	720	850
Poisson coefficient ν_{12}	0,48	0,47	0,47
Poisson coefficient ν_{21}	0,02	0,02	0,03
Breaking tensile (N/mm²), parallel to grain direction σ_1	50	60	70
Breaking tensile (N/mm²), perpendicular to grain direction σ_2	2	2	2
Breaking compression (N/mm²), parallel to grain direction σ_1	28	34	39
Breaking compression (N/mm²), perpendicular to grain direction σ_2	4	5	7
Breaking shear (N/mm²) τ_{12} , τ_{13} **(1)**	7	8	9
Breaking shear (N/mm²) τ_{23} **(1)**	8	10	11

(1) Breaking shear stresses τ_{IL2} and τ_{IL1} are identical to, respectively, τ_{13} and τ_{23}.
Note 1: The values given in this Table are for general guidance only.

4.4.2 Thermoplastic honeycombs

The most common polymers used for thermoplastic honeycombs are polyethylen, polycarbonate and polypropylene.

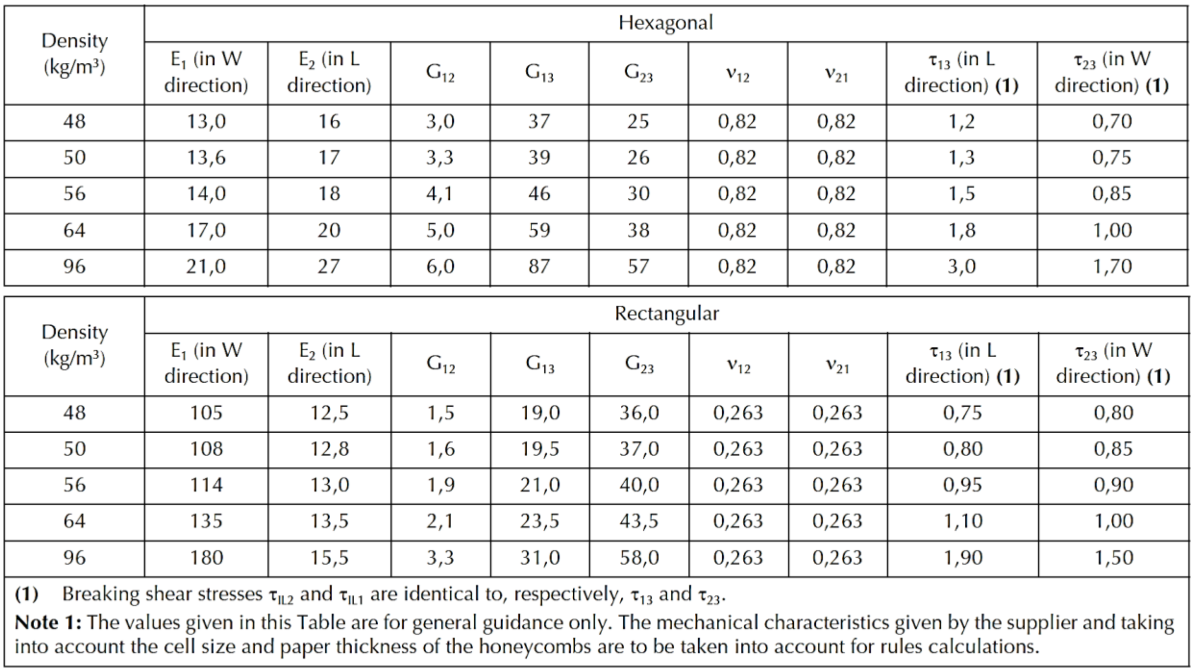
As a general rule, these thermoplastic honeycomb cores have relatively low stiffness and mechanical characteristics and are difficult to bond with the sandwich skins.

The cell shape may be diverse due to the fact that these honeycomb cores are obtained by extrusion process. The use of thermoplastic honeycombs is submitted to a special examination on a case-by-case basis due to the important diversity of these cores and their temperature sensitiveness. Special examination is mainly carried out through mechanical tests to estimate the interface and shear resistance of the core in a sandwich construction (see Sec 11).[31]

4.4.3 Meta-aramid honeycombs

The meta-aramid honeycomb cores are obtained from an aramid paper, dipped in resin system. Standard mechanical characteristics of meta-aramid honeycombs in relation to their density, cell size, and thickness are given in Tab 6 ***(See*** **Table 3.4.4 Meta-aramid honeycombs (BV) of this document)** *for information.*[31]

Table 3.4. 4 Meta-aramid honeycombs (BV)



Density (kg/m³)	Hexagonal								
	E_1 (in W direction)	E_2 (in L direction)	G_{12}	G_{13}	G_{23}	ν_{12}	ν_{21}	τ_{13} (in L direction) **(1)**	τ_{23} (in W direction) **(1)**
48	13,0	16	3,0	37	25	0,82	0,82	1,2	0,70
50	13,6	17	3,3	39	26	0,82	0,82	1,3	0,75
56	14,0	18	4,1	46	30	0,82	0,82	1,5	0,85
64	17,0	20	5,0	59	38	0,82	0,82	1,8	1,00
96	21,0	27	6,0	87	57	0,82	0,82	3,0	1,70

Density (kg/m³)	Rectangular								
	E_1 (in W direction)	E_2 (in L direction)	G_{12}	G_{13}	G_{23}	ν_{12}	ν_{21}	τ_{13} (in L direction) **(1)**	τ_{23} (in W direction) **(1)**
48	105	12,5	1,5	19,0	36,0	0,263	0,263	0,75	0,80
50	108	12,8	1,6	19,5	37,0	0,263	0,263	0,80	0,85
56	114	13,0	1,9	21,0	40,0	0,263	0,263	0,95	0,90
64	135	13,5	2,1	23,5	43,5	0,263	0,263	1,10	1,00
96	180	15,5	3,3	31,0	58,0	0,263	0,263	1,90	1,50

(1) Breaking shear stresses τ_{IL2} and τ_{IL1} are identical to, respectively, τ_{13} and τ_{23}.

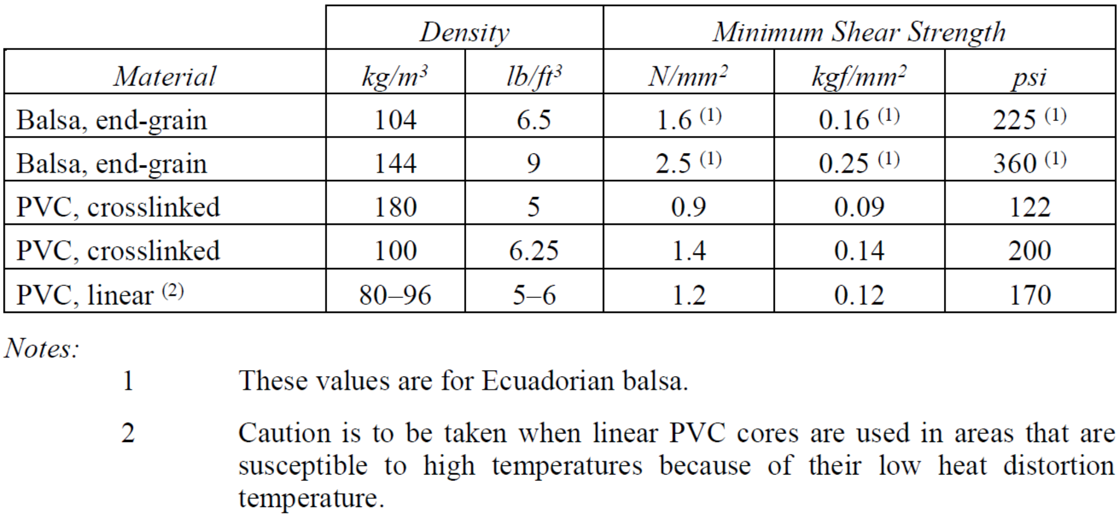
Note 1: The values given in this Table are for general guidance only. The mechanical characteristics given by the supplier and taking into account the cell size and paper thickness of the honeycombs are to be taken into account for rules calculations.

3.4.3 American Bureau of Shipping (CM)

American Bureau of Shipping give guidelines on a small variety of materials compared to BV. *Rule for Materials and Welding (January 2018)* Ch. 6 Sec. 1 contains guidelines on PVC, cross-linked and linear, and balsa wood. Nevertheless ABS may accept different core materials after special consideration as it is made clear in segment five (5 Core Materials) of the referenced section, which is presented below.

Properties of the materials are presented in *Table 3.4.5 Properties of Core Materials (ABS).* In addition ABS suggest test ASTM C273 to determine the shear strength and modulus.

Table 3.4. 5 Properties of Core Materials (ABS)



	Density		*Minimum Shear Strength*		
Material	*kg/m³*	*lb/ft³*	*N/mm²*	*kgf/mm²*	*psi*
Balsa, end-grain	104	6.5	1.6 (1)	0.16 (1)	225 (1)
Balsa, end-grain	144	9	2.5 (1)	0.25 (1)	360 (1)
PVC, crosslinked	180	5	0.9	0.09	122
PVC, crosslinked	100	6.25	1.4	0.14	200
PVC, linear (2)	80–96	5–6	1.2	0.12	170

Notes:

1 These values are for Ecuadorian balsa.

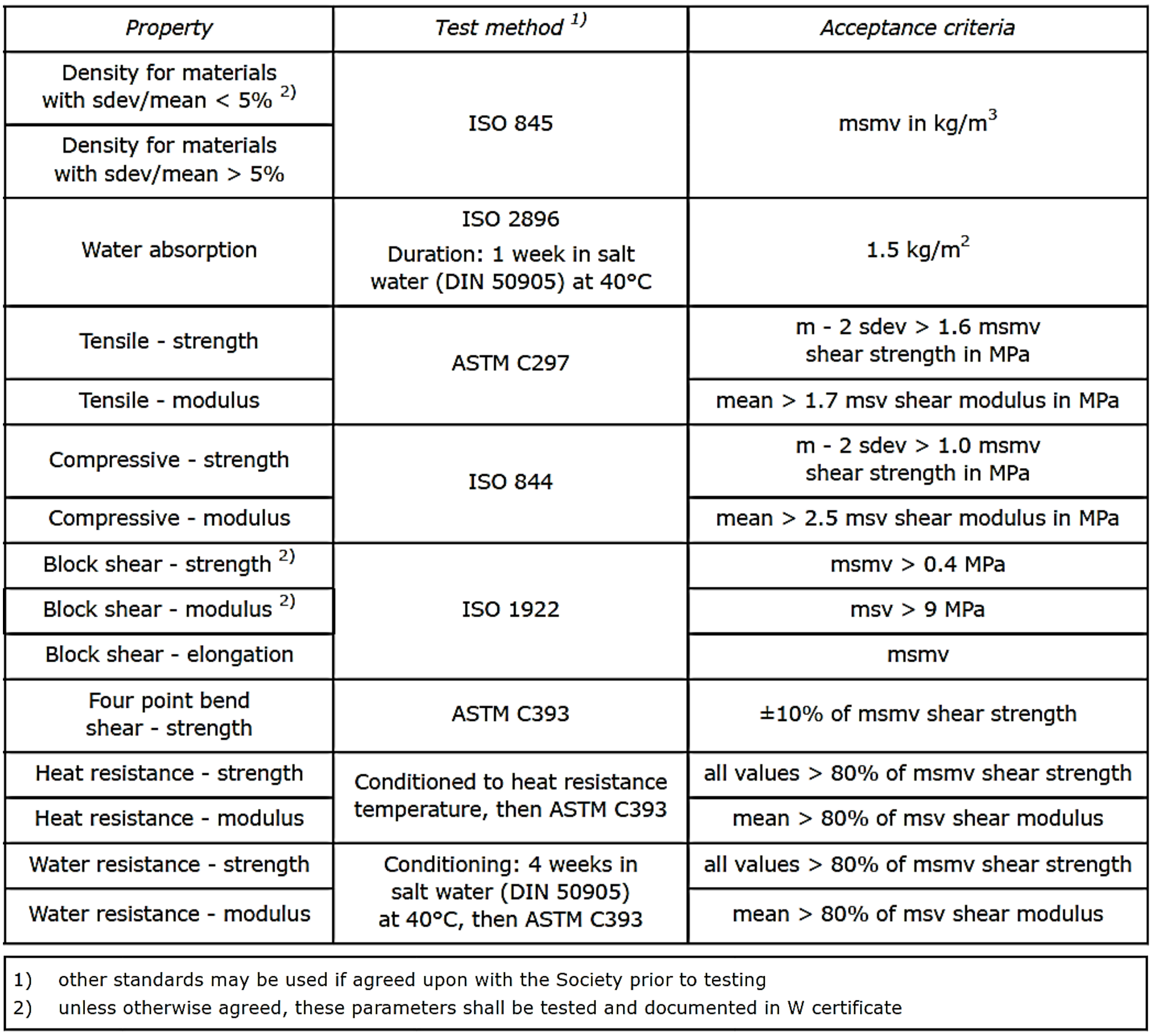
2 Caution is to be taken when linear PVC cores are used in areas that are susceptible to high temperatures because of their low heat distortion temperature.

3.4.4 Det Norske Veritas - Germanischer Lloyd (CM)

In *Rules for classification: Ships (October 2015)* Pt. 2, Ch. 3, Sec. 2, DNV-GL propose test methods and presents general requirements that consider most grades of closed cell polymeric foams and end grain balsa core. But, as it is stated in the rulebook *“For core materials of particular composition or structure, e.g. honeycombs, other/additional requirements may be introduced”*, probably after a special agreement with the classification society.

As for closed cell polymeric foam and end grain balsa wood cores, each property is related to the appropriate International Standard as they presented in *Table 3.4.6 General requirements for all core materials (Made of Closed Cell Foam) (DNV-GL)* and *Table 3.4.7 Requirements for balsa wood core materials (DNV-GL),* respectively.

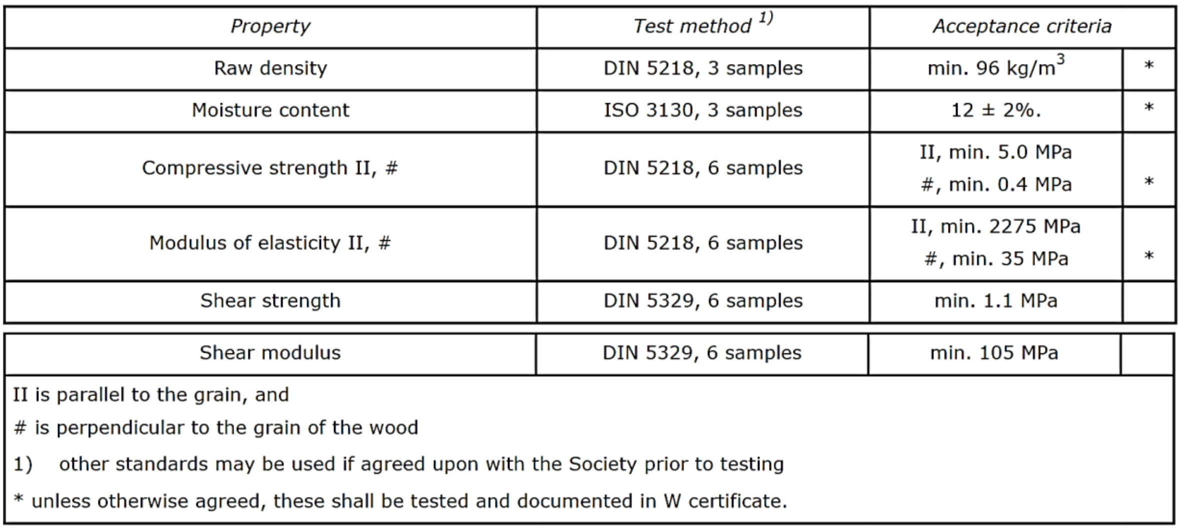
Table 3.4. 6 General requirements for all core materials (Made of Closed Cell Foam) (DNV-GL) [62, 63, 64, 65, 66, 67]



Property	*Test method* 1)	*Acceptance criteria*
Density for materials with sdev/mean < 5% 2)	ISO 845	msmv in kg/m^3
Density for materials with sdev/mean > 5%		
Water absorption	ISO 2896 Duration: 1 week in salt water (DIN 50905) at 40°C	1.5 kg/m^2
Tensile - strength	ASTM C297	m - 2 sdev > 1.6 msmv shear strength in MPa
Tensile - modulus		mean > 1.7 msv shear modulus in MPa
Compressive - strength	ISO 844	m - 2 sdev > 1.0 msmv shear strength in MPa
Compressive - modulus		mean > 2.5 msv shear modulus in MPa
Block shear - strength 2)	ISO 1922	msmv > 0.4 MPa
Block shear - modulus 2)		msv > 9 MPa
Block shear - elongation		msmv
Four point bend shear - strength	ASTM C393	±10% of msmv shear strength
Heat resistance - strength	Conditioned to heat resistance temperature, then ASTM C393	all values > 80% of msmv shear strength
Heat resistance - modulus		mean > 80% of msv shear modulus
Water resistance - strength	Conditioning: 4 weeks in salt water (DIN 50905) at 40°C, then ASTM C393	all values > 80% of msmv shear strength
Water resistance - modulus		mean > 80% of msv shear modulus

1) other standards may be used if agreed upon with the Society prior to testing
2) unless otherwise agreed, these parameters shall be tested and documented in W certificate

Table 3.4. 7 Requirements for balsa wood core materials (DNV-GL)



Property	Test method 1)	Acceptance criteria	
Raw density	DIN 5218, 3 samples	min. 96 kg/m^3	*
Moisture content	ISO 3130, 3 samples	12 ± 2%.	*
Compressive strength II, #	DIN 5218, 6 samples	II, min. 5.0 MPa #, min. 0.4 MPa	*
Modulus of elasticity II, #	DIN 5218, 6 samples	II, min. 2275 MPa #, min. 35 MPa	*
Shear strength	DIN 5329, 6 samples	min. 1.1 MPa	
Shear modulus	DIN 5329, 6 samples	min. 105 MPa	

II is parallel to the grain, and

is perpendicular to the grain of the wood

1) other standards may be used if agreed upon with the Society prior to testing

* unless otherwise agreed, these shall be tested and documented in W certificate.

3.4.5 Lloyd's Register (CM)

LR provides rules on several types of core materials such as end-grain balsa, rigid foams (PUR, PVC etc.) and synthetic felt type materials with or without microspheres.

In *Rules for the Manufacture, Testing and Certification of Materials (July 2018)* Ch. 14 Sec. 2, LR determines the data to be provided generally for core materials with rule **2.7.1**. Additional requirements for rigid foams are given with rule **2.9.4** and for synthetic felt type materials are given with rules **2.10.1** and **2.10.3** of the previous referenced section. These rules are presented below:

2.7.1 *General requirements. The following data is to be provided for each type of core material:*

(a) Type of material.

(b) Density.

(c) Description (block, scrim mounted, grooved).

(d) Thickness and tolerance.

(e) Sheet/block dimensions.

(f) Surface treatment.[1]

2.9.4 *The following test data is to be submitted for each type of foam:*

(a) Density.

(b) Tensile strength (stress at maximum load).

(c) Tensile modulus of elasticity.

(d) Compressive strength (stress at maximum load).

(e) Compressive modulus of elasticity.

2.10.1 *For materials of this type, the following data is required in addition to the requirements 2.7.1:*

(a) Fibre type.

(b) Width.

(c) Width of finished material.

(d) Weight per unit area of the manufactured material.

(e) Weight per linear metre of the manufactured material.

(f) Compatibility.

(g) Details of the method of combining.[1]

2.10.3 *The following properties are to be determined:*

(a) Tensile strength (stress at maximum load).

(b) Tensile strain at break.

(c) Modulus of elasticity in tension or secant modulus at 0,25 per cent and 0,5 per cent strain.

(d) Compressive strength (stress at maximum load).

(e) Compressive modulus.

(f) Flexural strength (stress at maximum load).

(g) Modulus of elasticity in flexure.

(h) Fibre content.

(i) Water absorption.[1]

Furthermore, like DNV-GL, LR provides a table with test methods that correspond to properties, in *Rules for the Manufacture, Testing and Certification of Materials (July 2018)* Ch. 14 Sec. 3. Data of this table are presented on *Table 3.4.8 Test on end-grain balsa (LR).*

The referenced section contains also supplementary rules on testing of the material, with rules **3.8.1**, **3.8.3**, **3.8.4** and **3.8.5**, which are also presented below. In this rules is indicated that rigid foams and synthetic felt type materials shall be tested according with the requirements of *Table 3.4.8 Test on end-grain balsa (LR).* Also, in terms of synthetic felt type materials, it is suggested that similar tests of laminate specimens, which are presented in the following *3.5 Laminates* section, are to be conducted.

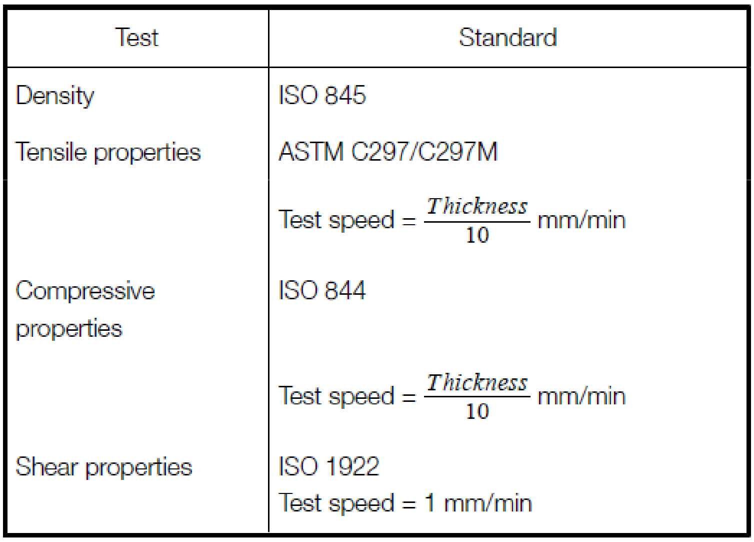
3.8.1 *Initially, the core shear strength and modulus are to be determined by ISO 1922 or ASTM C273/C273M. Test sandwich panels are then to be prepared and subjected to four-point flexural tests to determine the apparent shear properties according to*

- *(a) ASTM C393/C393M (short beam) at two representative thicknesses (i.e. 15 mm and 30 mm). Testing is to be carried out at ambient temperature and at 70°C. The following requirements are to be observed:*
- *(b) Each skin is to be identical and have a thickness not greater than 21 per cent of the nominal core thickness. For hand laid constructions, each skin is to comprise a lightweight chopped strand mat reinforcement (300 g/m2) consolidated at a glass content, by weight, of 0,3 against the core, plus the required number of woven reinforcements consolidated, using an isophthalic polyester resin, to give a minimum glass content, by weight, of 0,5.*
- *(c) The method of construction of the sandwich laminate is to reflect the core material manufacturer's instructions for use, i.e. application of bonding paste, surface primer or any other recommended system.*
- *(d) Where vacuum bagging techniques or equivalent systems are used, these will be subject to individual consideration.*
- *(e) All resins and reinforcements are to hold current LR approval.*
- *(f) Curing conditions are to be in accordance with Ch 14, 3.2 Preparation of test samples 3.2.3 and Ch 14, 3.2 Preparation of test samples 3.2.4 (**these segments are not presented in this document**).*
- *(g) (f) The dimensions of the test samples should be based on the requirements of ASTM C393 Paragraph 5.1, and the ratio parameters as indicated in ASTM C393 Paragraph 5.2, using a proportional limit stress (F) for the woven roving skins of 130 N/mm^2 and a span (a 2) of not less than 400 mm.*[1]

***3.8.3** The following requirements apply to end-grain balsa:*

- *(a) The data requirements of **2.7.1** are to be provided, where applicable, according to suitable National or International Standards.*
- *(b) The balsa is to be tested according to the requirements of **3.8.1.***
- *(c) The test methods for balsa are given in Table 14.3.4 Tests on end-grain balsa (**see Table 3.4.8 Test on end-grain balsa (LR) of this document**).*[1]

Table 3.4. 8 Test on end-grain balsa (LR)[62, 64, 65, 66]



Test	Standard
Density	ISO 845
Tensile properties	ASTM C297/C297M Test speed = $\frac{Thickness}{10}$ mm/min
Compressive properties	ISO 844 Test speed = $\frac{Thickness}{10}$ mm/min
Shear properties	ISO 1922 Test speed = 1 mm/min

***3.8.4** The following requirements apply to rigid foams:*

- *(a) The data requirements of **2.7.1** are to be provided in accordance with a suitable National or International Standard.*
- *(b) The foam is to be tested according to the requirements of **3.8.1.***
- *(c) The test methods for rigid foams are to be in accordance with Table 14.3.4 Tests on end-grain balsa (**see Table 3.4.8 Test on end-grain balsa (LR) of this document**).*[1]

***3.8.5** The following requirements apply to synthetic felt type materials:*

- *(a) The data requirements of **2.10.1** are to be provided according to suitable National or International Standards.*
- *(b) The material is to be tested according to the requirements **3.8.1**, with the following modifications:*
- *— The core of the laminate test sandwich panel is to be prepared with a fibre content as recommended by the manufacturer.*
- *— The felt fibre/resin ratio is to be stated.*
- *— The required test thicknesses of the cores are to be changed from 30 mm and 15 mm to 12 mm and 6 mm respectively.*
- *(c) The prepared laminate of the base material is to be of minimum thickness 3,5 mm with a minimum of three layers.*
- *(d) The specified tests on the laminate (see **2.10.3**) are to be conducted according to the requirements of Table 14.3.3 Tests on laminate specimens **(see Table 3.5. 14 Tests on laminate specimens (LR) of this document)***[1]

Lastly in *Rules for the Manufacture, Testing and Certification of Materials (July 2018)* Ch. 14 Sec. 5 tables with minimum mechanical characteristics of certain core materials of PUR, PVC and end grain balsa, data of which are presented in *Table 3.4.9 Minimum characteristics and mechanical properties of rigid expanded foams at 20°C (LR)* and *Table 3.4.10 Minimum* *characteristics and mechanical properties of end-grain balsa (LR).* At the same section though it is stated that other types of foam will be subjected to individual consideration and that a minimum core shear strength of 0,5 N/mm^2 is to be achieved.

Table 3.4. 9 Minimum characteristics and mechanical properties of rigid expanded foams at 20°C (LR)

Material	Apparent density kg/m^3	Strength (stress at maximum load) (N/mm^2)			Modulus of elasticity (N/mm^2)	
		Tensile	Compressive	Shear	Compressive	Shear
Polyurethane	96	0,85	0,60	0,50	17,20	8,50
Polyvinylchloride	60					

Table 3.4. 10 Minimum characteristics and mechanical properties of end-grain balsa (LR)

Apparent density (kg/m^3)	Strength (stress at maximum load) (N/mm^2)					Compressive modulus of elasticity (N/mm^2)		Shear modulus of elasticity (N/mm^2)
	Compressive		Tensile		Shear			
	Direction of stress					Direction of stress		
	Parallel to grain	Perpendicular to grain	Parallel to grain	Perpendicular to grain		Parallel to grain	Perpendicular to grain	
96	5,0	0,35	9,00	0,44	1,10	2300	35,2	105
144	10,6	0,57	14,6	0,70	1,64	3900	67,8	129
176	12,8	0,68	20,5	0,80	2,00	5300	89,6	145

3.4.6 Registro Italiano Navale (CM)

RINA's rule on core materials are almost identical to LR. A major difference though, is that RINA excludes the rules on synthetic felt type materials. In *Rules for the Classification of Pleasure Yachts (January 2019)* Pt. D, Ch. 6, Sec. 2 the data to be provided are determined, which are same as LR indicates and are not presented here presented, *see 3.4.5 Lloyd's Register (CM)*. Likewise in *Rules for the Classification of Pleasure Yachts (January 2019)* Pt. D, Ch. 6, Sec. 3, RINA describes the test methods and suggests the International Standard to be followed, which are also identical to LR and are not presented either.

One point of deviation from LR that presents interest is that RINA gives rigid foams minimum values of mechanical properties (compressive and shear strength and corresponding moduli of elasticity) in the form of figures. These figures are *Figure 3.4.1 Compressive Properties of PVC type expanded foam plastics (RINA), Figure 3.4.2 Shear Properties of PVC type expanded foam plastics (RINA), Figure 3.4.3 Compressive Properties of PUR type expanded foam plastics (RINA)* and *Figure 3.4.4 Shear Properties of PUR type expanded foam plastics (RINA)* and are presented below.

Lastly, it's worth noting that RINA also provides *Table 3.4.11 Mechanical properties of balsa wood (RINA)* which is similar to *Table 3.4.10 Minimum characteristics and mechanical properties of end-grain balsa (LR)*, but with some discrepancies on the values of compressive modulus at direction parallel to fibres.

Table 3.4. 11 Mechanical properties of balsa wood (RINA)

Density (kg/m^3)	Ultimate strength (N/mm^2)					Compressive modulus		Shear modulus of elasticity (N/mm^2)
	Compressive		Tensile		Shear	Stress direction		
	Stress direction							
	Parallel to fibres	Perpendicular to fibres	Parallel to fibres	Perpendicular to fibres		Parallel to fibres	Perpendicular to fibres	
96	5,00	0,35	9,00	0,44	1,10	22,75	35,20	105
144	10,6	0,57	14,6	0,70	1,64	39,00	67,8	129
175	12,80	0,65	20,60	0,80	2,10	52,90	98,60	145

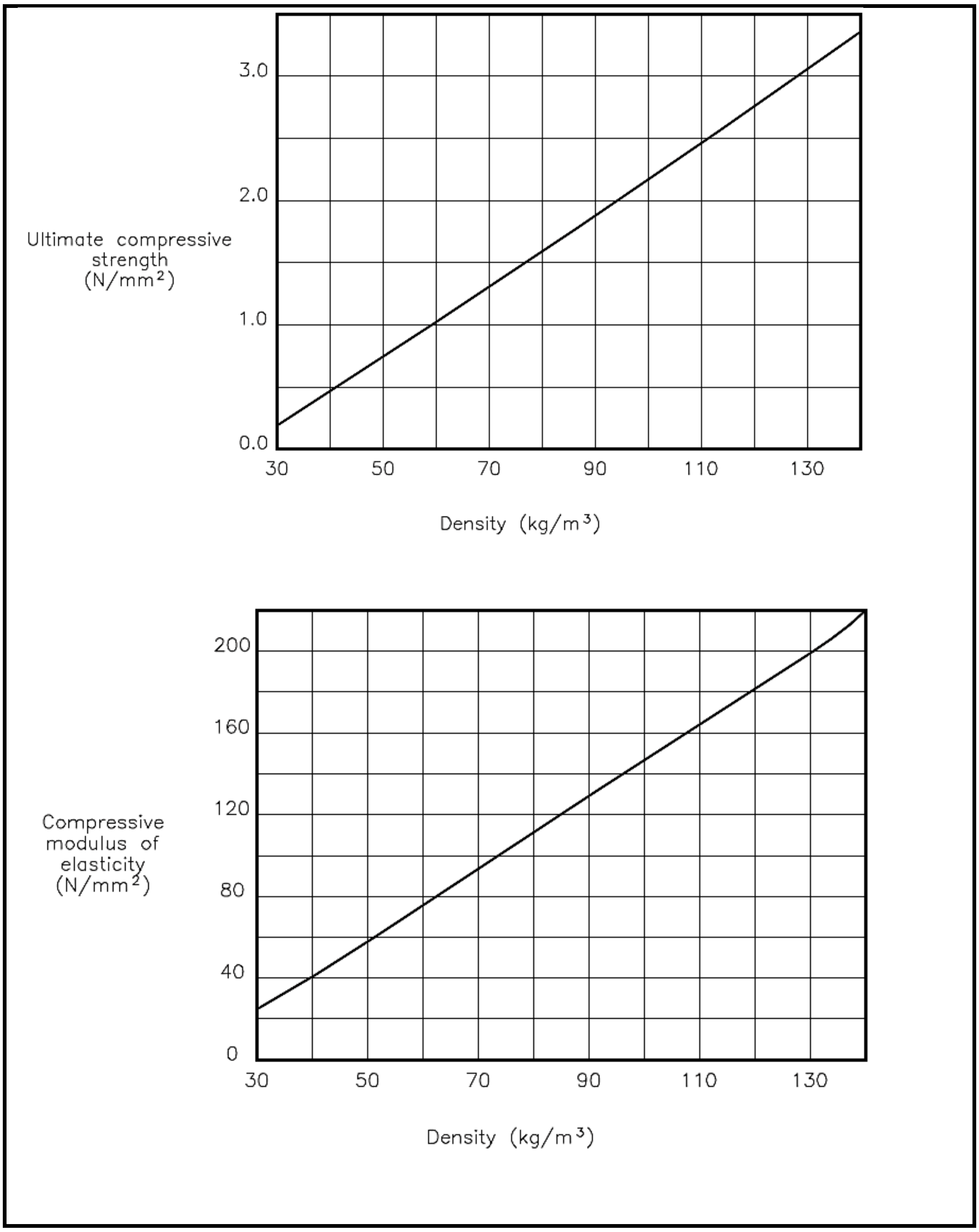


Figure 3.4. 1 Compressive Properties of PVC type expanded foam plastics (RINA)

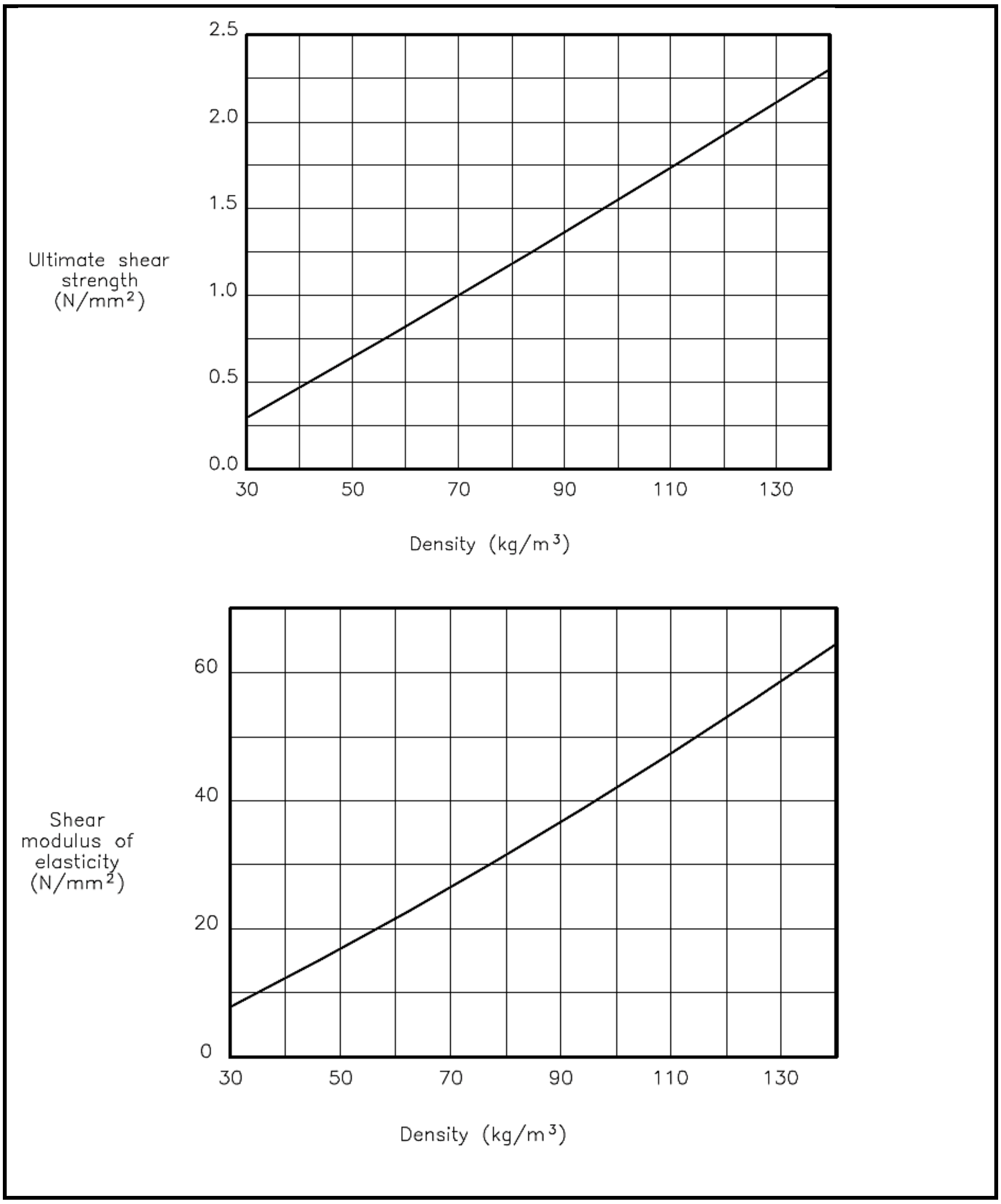


Figure 3.4. 2 Shear Properties of PVC type expanded foam plastics (RINA)

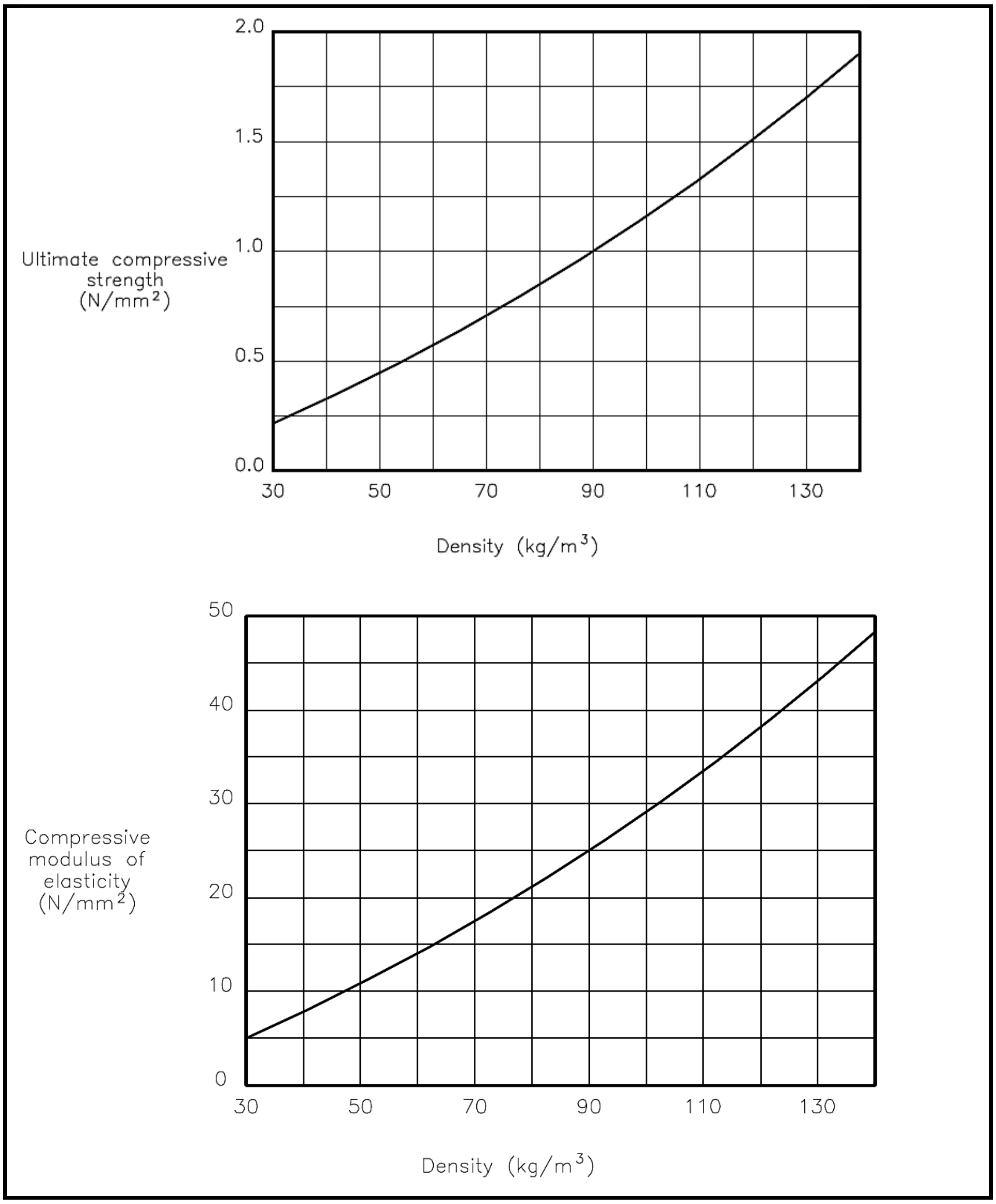


Figure 3.4. 3 Compressive Properties of PUR type expanded foam plastics (RINA)

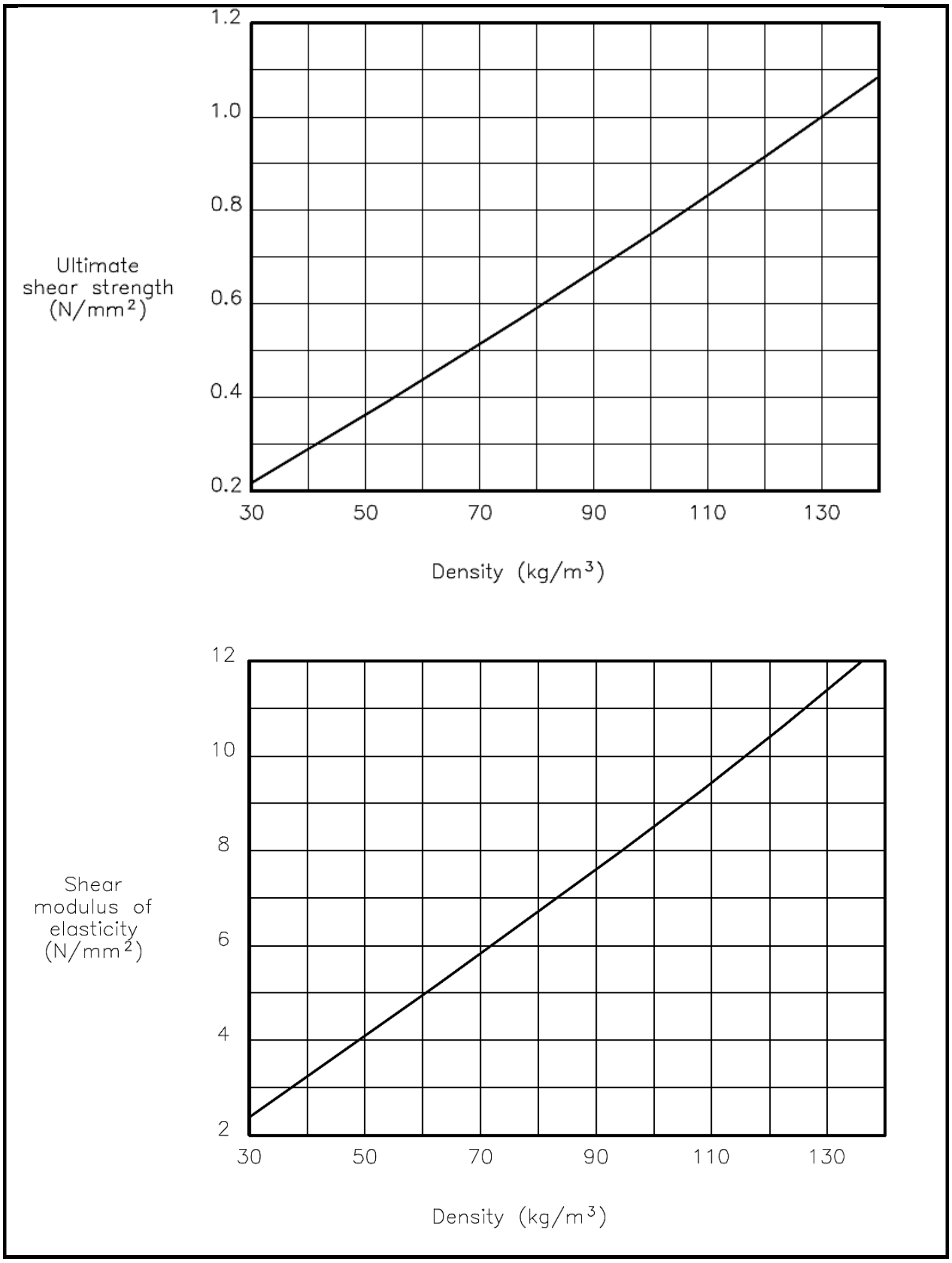


Figure 3.4. 4 Compressive Properties of PUR type expanded foam plastics (RINA)

3.4.7 Conclusion (CM)

LR'and RINA rules on core material are the most analytic and precise on the requirements needed for approval, regulating various types of products and proposing appropriate test standards to be conducted. DNV-GL rules presents similar attributes but the small variety of products immediately regulated makes them inferior to LR and RINA. On the other hand, BV may not indicate the test methods to be conducted, but includes the most core materials than any other classification society, also specifying their minimum characteristics for various densities.

<u>*Section*</u>

3.5 Laminates

3.5.1 General (L)

A composite laminate is a combination of fibrous composite materials (fibers in a matrix) that are bonded together layer by layer to obtain the required engineering properties, such as bending stiffness, strength, and in-plane stiffness.

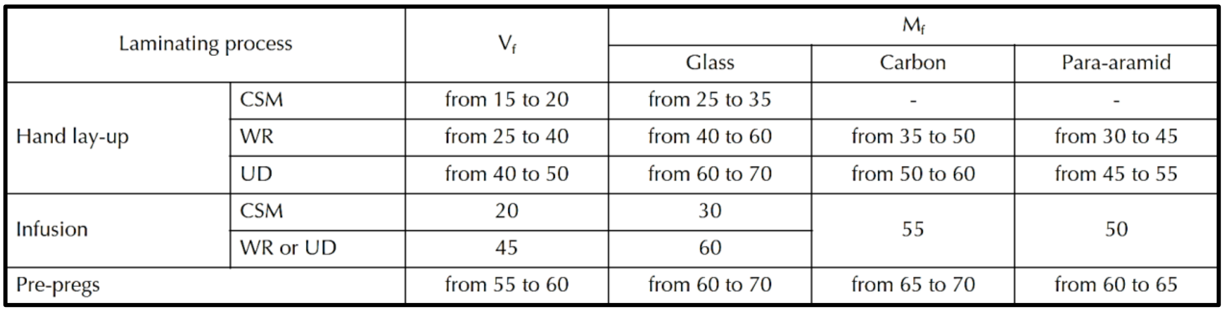
3.5.2 Bureau Veritas (L)

In order to determine mechanical characteristics of an individual laminate, BV provides a methodology that consists of analytical calculations taking into account the type of raw materials, the fibre/resin mix ratio and the type of stress in relation to the reinforcement orientation.

The *Hull in Composite Materials and Plywood, Material Approval, Design Principles, Construction and Survey* (November 2018) Sec. 4 deals with the methodology to determine the theoretical breaking stresses of the individual layers. Firstly, specifications on resin/fibre mix ratios are to be made, which express the amount of fibres and/or resins in an individual layer, usually determined by the shipyard.

However BV presents common values of contents in mass and in volume of fibres, $M_f\ and\ V_f$ respectively, which are presented in *Table 3.5.1 Resin/fibre mix ratios (in %) (BV).* The corresponding resin values can be calculated by subtracting the fibre values from a unit.

Table 3.5. 1 Resin/fibre mix ratios (in %) (BV).



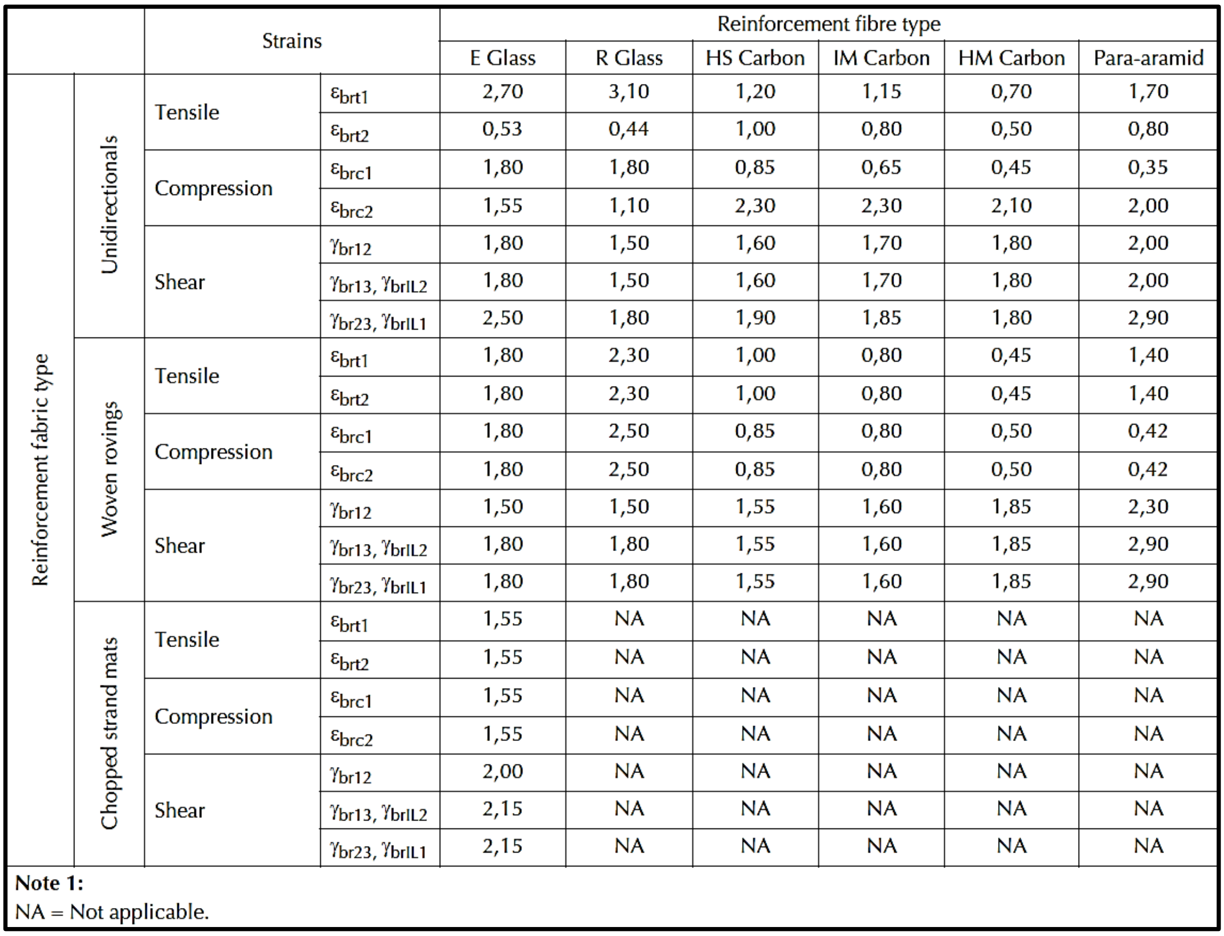
Laminating process		V_f	M_f		
			Glass	Carbon	Para-aramid
Hand lay-up	CSM	from 15 to 20	from 25 to 35	-	-
	WR	from 25 to 40	from 40 to 60	from 35 to 50	from 30 to 45
	UD	from 40 to 50	from 60 to 70	from 50 to 60	from 45 to 55
Infusion	CSM	20	30	55	50
	WR or UD	45	60		
Pre-pregs		from 55 to 60	from 60 to 70	from 65 to 70	from 60 to 65

In the sequence of the methodology, elastic coefficients of individual layers are calculated. In these calculations, whatever is the type of reinforcement making up of the individual layer is (CSM, WR or UD), the first step of the methodology demands the estimation of the elastic coefficients of an equivalent unidirectional (UD). The elastic coefficients of a woven roving (WR) or a chopped strand mat (CSM) are calculated on the basis of the elastic coefficients of the equivalent UD.

Finally the theoretical individual layer breaking stresses are calculated based on the elastic coefficients, a resin system coefficient and theoretical breaking strains. The resin system coefficient is a factor of breaking stress and can take the value of 0,8 , 0,9 and 1 for polyester, vinylester and epoxy respectively, indicating that epoxy resin system may withstand higher stresses.

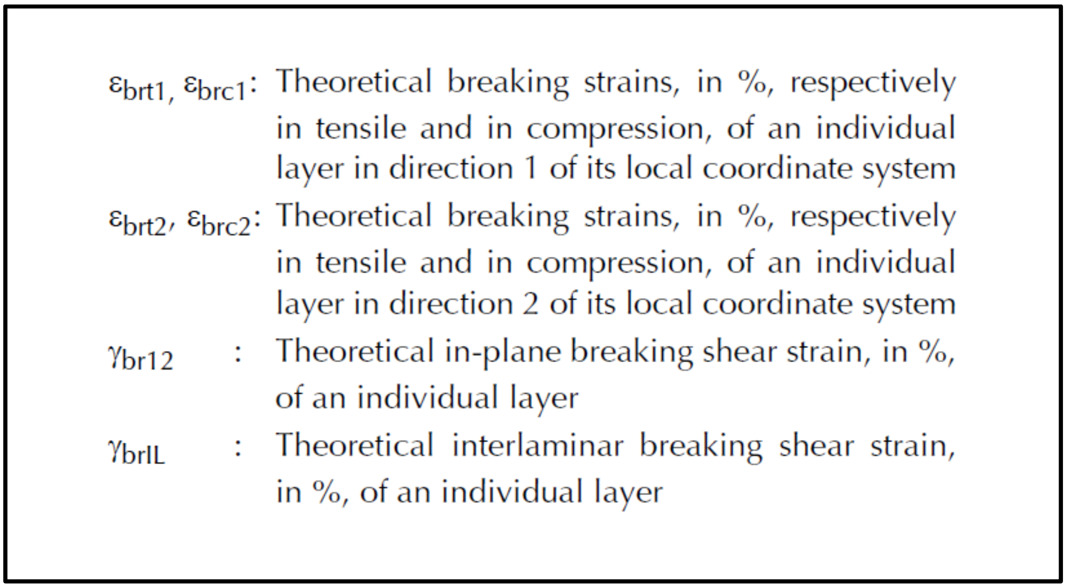
The theoretical breaking strains are given in *Table 3.5.2 Theoretical breaking strains, in % (BV)* and their definitions in *Figure 3.5.1 Definitions of theoretical breaking strains in % (BV),* as in Hull in Composite Materials and Plywood, Material Approval, Design Principles, Construction and Survey (November 2018) Sec. 4, by BV.

Table 3.5. 2 Theoretical breaking strains, in % (BV)



		Strains		Reinforcement fibre type					
				E Glass	R Glass	HS Carbon	IM Carbon	HM Carbon	Para-aramid
Reinforcement fabric type	Unidirectionals	Tensile	ε_{brt1}	2,70	3,10	1,20	1,15	0,70	1,70
			ε_{brt2}	0,53	0,44	1,00	0,80	0,50	0,80
		Compression	ε_{brc1}	1,80	1,80	0,85	0,65	0,45	0,35
			ε_{brc2}	1,55	1,10	2,30	2,30	2,10	2,00
		Shear	γ_{br12}	1,80	1,50	1,60	1,70	1,80	2,00
			$\gamma_{br13}, \gamma_{brIL2}$	1,80	1,50	1,60	1,70	1,80	2,00
			$\gamma_{br23}, \gamma_{brIL1}$	2,50	1,80	1,90	1,85	1,80	2,90
	Woven rovings	Tensile	ε_{brt1}	1,80	2,30	1,00	0,80	0,45	1,40
			ε_{brt2}	1,80	2,30	1,00	0,80	0,45	1,40
		Compression	ε_{brc1}	1,80	2,50	0,85	0,80	0,50	0,42
			ε_{brc2}	1,80	2,50	0,85	0,80	0,50	0,42
		Shear	γ_{br12}	1,50	1,50	1,55	1,60	1,85	2,30
			$\gamma_{br13}, \gamma_{brIL2}$	1,80	1,80	1,55	1,60	1,85	2,90
			$\gamma_{br23}, \gamma_{brIL1}$	1,80	1,80	1,55	1,60	1,85	2,90
	Chopped strand mats	Tensile	ε_{brt1}	1,55	NA	NA	NA	NA	NA
			ε_{brt2}	1,55	NA	NA	NA	NA	NA
		Compression	ε_{brc1}	1,55	NA	NA	NA	NA	NA
			ε_{brc2}	1,55	NA	NA	NA	NA	NA
		Shear	γ_{br12}	2,00	NA	NA	NA	NA	NA
			$\gamma_{br13}, \gamma_{brIL2}$	2,15	NA	NA	NA	NA	NA
			$\gamma_{br23}, \gamma_{brIL1}$	2,15	NA	NA	NA	NA	NA

Note 1:
NA = Not applicable.



ε_{brt1}, ε_{brc1}: Theoretical breaking strains, in %, respectively in tensile and in compression, of an individual layer in direction 1 of its local coordinate system

ε_{brt2}, ε_{brc2}: Theoretical breaking strains, in %, respectively in tensile and in compression, of an individual layer in direction 2 of its local coordinate system

γ_{br12} : Theoretical in-plane breaking shear strain, in %, of an individual layer

γ_{brIL} : Theoretical interlaminar breaking shear strain, in %, of an individual layer

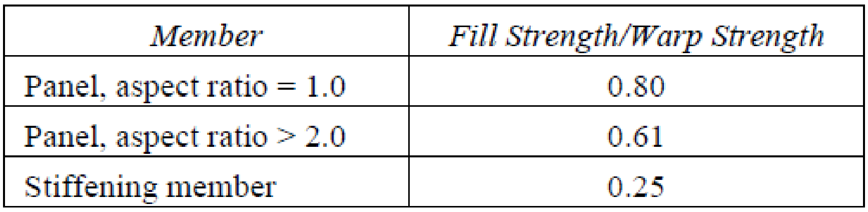
Figure 3.5. 1 Definitions of theoretical breaking strains in % (BV)

3.5.3 American Bureau of Shipping (L)

ABS provides indications on the mechanical properties to be determined and gives International Standard tests that associated with laminate properties. In addition, in *Rules for Materials and Welding (2018)* Ch. 6 Sec. 1 it gives the average mechanical properties for various laminating materials, which are presented on *Table 3.5.4 Laminate properties (ABS).* These values are minimum for hand lay-up construction and are to be used for guidance only.

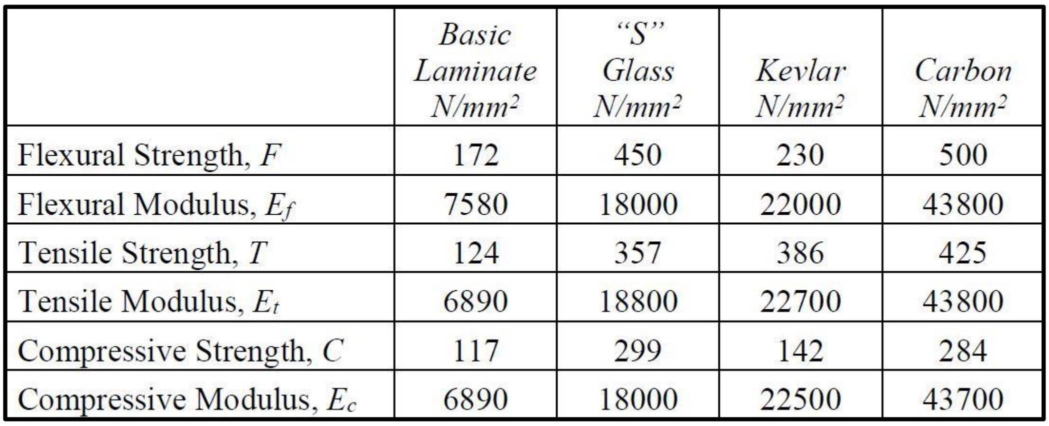
Specifically for uni-directional rovings, ABS gives table with the ratios of the verified minimum laminate strengths in the fill direction to those in the warp direction that have to be maintained in order to prevent laminate failure in any direction. The ratios are given in *Table 3.5.3 Uni-directional laminates strength ratios (ABS).*

Table 3.5. 3 Uni-directional laminates strength ratios (ABS)



Member	*Fill Strength/Warp Strength*
Panel, aspect ratio = 1.0	0.80
Panel, aspect ratio > 2.0	0.61
Stiffening member	0.25

Table 3.5. 4 Laminate properties (ABS)



	Basic Laminate N/mm²	*"S" Glass N/mm²*	*Kevlar N/mm²*	*Carbon N/mm²*
Flexural Strength, *F*	172	450	230	500
Flexural Modulus, E_f	7580	18000	22000	43800
Tensile Strength, *T*	124	357	386	425
Tensile Modulus, E_t	6890	18800	22700	43800
Compressive Strength, *C*	117	299	142	284
Compressive Modulus, E_c	6890	18000	22500	43700

An interesting entry in ABS *Rules for Materials and Welding (2018)* Ch. 6 Sec. 1 is an equation for calculating the average cured laminate thickness for mat or woven rovings having glass content different than basic laminate's, which is also provided as guidance to the designer. Basic laminate, defined by ABS, as a laminate consists of an unsaturated general-purpose polyester resin and alternate plies of E-glass, fiberglass mat and fiberglass-woven roving fabricated by the contact or hand lay-up process. The minimum glass content of this laminate is 35% by weight. The equation is presented below:

$$t = \frac{Wk}{c}\left(\frac{305}{f_g} - 2{,}69\right)\, mm$$

Where,

k = 0,35 mm

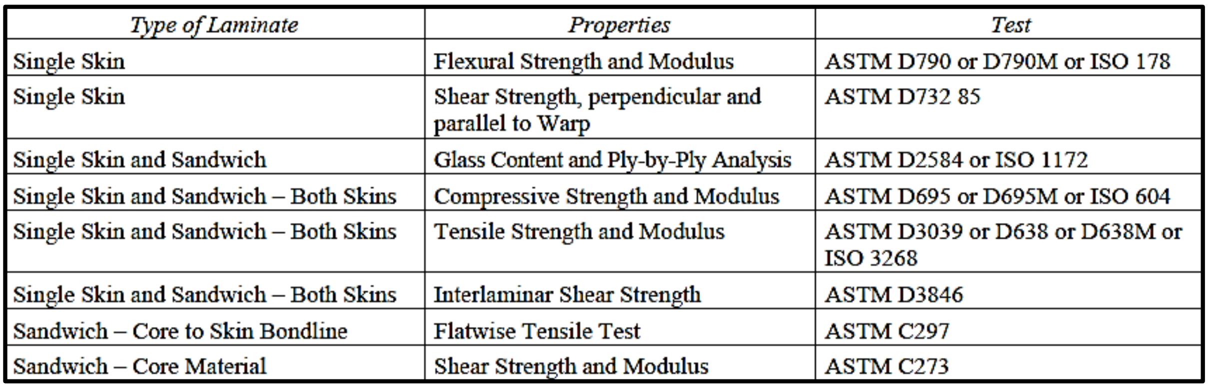
f_g = glass content, percentage by weight, of one ply of the mat and one ply of the woven-roving of the laminate to be used

c = glass content per pair of composite fiberglass reinforcement of basic laminate
= 1272 g/m^2

W = total weight of fiberglass reinforcement of the laminate in g/m^2, of the laminate thickness, t

As it was mentioned, in *Rules for Materials and Welding (2018)* Ch. 6 Sec. 2 mechanical tests that are used to specify laminate properties are presented. These data are given in *Table 3.5.5 Tests for Physical Properties of FRP Laminates (ABS).*

Table 3.5. 5 Tests for Physical Properties of FRP Laminates (ABS)[68, 52, 69 ,70 ,71, 72, 73, 74, 75]



Type of Laminate	*Properties*	*Test*
Single Skin	Flexural Strength and Modulus	ASTM D790 or D790M or ISO 178
Single Skin	Shear Strength, perpendicular and parallel to Warp	ASTM D732 85
Single Skin and Sandwich	Glass Content and Ply-by-Ply Analysis	ASTM D2584 or ISO 1172
Single Skin and Sandwich – Both Skins	Compressive Strength and Modulus	ASTM D695 or D695M or ISO 604
Single Skin and Sandwich – Both Skins	Tensile Strength and Modulus	ASTM D3039 or D638 or D638M or ISO 3268
Single Skin and Sandwich – Both Skins	Interlaminar Shear Strength	ASTM D3846
Sandwich – Core to Skin Bondline	Flatwise Tensile Test	ASTM C297
Sandwich – Core Material	Shear Strength and Modulus	ASTM C273

3.5.4 Det Norske Veritas - Germanischer Lloyd (L)

On this particular matter DNV-GL does not dispose a section or segment for delivering the rules on laminates, rather in *Rules for classification: Ships (October 2015)* Pt. 2, Ch. 3, Sec. 2 prescribes rules on laminates in the reinforcement segment. As a result DNV-GL gives rules on laminates containing glass, carbon and aramid reinforcement in different tables.

Alike DNV-GL reinforcement rules, which are presented in segment *3.2.4 Det Norske Veritas - Germanischer Lloyd (R),* laminate rules designate the properties to be determined and relate them to the corresponding International Standard. Requirements for glass fibre products are given in *Table 3.5.6 Laminate with glass fibre reinforcements (DNV-GL),* where it shall be noticed that requirements on compressive properties are missing.

Table 3.5. 6 Laminate with glass fibre reinforcements (DNV-GL)[76, 51]

Property	*Test method 1)*	*Acceptance criteria*
Interlaminar shear strength (ILSS), Short-Beam Test 3)	ISO 14130	manufacturer's specified value
Tensile strength of laminate 2, 3)	ISO 527-1,4,5	To be agreed with the Society prior to testing
Tensile modulus		
Tensile elongation 2)		

1) other standards may be used if agreed upon with the Society prior to testing
2) unless otherwise agreed, these parameters shall be tested and documented in W certificate
3) fibre volume content according to ISO 1172 of the actual laminate to be tested and reported

Concerning carbon fibre reinforced laminates, requirements are presented in *Table 3.5.7 Laminates with carbon fibre reinforcements (DNV-GL),* followed by *Table 3.5.8 Acceptance criteria of laminates with carbon fibre reinforcements (DNV-GL)* that presents various acceptance criteria based on fabrics that are used (UD, Biaxial, etc.).

Table 3.5. 7 Laminates with carbon fibre reinforcements (DNV-GL) [51, 77, 78]

Property	*Test method* 1)	*Acceptance criteria*
Tensile		According to Table 7
— strength	ISO 527-1 ISO 527-4 (specimen type 3) ISO 527-5 (specimen type A)	
— modulus		
— elongation		
Compressive		
— strength	ISO 14126 (method 1, specimen type A 2))	
— modulus		
— failure strain		
Flexural		
— strength	ISO 14125 (method A)	
Fibre volume content	DIN EN 2564	50% ± 5
1) other standards may be agreed upon with the Society prior to testing 2) reduction of the free buckling length to 8 mm ± 0.25 mm is allowed		

(For Table 7 see following Table 3.5.8 Acceptance criteria of laminates with carbon fibre reinforcements (DNV-GL) of this document)

Table 3.5. 8 Acceptance criteria of laminates with carbon fibre reinforcements (DNV-GL)

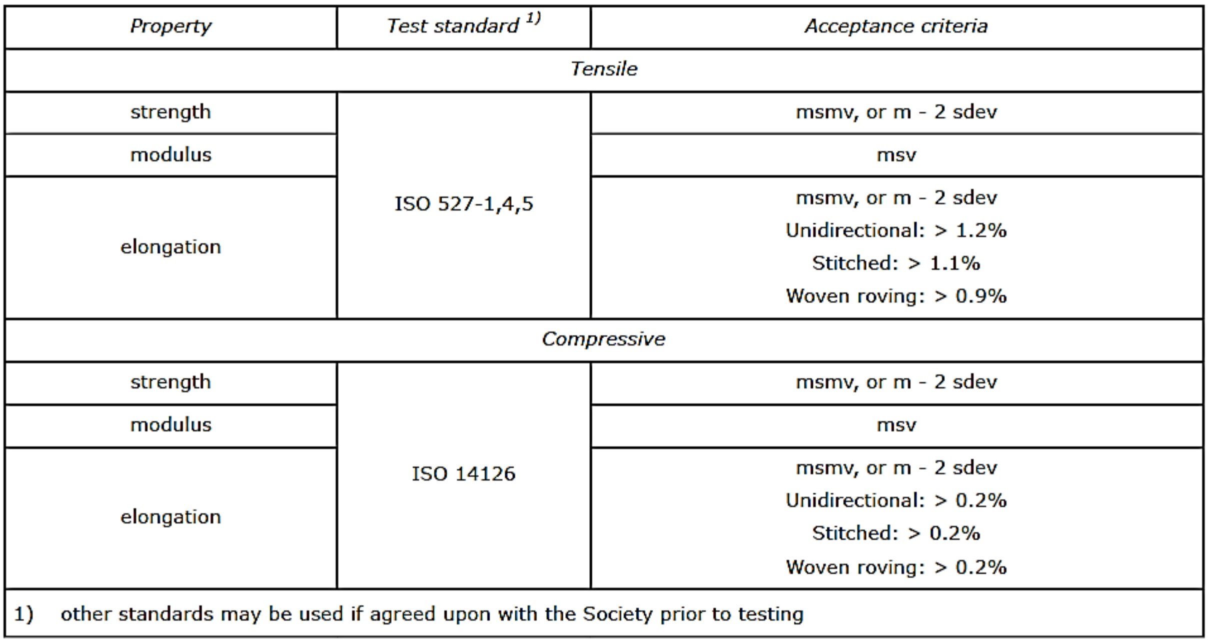
Property	*Unit*	*Unidirectional* *0°*	*Biaxial* *±45° or 0°/90°*	*Triaxial* *0°/±45°*	*Quadraxial* *0°/90°/±45°*
Tensile					
— strength	MPa	1125	625	565	500
— modulus	GPa	100	55	45	42
Compressive					
— strength	MPa	750	415	375	335
— modulus	GPa	87.5	48	44	40
Flexural					
— strength	MPa	900	500	400	365
1) these values refer to a fibre volume fraction of 50% ± 5%, a uniform lay-up and the 0° direction. Other parameters may be accepted if agreed upon with the Society prior to testing					

Similar requirements are given for laminates with aramid reinforcement in *Table 3.5.9 Interlaminar shear strength of laminates with aramid reinforcements (DNV-GL)* and *Table 3.5.10 Laminates with aramid reinforcements (DNV-GL),* as the ISO-standards that are suggested are the same. However in *Table 3.5.10 Laminates with aramid reinforcements (DNV-GL)* acceptance criteria for stitched and woven rovings are presented, which were not part of the previous two materials (laminate with glass and carbon reinforcements).

Table 3.5. 9 Interlaminar shear strength of laminates with aramid reinforcements (DNV-GL)[76]

Property	*Test method 1)*	*Acceptance criteria*
Interlaminar shear strength (ILSS), Short-Beam Test 3)	ISO 14130	manufacturer's specified value (msmv)
1) unless otherwise agreed, these parameters shall be tested and documented in W 2) other standards may be used if agreed upon with the Society prior to testing certificate		

Table 3.5. 10 Laminates with aramid reinforcements (DNV-GL)[51, 77]



Property	*Test standard 1)*	*Acceptance criteria*
Tensile		
strength	ISO 527-1,4,5	msmv, or m - 2 sdev
modulus		msv
elongation		msmv, or m - 2 sdev Unidirectional: > 1.2% Stitched: > 1.1% Woven roving: > 0.9%
Compressive		
strength	ISO 14126	msmv, or m - 2 sdev
modulus		msv
elongation		msmv, or m - 2 sdev Unidirectional: > 0.2% Stitched: > 0.2% Woven roving: > 0.2%
1) other standards may be used if agreed upon with the Society prior to testing		

Where,

msmv = manufacturer's specified minimum value

$m \pm 2\, sdev$ = mean ± 2 sdev of type test results

$sdev$ = standard deviation of type test results

3.5.5 Lloyd's Register (L)

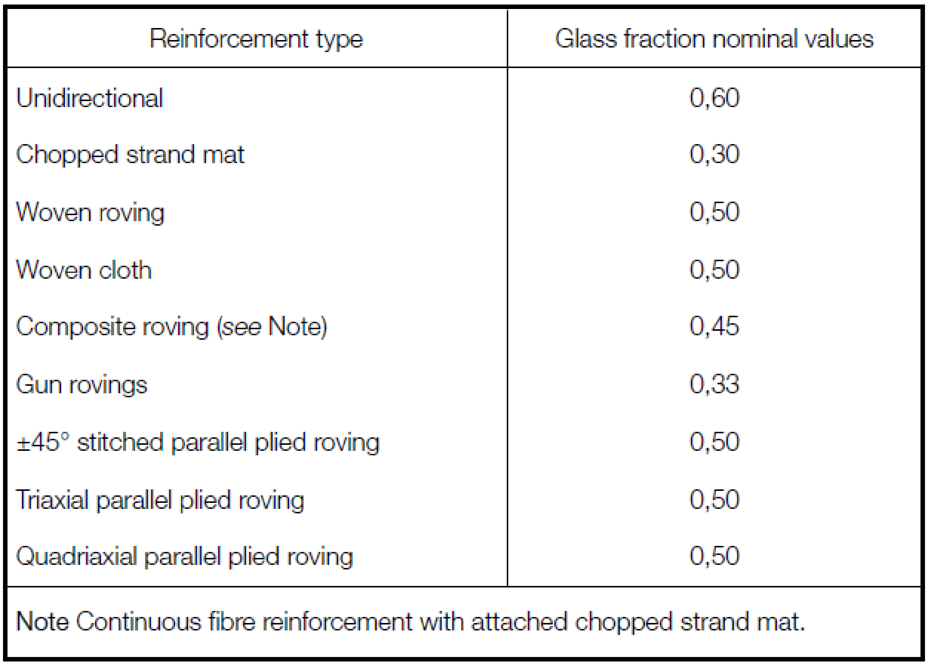
In *Rules for the Manufacture, Testing and Certification of Materials (July 2018)* Ch. 14 Sec. 2, LR already sets requirements on how the laminate specimens shall be prepared in order to be tested. Rule **2.4.2**, which is presented below, dictates that the preparation that ought to be followed, in which specifications are included for different types of reinforcements. In addition LR states that the laminate is to be tested in air in the directions indicated by *Table 3.5.13 Fibre orientations in reinforced test specimens (LR)*.

2.4.2 *Tests of the mechanical properties are to be made on laminate samples containing the reinforcement and prepared as follows:*
(a) an approved resin of suitable type is to be used;
(b) a minimum of three layers of the reinforcement is to be laid with parallel ply to give a laminate not less than 4 mm thick;

(c) the weights of resin and reinforcement used are to be recorded together with the measured thickness of the laminate, including the measured weight per unit area of the reinforcement used;
(d) for glass reinforcements, the glass/resin ratios, by weight, as shown in Table 14.2.2 Glass fraction by weight for different reinforcement types are to be used;
(e) for reinforcement type other than glass, a fibre volume fraction, as shown in Table 14.2.3 Content by volume for different reinforcement types, is to be used[1]

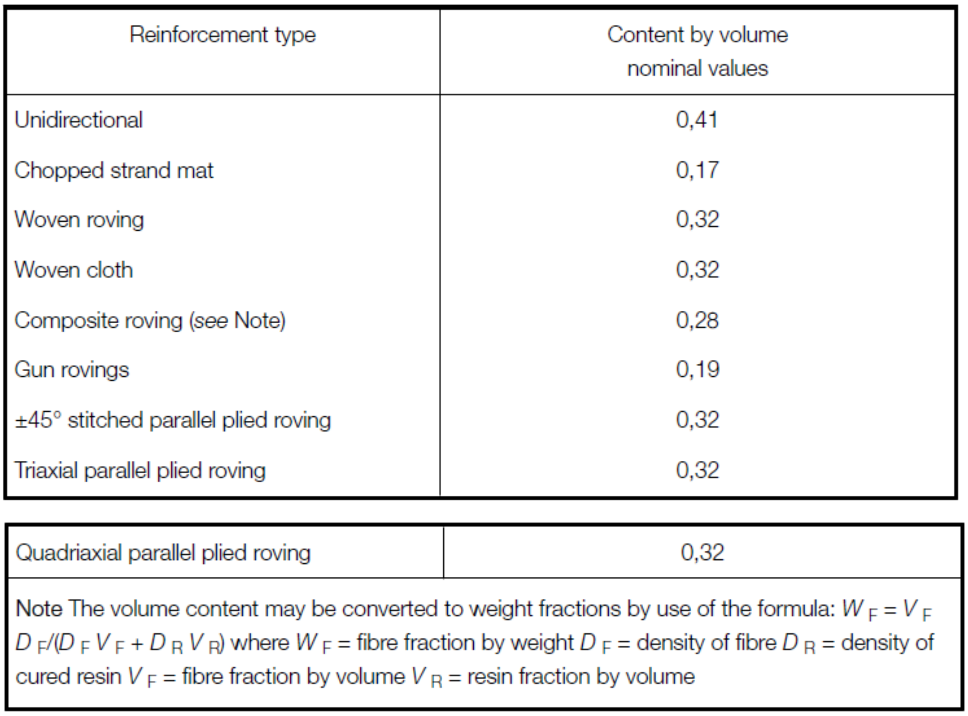
The data of above rule of "Table 14.2.2" and "Table 14.2.3" can be found on the following *Table 3.5.11 Glass fraction by weight for different reinforcement (LR)* and *Table 3.5.12 Content by volume for different reinforcement types (LR)* respectively.

Table 3.5. 11 Glass fraction by weight for different reinforcement types (LR)



Reinforcement type	Glass fraction nominal values
Unidirectional	0,60
Chopped strand mat	0,30
Woven roving	0,50
Woven cloth	0,50
Composite roving (*see* Note)	0,45
Gun rovings	0,33
±45° stitched parallel plied roving	0,50
Triaxial parallel plied roving	0,50
Quadriaxial parallel plied roving	0,50
Note Continuous fibre reinforcement with attached chopped strand mat.	

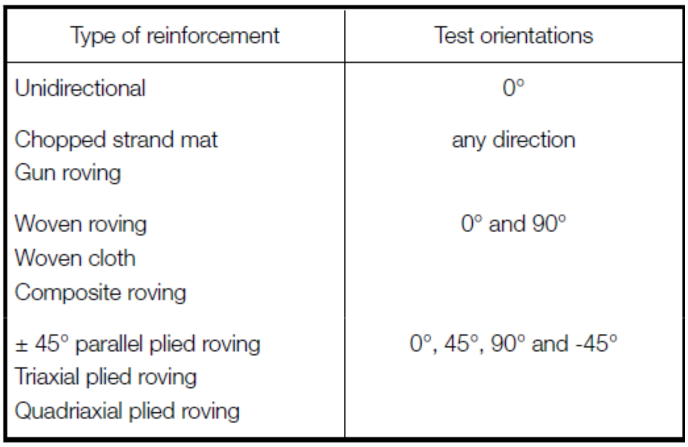
Table 3.5. 12 Content by volume for different reinforcement types (LR)



Reinforcement type	Content by volume nominal values
Unidirectional	0,41
Chopped strand mat	0,17
Woven roving	0,32
Woven cloth	0,32
Composite roving (*see* Note)	0,28
Gun rovings	0,19
±45° stitched parallel plied roving	0,32
Triaxial parallel plied roving	0,32
Quadriaxial parallel plied roving	0,32

Note The volume content may be converted to weight fractions by use of the formula: $W_F = V_F D_F/(D_F V_F + D_R V_R)$ where W_F = fibre fraction by weight D_F = density of fibre D_R = density of cured resin V_F = fibre fraction by volume V_R = resin fraction by volume

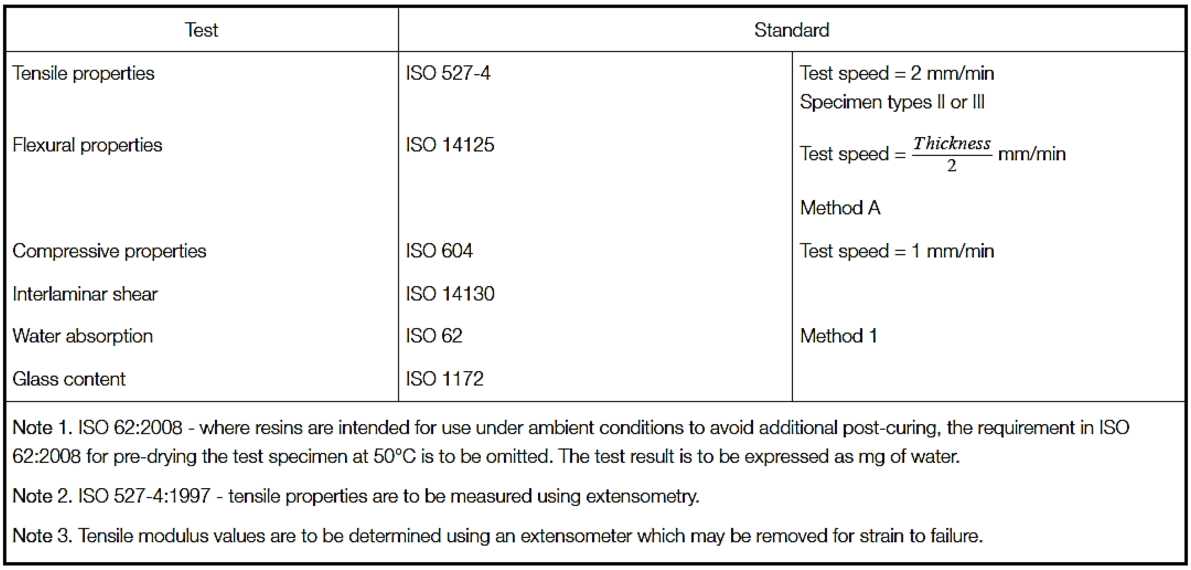
Table 3.5. 13 Fibre orientations in reinforced test specimens (LR)



Type of reinforcement	Test orientations
Unidirectional	0°
Chopped strand mat Gun roving	any direction
Woven roving Woven cloth Composite roving	0° and 90°
± 45° parallel plied roving Triaxial plied roving Quadriaxial plied roving	0°, 45°, 90° and -45°

Furthermore LR indicates the properties to be determined corresponding them with the appropriate International Standard as it is presented in *Table 3.5.14 Tests on laminate specimens (LR).* The difference with DNV-GL on this matter is that LR sets Standards to which laminate specimens of any type are to be tested and not have variations based on reinforcement type.

Table 3.5. 14 Tests on laminate specimens (LR)[51,78,60,76,55,79]



Test	Standard	
Tensile properties	ISO 527-4	Test speed = 2 mm/min Specimen types II or III
Flexural properties	ISO 14125	Test speed = $\frac{Thickness}{2}$ mm/min Method A
Compressive properties	ISO 604	Test speed = 1 mm/min
Interlaminar shear	ISO 14130	
Water absorption	ISO 62	Method 1
Glass content	ISO 1172	

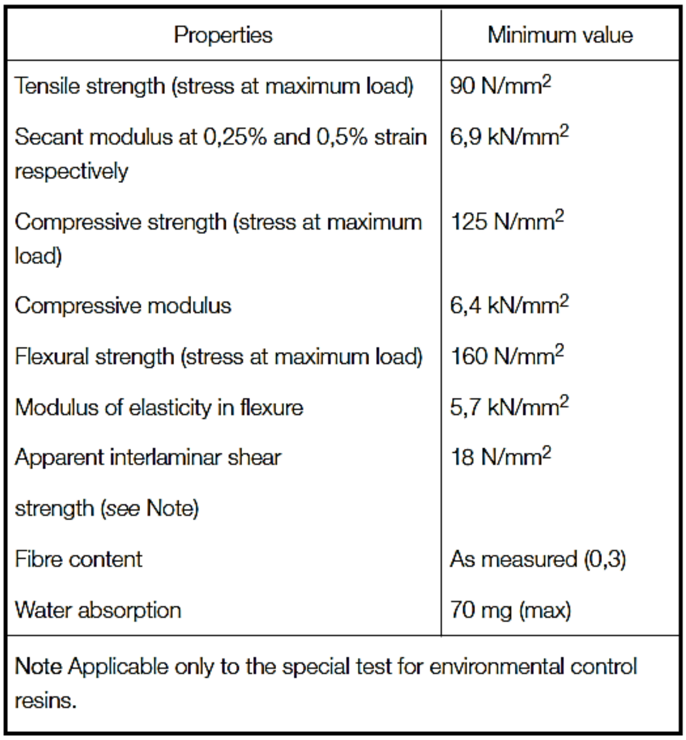
Note 1. ISO 62:2008 - where resins are intended for use under ambient conditions to avoid additional post-curing, the requirement in ISO 62:2008 for pre-drying the test specimen at 50°C is to be omitted. The test result is to be expressed as mg of water.

Note 2. ISO 527-4:1997 - tensile properties are to be measured using extensometry.

Note 3. Tensile modulus values are to be determined using an extensometer which may be removed for strain to failure.

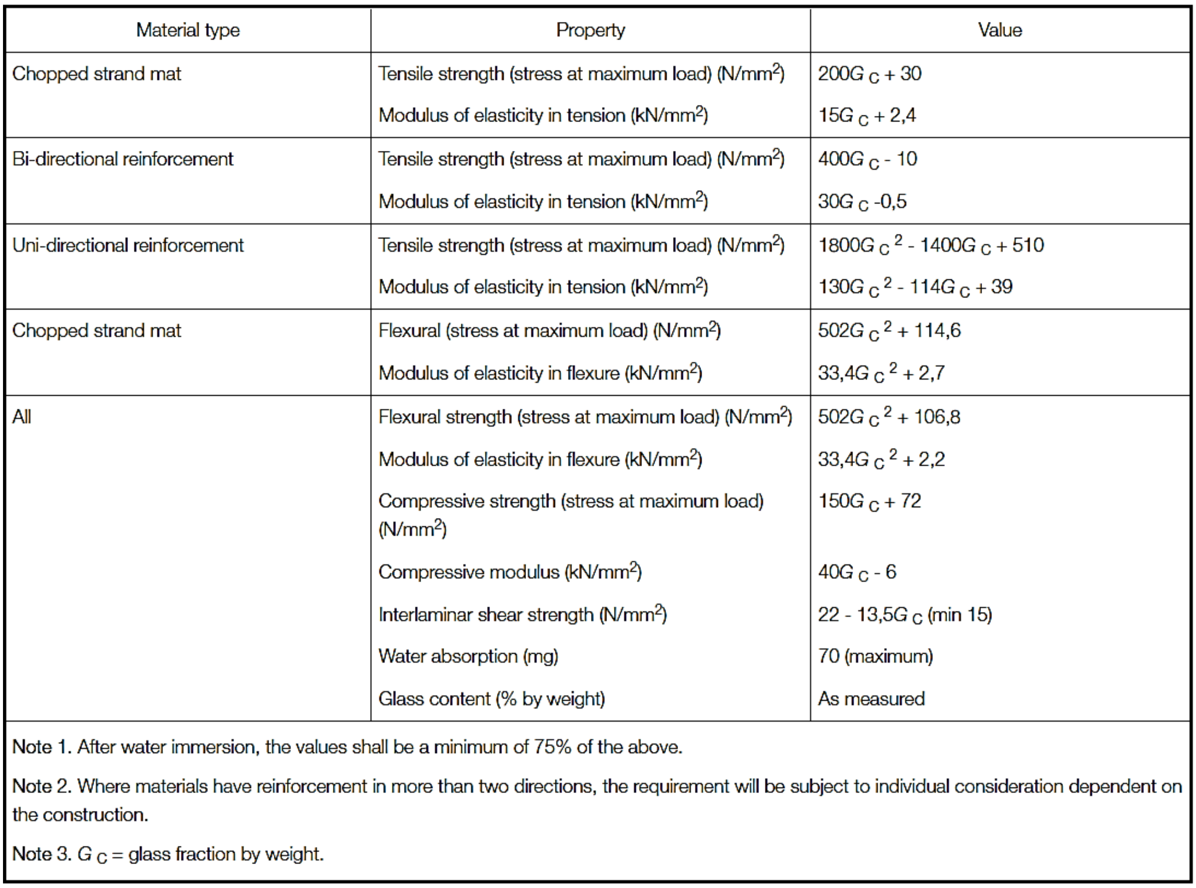
When resins tested according to the requirements given in *3.2.5 Lloyd's Register (Res.*), in Rules for the Manufacture, Testing and Certification of Materials (July 2018) Ch. 14 Sec. 5 LR provides *Table 3.5.15 Laminating resins, minimum values for properties for CSM laminate at 0,3 glass fraction by weight (LR)* that gives the minimum properties for chopped strand mat. Also, in the same section, *Table 3.5.16 Laminates, minimum property requirements (LR)* give minimum mechanical properties of laminates, which have been tested accordingly, of any type of fabric as a function of G_c (glass fraction by weight).

Table 3.5. 15 Laminating resins, minimum values for properties for CSM laminate at 0,3 glass fraction by weight (LR)



Properties	Minimum value
Tensile strength (stress at maximum load)	90 N/mm^2
Secant modulus at 0,25% and 0,5% strain respectively	6,9 kN/mm^2
Compressive strength (stress at maximum load)	125 N/mm^2
Compressive modulus	6,4 kN/mm^2
Flexural strength (stress at maximum load)	160 N/mm^2
Modulus of elasticity in flexure	5,7 kN/mm^2
Apparent interlaminar shear strength (*see* Note)	18 N/mm^2
Fibre content	As measured (0,3)
Water absorption	70 mg (max)
Note Applicable only to the special test for environmental control resins.	

Table 3.5. 16 Laminates, minimum property requirements (LR)



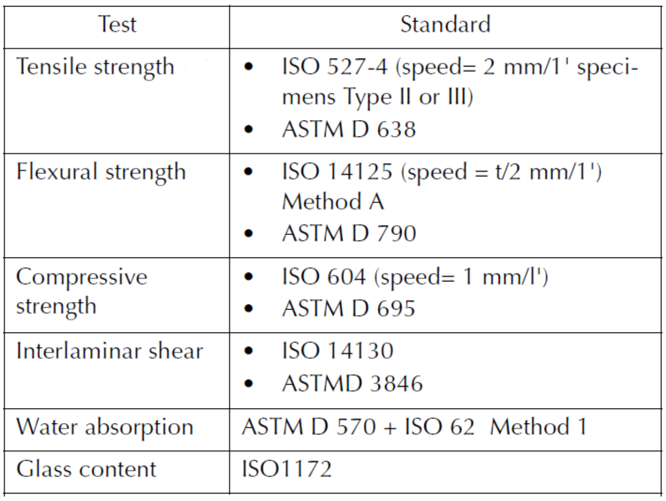
Material type	Property	Value
Chopped strand mat	Tensile strength (stress at maximum load) (N/mm^2)	$200G_C + 30$
	Modulus of elasticity in tension (kN/mm^2)	$15G_C + 2,4$
Bi-directional reinforcement	Tensile strength (stress at maximum load) (N/mm^2)	$400G_C - 10$
	Modulus of elasticity in tension (kN/mm^2)	$30G_C -0,5$
Uni-directional reinforcement	Tensile strength (stress at maximum load) (N/mm^2)	$1800G_C^2 - 1400G_C + 510$
	Modulus of elasticity in tension (kN/mm^2)	$130G_C^2 - 114G_C + 39$
Chopped strand mat	Flexural (stress at maximum load) (N/mm^2)	$502G_C^2 + 114,6$
	Modulus of elasticity in flexure (kN/mm^2)	$33,4G_C^2 + 2,7$
All	Flexural strength (stress at maximum load) (N/mm^2)	$502G_C^2 + 106,8$
	Modulus of elasticity in flexure (kN/mm^2)	$33,4G_C^2 + 2,2$
	Compressive strength (stress at maximum load) (N/mm^2)	$150G_C + 72$
	Compressive modulus (kN/mm^2)	$40G_C - 6$
	Interlaminar shear strength (N/mm^2)	$22 - 13,5G_C$ (min 15)
	Water absorption (mg)	70 (maximum)
	Glass content (% by weight)	As measured
Note 1. After water immersion, the values shall be a minimum of 75% of the above. Note 2. Where materials have reinforcement in more than two directions, the requirement will be subject to individual consideration dependent on the construction. Note 3. G_C = glass fraction by weight.		

3.5.6 Registro Italiano Navale (L)

RINA rules on laminates are once again quite similar to LR. Considering the preparation of laminate specimens, the rules that are presented in *Rules for the Classification of Pleasure Yachts (January 2019)* Pt. D, Ch. 6, Sec. 2 are identical to LR and are not presented.

In the same section RINA lists test standards to which laminate specimens of any type are to be tested, proposing same ISO tests as LR, but RINA includes ASTM alternatives as it is presented in *Table 3.5.17 Test standards for laminate specimens (RINA).*

Table 3.5. 17 Test standards for laminate specimens (RINA) [51,78,60,76,55,79]



Test	Standard
Tensile strength	• ISO 527-4 (speed= 2 mm/1' specimens Type II or III) • ASTM D 638
Flexural strength	• ISO 14125 (speed = t/2 mm/1') Method A • ASTM D 790
Compressive strength	• ISO 604 (speed= 1 mm/l') • ASTM D 695
Interlaminar shear	• ISO 14130 • ASTMD 3846
Water absorption	ASTM D 570 + ISO 62 Method 1
Glass content	ISO1172

RINA also, alike LR, gives minimum mechanical properties of laminates as a function of Gc (glass fraction by weight), but neither the types of fabrics that these values refer to are defined nor the units that correspond to the calculations, are defined. Probably the applying minimum values correspond to N/mm^2, since these are the mainly used units by RINA, which also provide reasonable results. Also it may be assumed that these minimum values apply to all type of fabrics, as there is no further indication.

Nevertheless the equations are not all that different compare to LR, which in RINA case, are matched with minimum property values, data of which are listed in *Table 3.5.18 Minimum property values for laminates (RINA).* Notice that the common property values between *Table 3.5.16 Laminates, minimum property requirements (LR)* referring to all types of material by LR and *Table 3.5.18 Minimum property values for laminates (RINA)* are almost identical.

Table 3.5. 18 Minimum property values for laminates (RINA)

R_m = ultimate tensile strength = $1278\ G_c^2 - 510\ G_c + 123$	85
E = tensile modulus of elasticity = $(37\ G_c - 4{,}75) \cdot 10^3$	6350
R_{mc} = ultimate compressive strength = $150\ G_c + 72$	117
E_c = compressive modulus of elasticity = $(40\ G_c - 6) \cdot 10^3$	6000
R_{mf} = ultimate flexural strength = $(502\ G_c^2 + 107)$	152
E_f = flexural modulus of elasticity = $(33{,}4\ G_c^2 + 2{,}2) \cdot 10^3$	5200
R_{mt} = ultimate shear strength = $80\ G_c + 38$	62
G = shear modulus oe elasticity = $(1{,}7\ G_c + 2{,}24) \cdot 10^3$	2750
R_{mti} = ultimate interlaminar shear strength = $22{,}5 - 17{,}5\ G_c$	17

3.5.7 Conclusion (L)

During the design phase, the theoretical procedure, indicated by BV, should be especially practical, as it gives the opportunity to the shipbuilder or the engineer to immediately estimate mechanical characteristics of products of various rovings, fibre types and resins. While for survey purposes DNV-GL, LR and RINA would be more useful providing thorough information on material tests. LR and RINA are more explicit on test procedures, while DNV-GL makes distinct remarks depending on the fibre type of the laminate. Lastly, ABS provides the most compact information on the matter, but manages to include test, indicative property values and an equation for calculating the average cured laminate thickness for mat or woven rovings.

To illustrate the discrepancies of the minimum and theoretical mechanical properties of a layer (or laminate), as suggested by each society, line graphs are presented below, of properties and materials that the classification societies have in common. The graphs contain information on tensile, compressive, shear and interlaminar shear strength and the corresponding modulus of elasticity, except the interlaminar shear modulus of elasticity, as it given only by BV.

The examined materials are of glass fibre and carbon fibre reinforcement. As regards glass reinforced materials, minimum properties values are provided by LR and RINA, requirements given in *Table 3.5.16 Laminates, minimum property requirements (LR)* and *Table 3.5.18 Minimum property values for laminates (RINA)*, respectively. While, for products of carbon fibre reinforcement information on the minimum mechanical properties has been extracted from *Table 3.5.4 Laminate properties (ABS)* and *Table 3.5.8 Acceptance criteria of laminates with carbon fibre reinforcements (DNV-GL)*, as given by ABS and DNV-GL respectively. In addition, as the methodology on calculating theoretical breaking stresses of a single layer, described in *3.5.2 Bureau Veritas (L),* covers a wide variety of individual layers, BV indications for both glass and carbon fibre reinforcement are used for comparison.

It should be mentioned that use of sec. 5 of *Hull in Composite Materials and Plywood, Material Approval, Design Principles, Construction and Survey (November 2018)* is necessary, in order to obtain the values of the theoretical breaking stresses. Relevant moduli of elasticity have been calculate according to that section as well. Furthermore, considering the calculation instruction of BV, the following assumptions have been made:

- Total mass per square meter of dry reinforcement fabric equal to 450 g/m^2, for all fabrics
- The woven roving products have been calculated as balanced, C_{eq}=0,5. Where C_{eq} is the woven balance coefficient and equals to the mass ratio of dry reinforcement in warp direction to the total dry reinforcement of woven fabric.

Moreover, the fibre fraction ranges by weight for each roving under inspection are given in *Table 3.5.19 Fibre fraction by weight in per cent (%).*

Table 3.5. 19 Fibre fraction by weight in per cent (%)

	CSM	WR	UD
Glass	20 – 35	35 – 60	50 – 70
Carbon	NA	35 – 55	45 – 65

Firstly, the comparison of glass reinforced materials among BV, LR and RINA is presented. The minimum property requirements of LR does not refer to a certain resin or reinforcement type and are set side by side with relevant BV instructions for E-glass polyester layer and RINA requirements, which refer to E-glass type reinforcement. E-glass polyester layer where chosen as is the most common combination of material and it is widely used for construction purposes. Also, LR and RINA give comparable properties to BV E-glass polyester materials.

Relevant comparison line graphs of mechanical properties depending in glass fraction by weight are given in *Figure 3.5. 2 Tensile Strength of glass polyester layer, Figure 3.5. 3 Tensile Modulus of elasticity of glass polyester layer, Figure 3.5. 4 Compressive Strength of glass polyester layer, Figure 3.5. 5 Compressive Modulus of elasticity of glass polyester layer, Figure 3.5. 6 Shear Strength of glass polyester resin, Figure 3.5. 7 Shear Modulus of elasticity of glass polyester layer* and *Figure 3.5. 8 Interlaminar Shear Strength of glass polyester layer*.

To remind computations for Figure 3.5. 2 Tensile Strength of glass polyester layer involve tensile strength given as a function of glass fraction by weight by RINA for any type of roving. Similar calculations are also given by LR, but using different function depending on the type of reinforcement. Considering Chopped Strand Mat (CSM) and Woven Roving (WR) types, the tensile strength does not present great discrepancies among the societies, LR and RINA even give equal values in certain cases.

While between LR and RINA there is still no significant deviation concerning Unidirectional (UD) roving, especially for greater values of glass fraction, BV indications on theoretical tensile breaking stress result to values greater 110% to 180%, comparing to their requirements.

Comments made in the two previous paragraphs apply to Figure 3.5. 3 Tensile Modulus of elasticity of glass polyester layer, as well. Also it should be noted that for values of glass fraction equal to 0,50 to 0,60, the LR woven roving present greater modulus of elasticity compared to LR unidirectional layer. Also, the minimum tensile modulus of elasticity, suggested by RINA, equals to 6350 N/mm^2, so values below that point may be not taken into consideration.

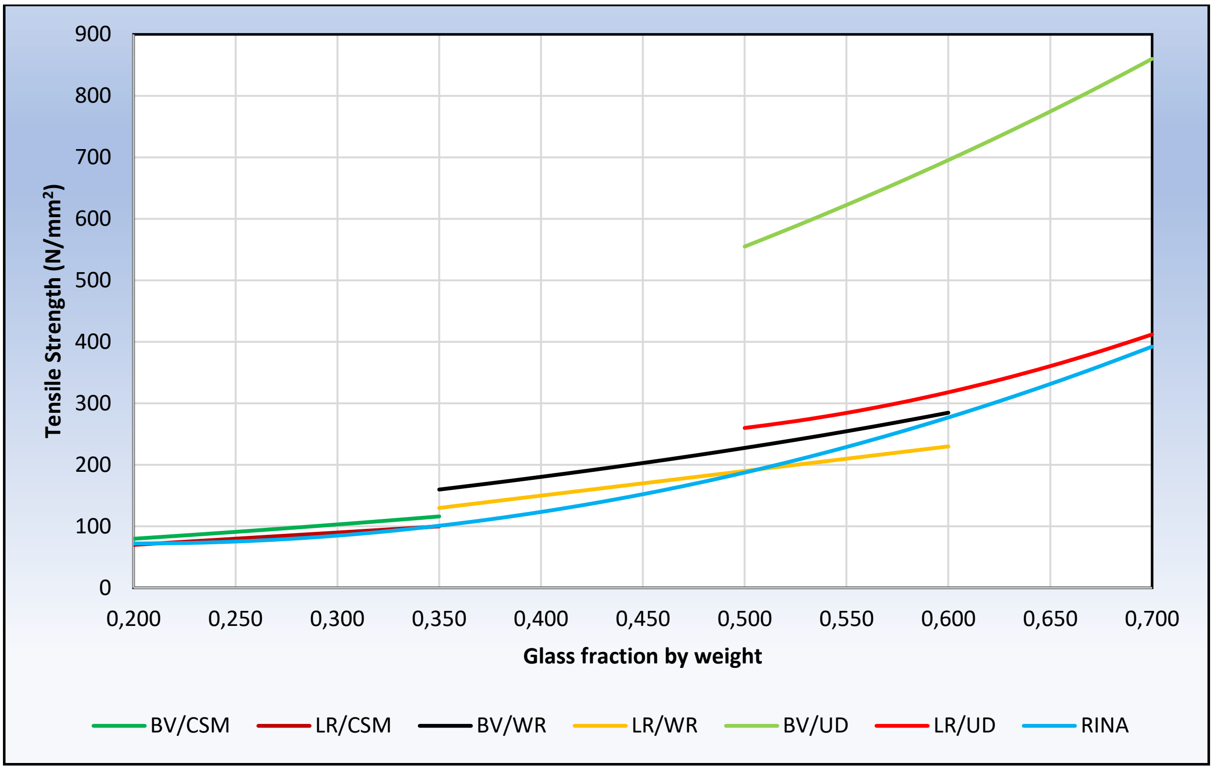


Figure 3.5. 2 Tensile Strength of glass polyester layer

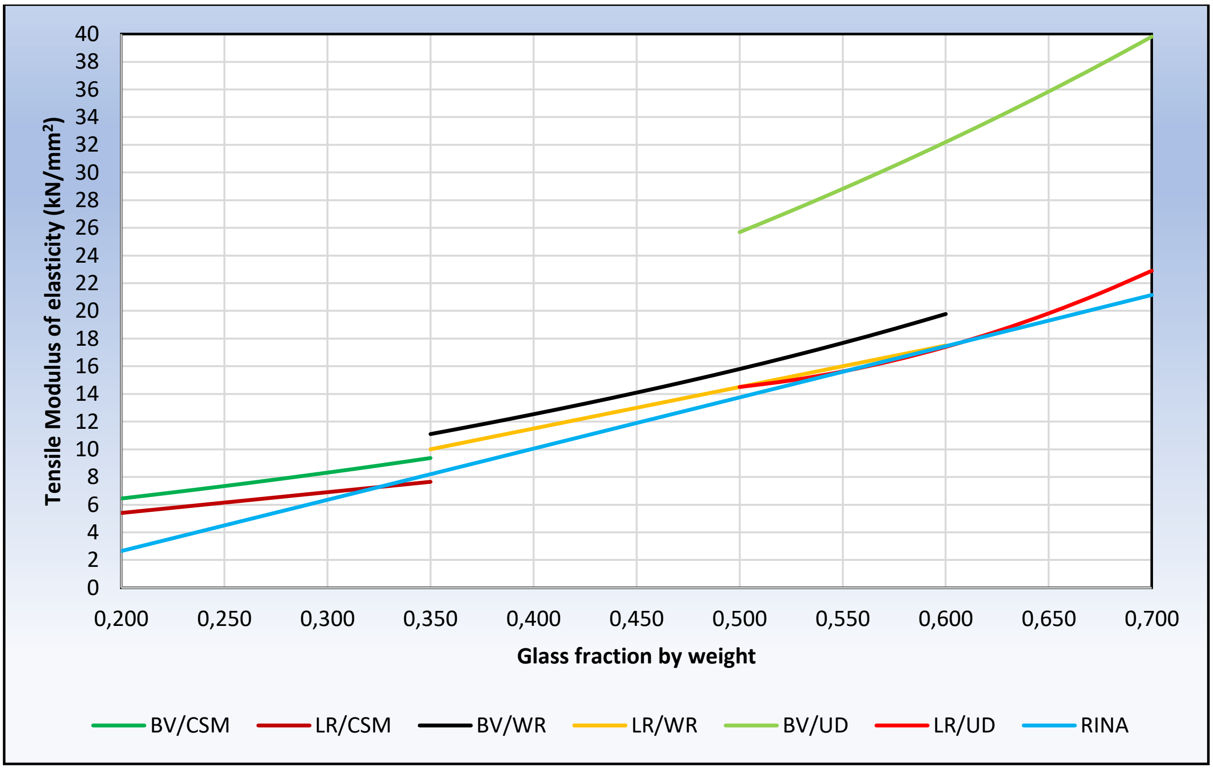


Figure 3.5. 3 Tensile Modulus of elasticity of glass polyester layer

As shown in *Figure 3.5. 4 Compressive Strength of glass polyester layer*, LR and RINA suggest identical function on computing compressive strength for general reinforcement type, which result to greater compressive strength for glass fraction ranges that refer to CSM. However, BV polyester woven roving is slightly stronger, especially for lower values of glass fraction, than LR and RINA. The BV unidirectional is even 2,5 times stronger than the LR and RINA corresponding values. Also, the minimum compressive strength equals to 117 N/mm^2, considering RINA.

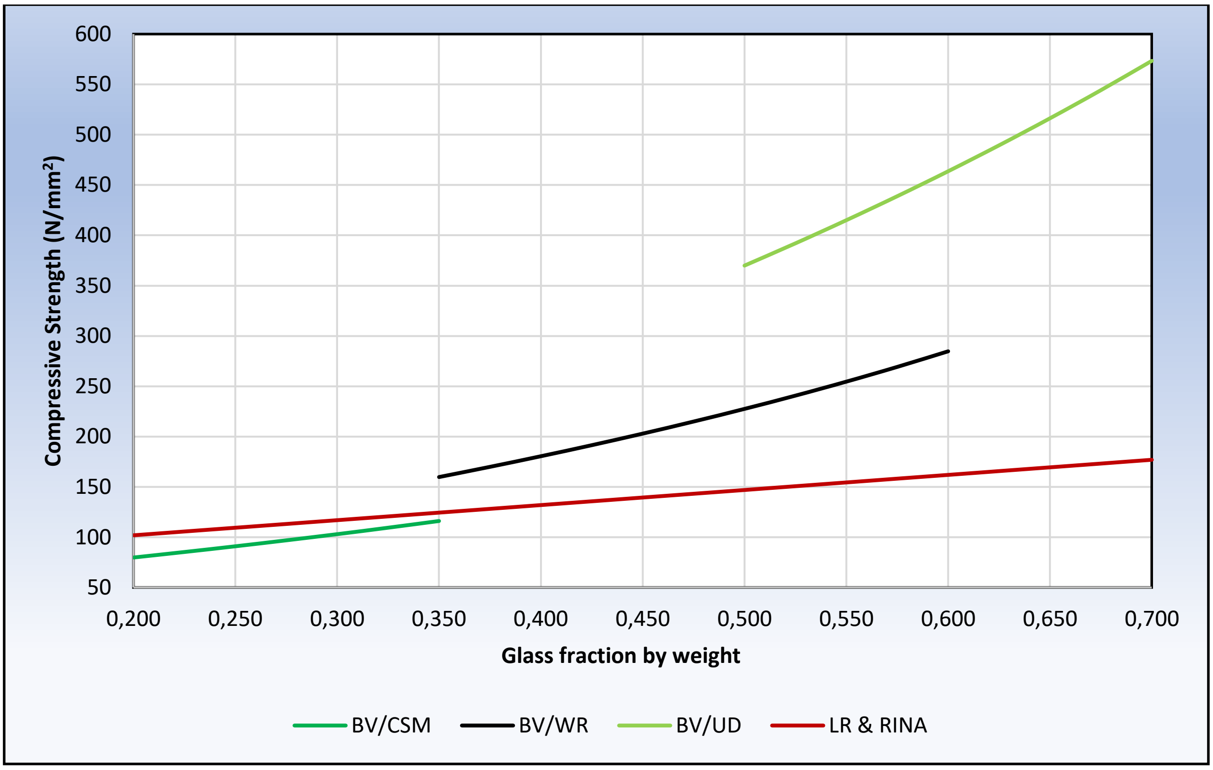


Figure 3.5. 4 Compressive Strength of glass polyester layer

LR and RINA provide identical minimum compressive modulus of elasticity functions, which result to lower values than relevant BV guidelines. The increase of compressive modulus of elasticity, among the BV reinforcement types, as shown in *Figure 3.5. 5 Compressive Modulus of elasticity of glass polyester layer*, is analogous to the increase of the compressive strength. In addition, note that BV guidelines indicate equal moduli of elasticity for tension and compression. The minimum compressive modulus of elasticity equals to 6000 N/mm^2, considering RINA.

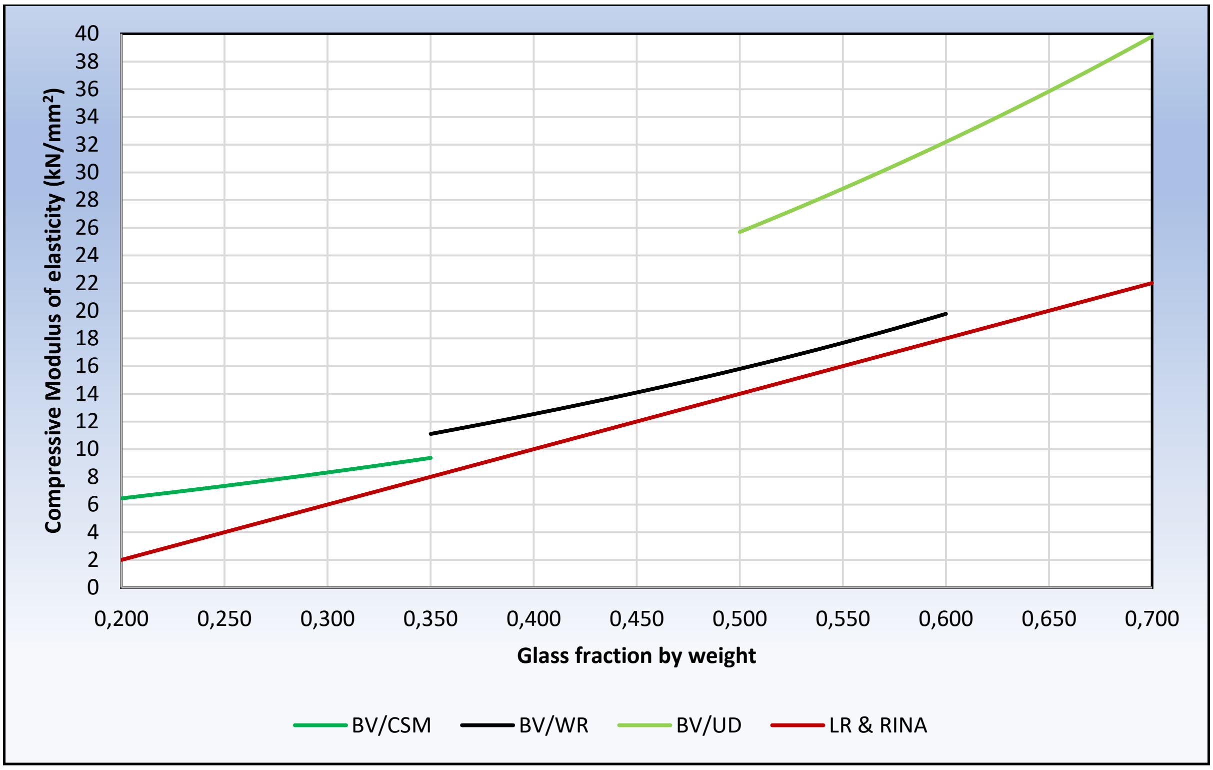


Figure 3.5. 5 Compressive Modulus of elasticity of glass polyester layer

As regards shear strength and relevant modulus of elasticity, LR does not set requirements on its minimum values, in contrast with BV and RINA, whose guidelines are compared in *Figure 3.5. 6 Shear Strength of glass polyester resin* and *Figure 3.5. 7 Shear Modulus of elasticity of glass polyester layer.* As shown in the referenced figures, RINA minimum values result to better shear properties than the theoretical computation of BV indicates. The only exception is the CSM of BV, which presents greater shear modulus of elasticity for most of the glass fraction by weight values, see *Figure 3.5. 7 Shear Modulus of elasticity of glass polyester layer*.

Note that the minimum shear strength and modulus of elasticity, suggested by RINA, equals to 62 N/mm^2 and 2750 N/mm^2, respectively, so values below those points may be not taken into consideration.

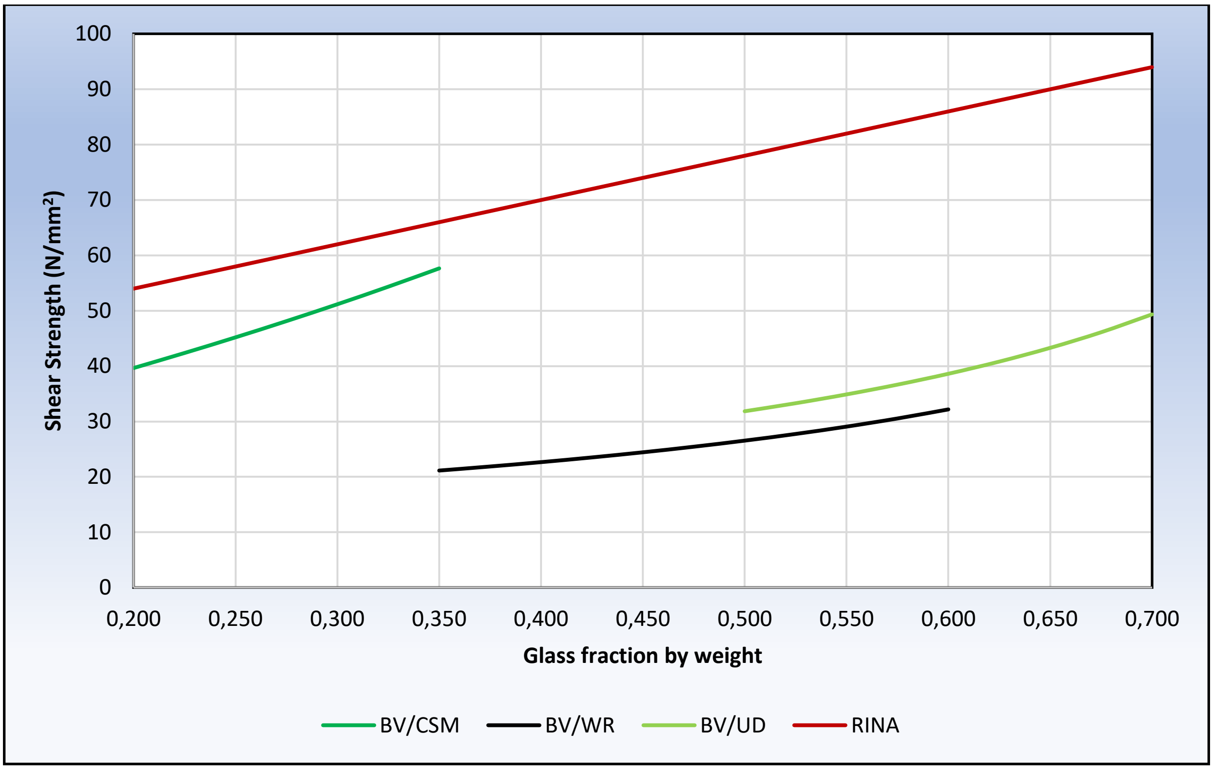


Figure 3.5. 6 Shear Strength of glass polyester resin

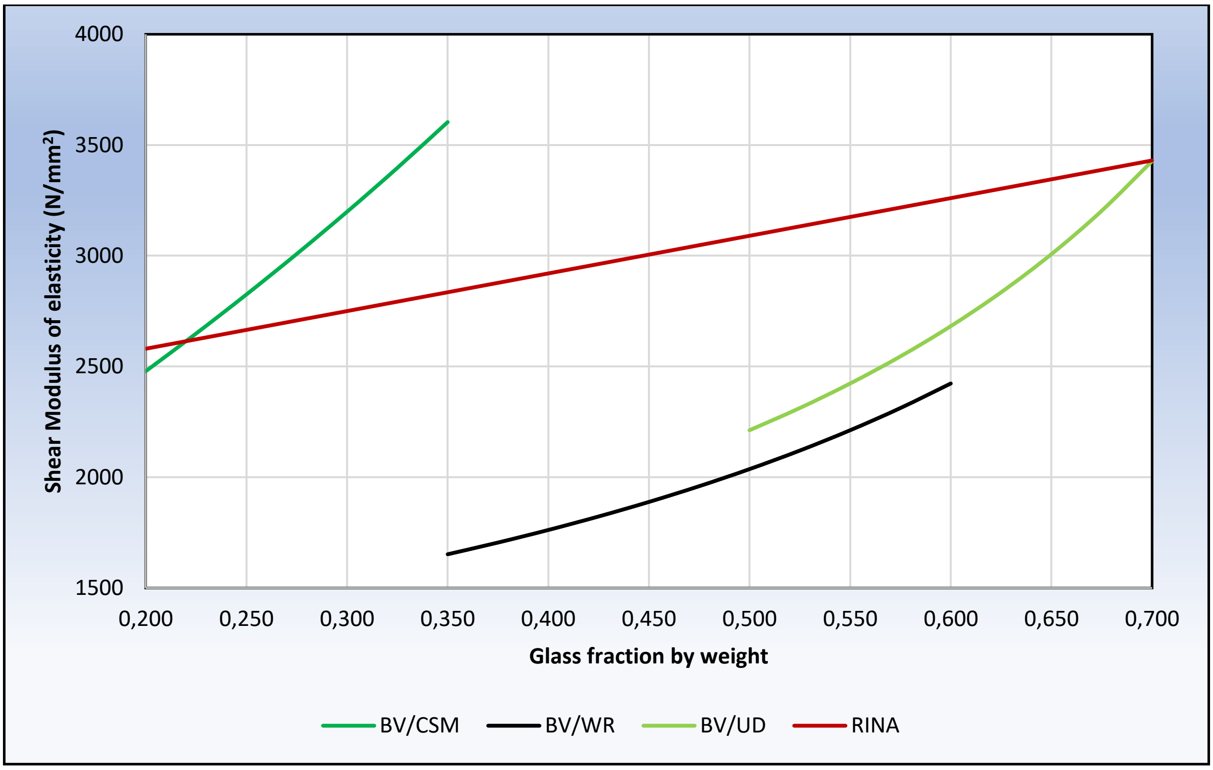


Figure 3.5. 7 Shear Modulus of elasticity of glass polyester layer

The last figure that refer to glass polyester layer is *Figure 3.5. 8 Interlaminar Shear Strength of glass polyester layer*, and its name reveal, it concern interlaminar shear strength. Interesting is the fact that LR and RINA equations as function of glass fraction by weight are declining, while BV theoretical interlaminar break stress is increasing for greater values of glass fraction for all the types of reinforcement. Also, in contrary with the previously discussed shear properties, CSM presents lower interlaminar shear strength, comparing the BV types of reinforcement. The minimum compressive strength equals to 15 N/mm^2 and 17 N/mm^2, considering LR and RINA, respectively.

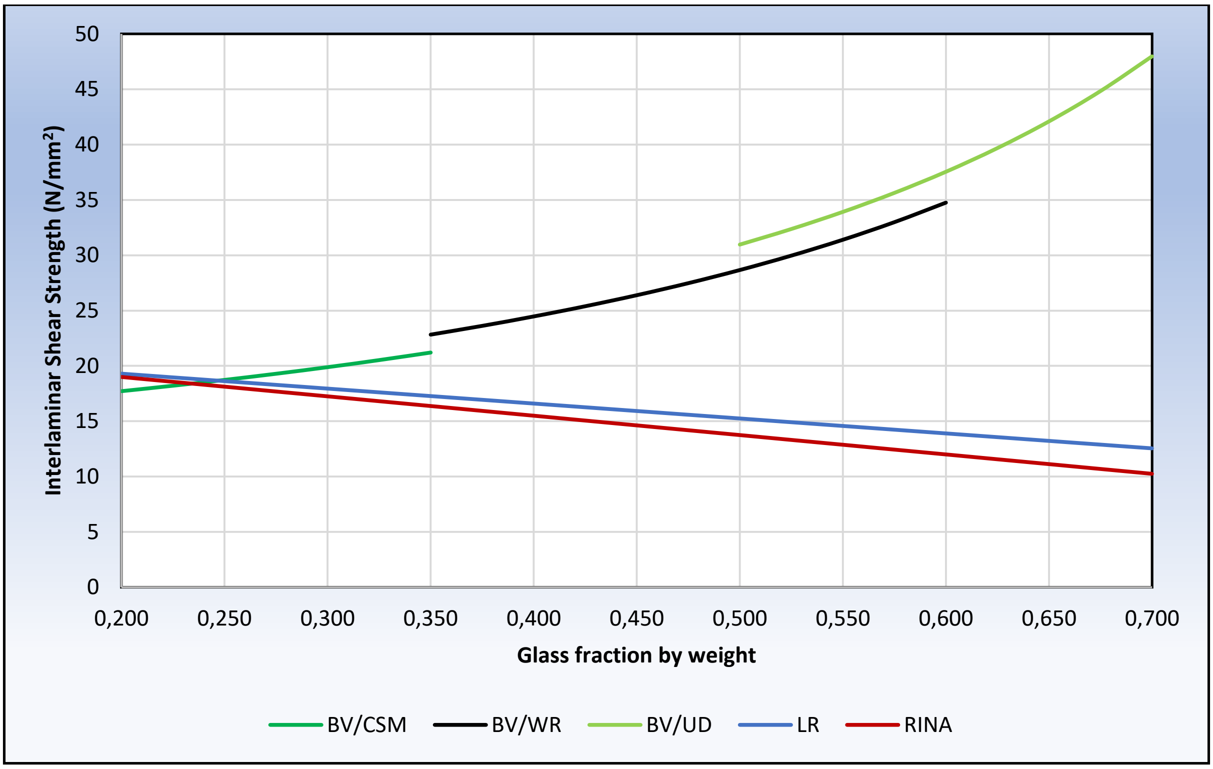


Figure 3.5. 8 Interlaminar Shear Strength of glass polyester layer

Since the methodology to determine the theoretical breaking stresses of an individual layers, as given in *Hull in Composite Materials and Plywood, Material Approval, Design Principles, Construction and Survey (November 2018)*, applies to various combinations of products, it makes it possible to study the perspective of BV about the influence of the resin type on the mechanical properties of a glass reinforced layer.

The reinforcement types and the glass fraction by weight ranges, which are under inspection, are the same as in the previous comparison and are given in *Table 3.5. 19 Fibre fraction by weight in per cent (%)*. E-glass type of fibre properties are used as well as the mechanical characteristics of polyester, vinylester and epoxy resins, as given in *Table 3.2. 1 Mechanical properties of fibres (BV), Table 3.3. 1 Mechanical characteristics of resins (BV)* and *Table 3.5. 2 Theoretical breaking strains, in % (BV)*. Further calculation and use of the instructions given in section 5 of *Hull in Composite Materials and Plywood, Material Approval, Design Principles, Construction and Survey (November 2018)*, are necessary.

The use of epoxy resin seem to increase the tensile strength of all the reinforcement types, also vinylester material are slightly stronger than polyester as shown in *Figure 3.5. 9 Tensile Strength of BV glass reinforced layers*. Similar improvements is observed on the compressive strength as indicated by *Figure 3.5. 11 Compressive Strength of BV glass reinforced layers*.

However, the polyester CSM and WR have the greatest tensile moduli of elasticity, compared to vinylester and epoxy layers, see *Figure 3.5. 10 Tensile/Compressive Modulus of elasticity of BV glass reinforced layers*. Epoxy resin layers have superior modulus of elasticity among the UD types and generally vinylester layers stiffness is the lowest. As mentioned before, BV guidelines indicate equal moduli of elasticity for tension and compression.

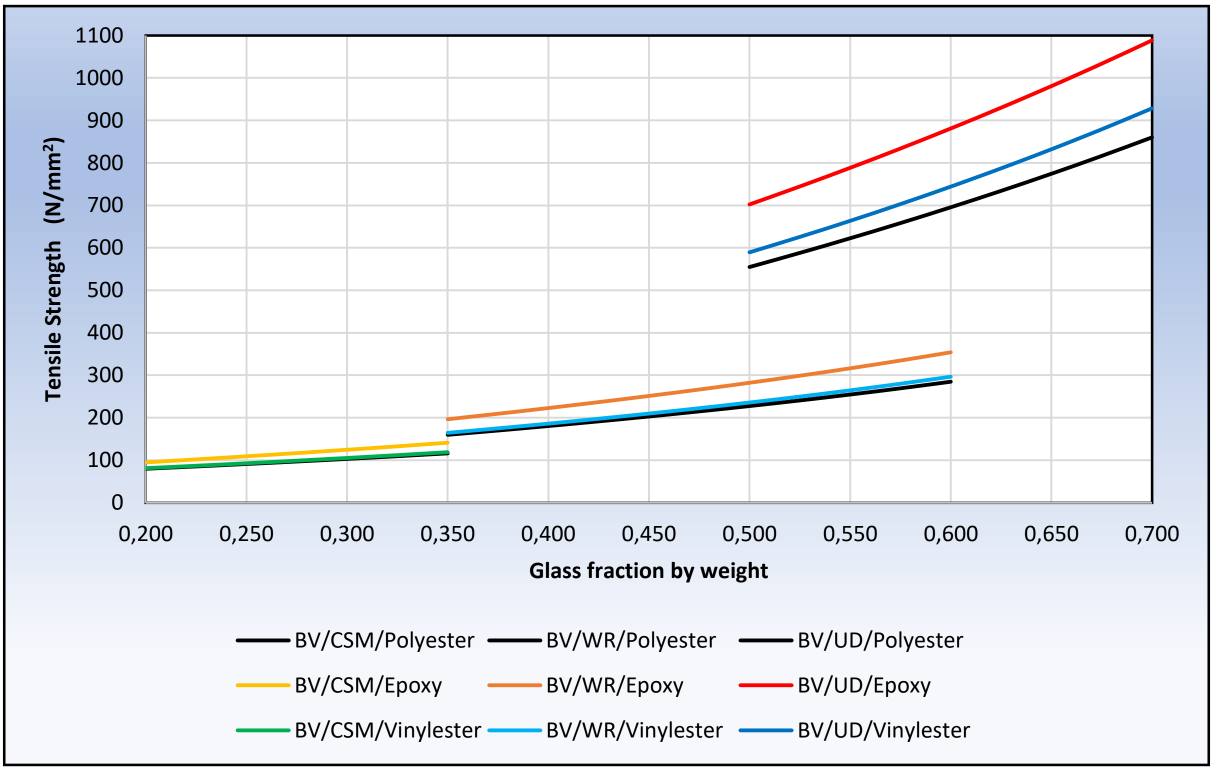


Figure 3.5. 9 Tensile Strength of BV glass reinforced layers

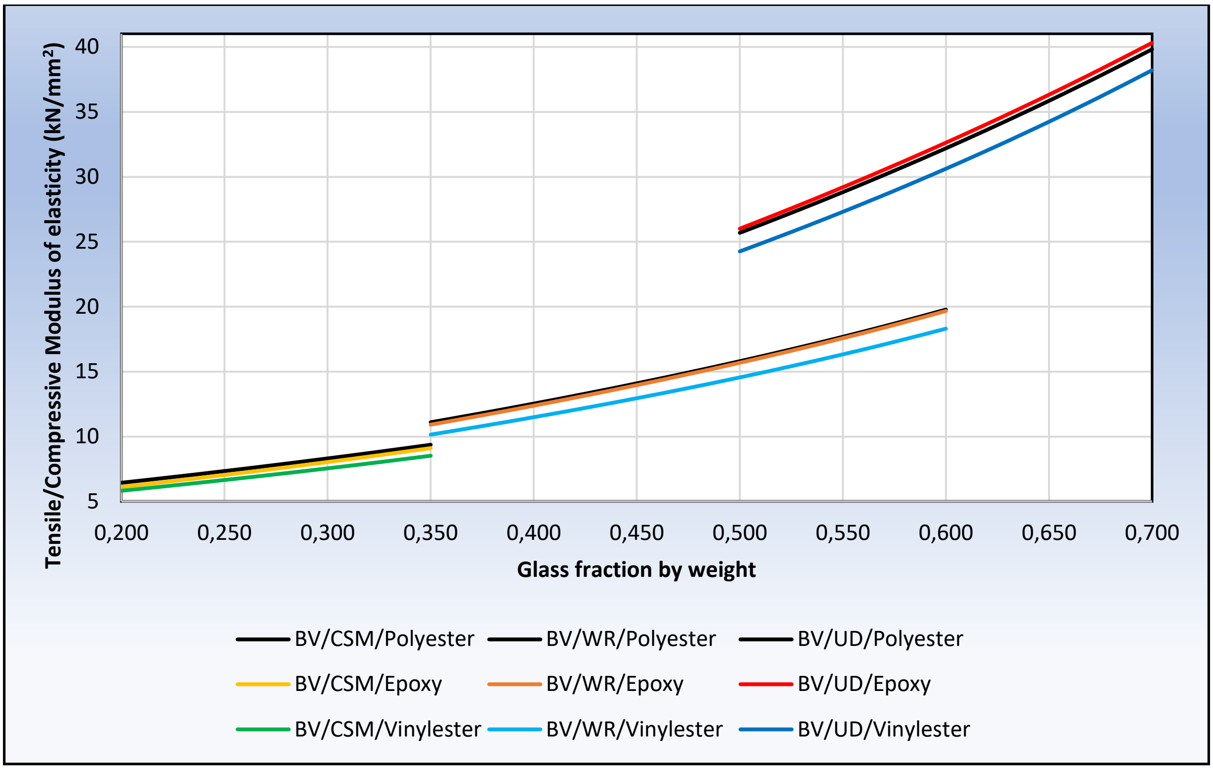


Figure 3.5. 10 Tensile/Compressive Modulus of elasticity of BV glass reinforced layers

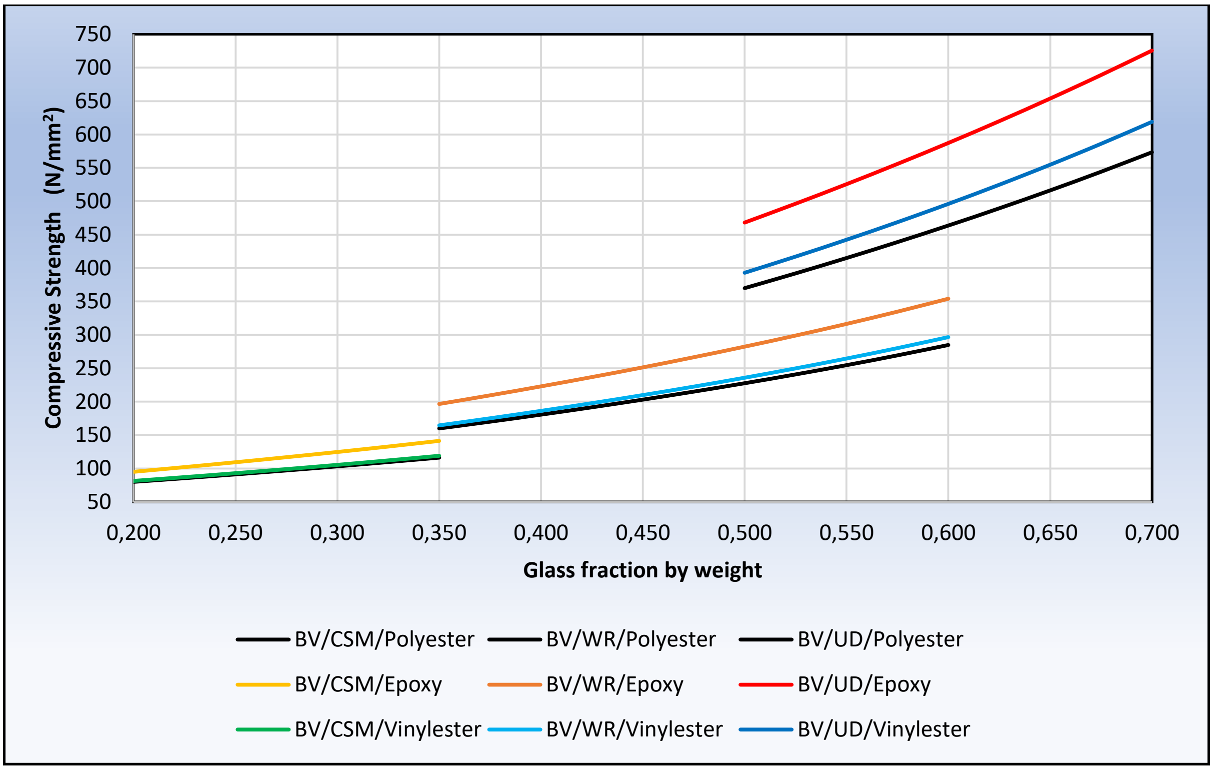


Figure 3.5. 11 Compressive Strength of BV glass reinforced layers

Alike tensile and compressive properties, epoxy resin layer have enhanced shear and interlaminar shear strength. As indicated by *Figure 3.5. 12 Shear Strength of BV glass reinforced layers* and *Figure 3.5. 14 Interlaminar Shear Strength of BV glass reinforced layers*, epoxy WR layers present better shear and intelaminar shear strength even than vinylester and polyester UDs.

The computations, given in of *Hull in Composite Materials and Plywood, Material Approval, Design Principles, Construction and Survey (November 2018),* Sec. 5, indicate same shear moduli of elasticity for WR and UD, which is also visible in *Figure 3.5. 13 Shear Modulus of elasticity of BV glass reinforced layers.* Also, while epoxy resins obviously result to greater moduli of elasticity, is not equally clear whether polyester or vinylester resin layer show higher shear stiffness. As the referenced figure indicates, in UD glass fraction by weight ranges, polyester layers are superior to vinylester, while the opposite applies for WR reinforcement types of lower glass content.

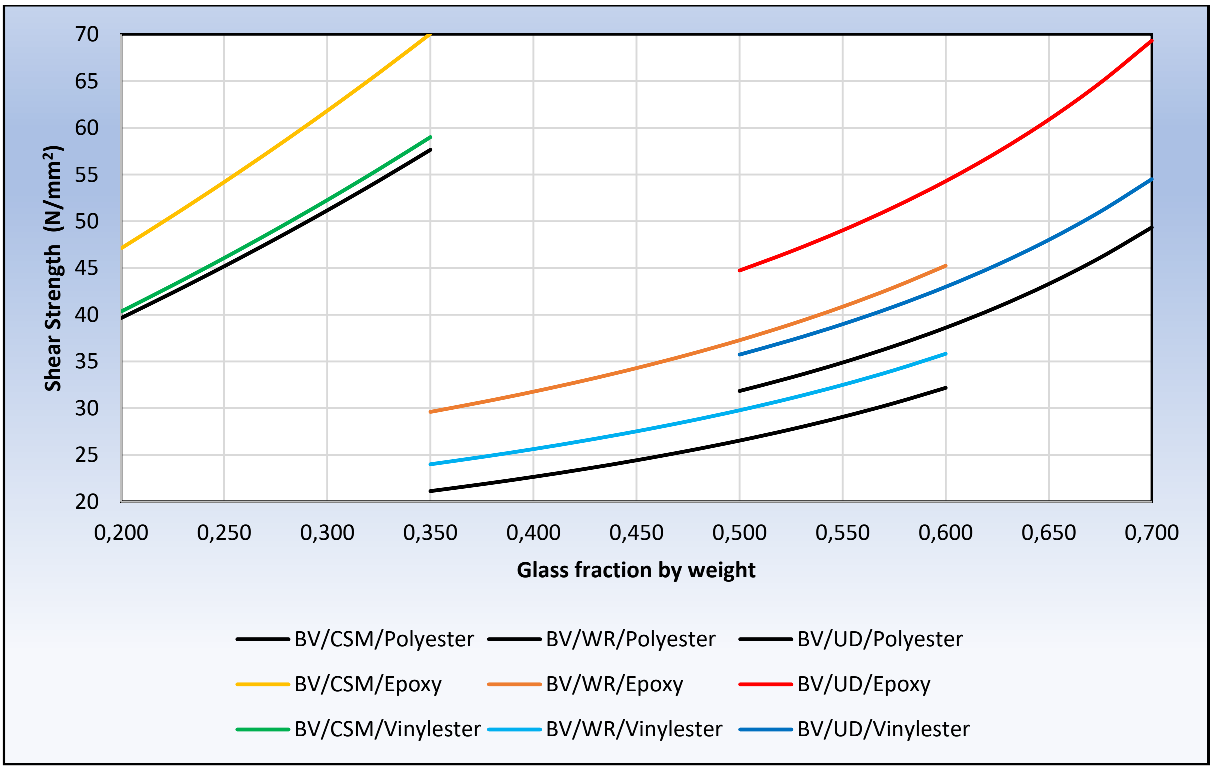


Figure 3.5. 12 Shear Strength of BV glass reinforced layers

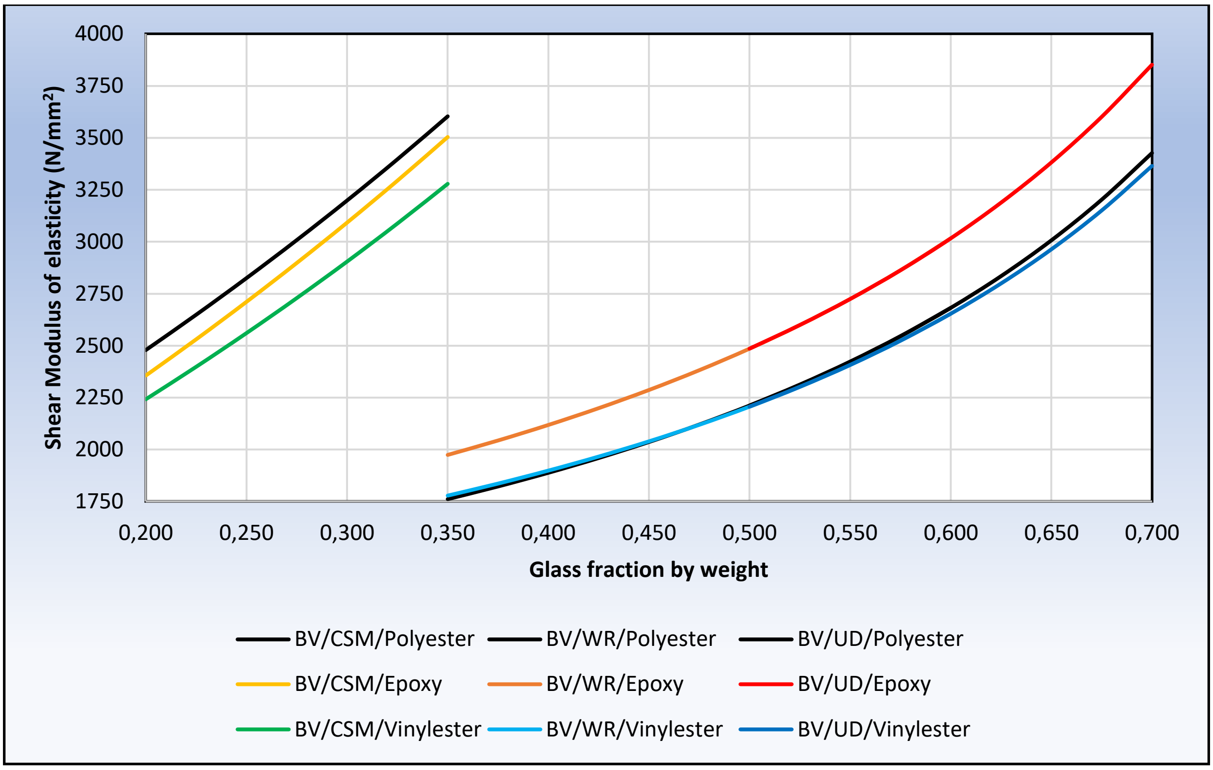


Figure 3.5. 13 Shear Modulus of elasticity of BV glass reinforced layers

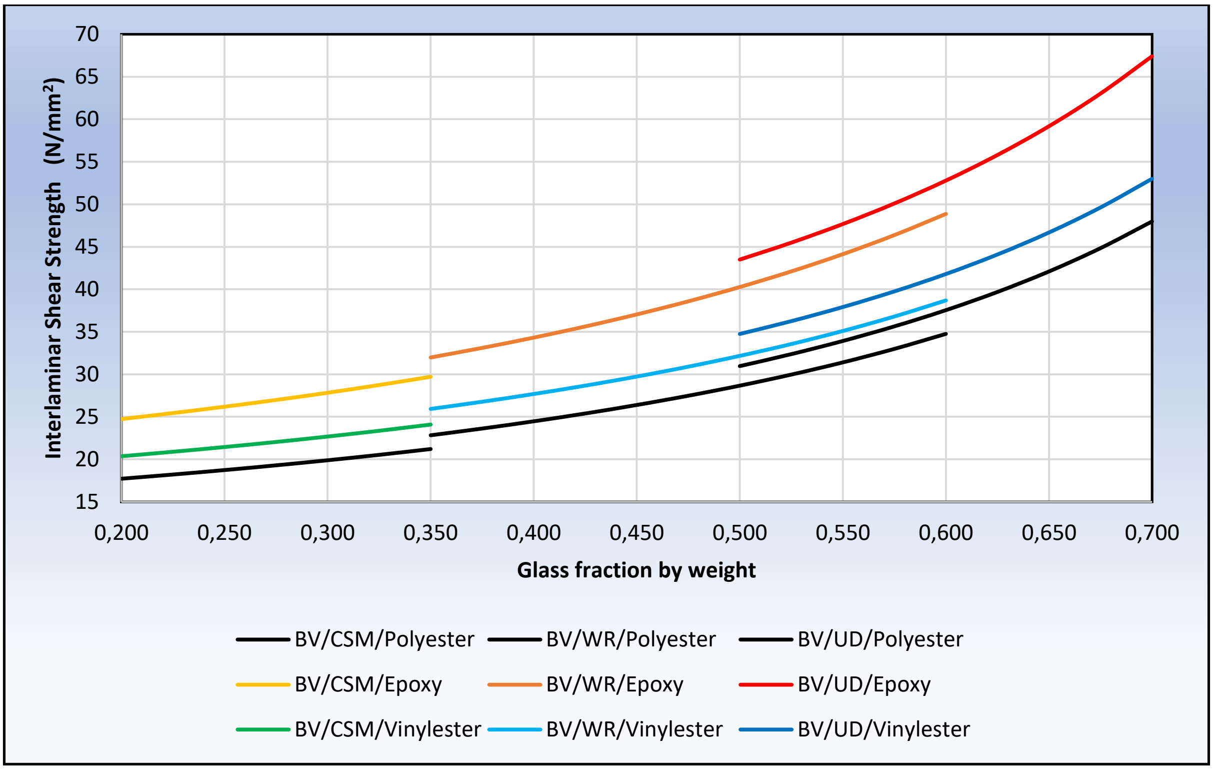


Figure 3.5. 14 Interlaminar Shear Strength of BV glass reinforced layers

Before the next comparison is presented, there are certain details that should be reminded. ABS and DNV-GL do not provide any equation, but rather give the minimum values of the mechanical properties, hence their date are figured as a straight line parallel to the carbon fraction by with axis. The minimum values that are indicated by DNV-GL in *Table 3.5. 8 Acceptance criteria of laminates with carbon fibre reinforcements (DNV-GL)* refer to laminates with carbon fraction by weight equal to 0,50 ± 0,05 and vary depending to the type of reinforcement. ABS does not specify neither the type of reinforcements neither nor the a carbon fraction by a weight value.

As regards the calculations of BV, the aforementioned methodology was used as in the previous comparison, and are applied for High Strength (HS), Intermediate Modulus (IM) and High Modulus (HM) carbon reinforcements. Also, epoxy resin is chosen, because it is the type of resin that is mainly used to work with carbon, and is one of the few materials that can adhere to carbon fiber. As mentioned in *3.5.4 Det Norske Veritas - Germanischer Lloyd (L),* DNV-GL suggests that even sizings based on epoxy resin are necessary for testing of carbon fibre reinforced materials.

In the next figure, *Figure 3.5. 15 Tensile Strength of carbon reinforced layers*, the aforementioned date have been gathered. The IM layers of BV has the greatest tensile strength amongst unidirectional laminates and HS are the second greatest. For lower values of carbon fraction by weight, DNV-GL unidirectional laminates surpass HS/UD at tensile strength, but for higher values is less strong that HM/UD. This means that for certain carbon fraction values DNV-GL minimum values equal BV theoretical breaking tensile stress, once with the HM and once with HS values.

Moreover, considering woven roving layers, the HS and IM layers present the same tensile strength and this is why BV/WR/HS line is not visible, it has been overlaid by BV/WR/IM line. This line is intersected by the minimum tensile strength, as suggested by ABS, close to median value. Lastly, DNV-GL requirements indicate stronger WR than the other societies, while BV HM is again the least strong layer.

Subsequently, the tensile and compressive moduli of elasticity of carbon layers are presented in a common figure, see *Figure 3.5. 16 Tensile/Compressive Modulus of elasticity of carbon reinforced layers*. These properties are presented commonly because the methodology of indicates same moduli for tensile and compression, as mention in the glass layers comparisons. In addition, it should be noted that ABS requirements are presented with one line as the tensile and compressive modulus of elasticity are equal to 43800 N/mm^2 and 43700 N/mm^2, respectively, and the difference would not be visible in that scale. Also, DNV-GL and ABS properties that refer to tension are marked with T and compression properties are marked with C.

Also , as their acronym indicate, HM and IM are indeed the layers with the highest and the intermediate tensile/compressive modulus of elastic, amongst BV material, in terms of WR and UD. DNV-GL requirements present similar characteristics with BV/HS materials, as the DNV-GL tensile and compression lines intersect the corresponding BV/HS lines, in terms of WR and UD. ABS values are lowers than DNV-GL, and are equal with BV/WR/HS tensile/compressive modulus of elasticity, for lower carbon fraction by weight values.

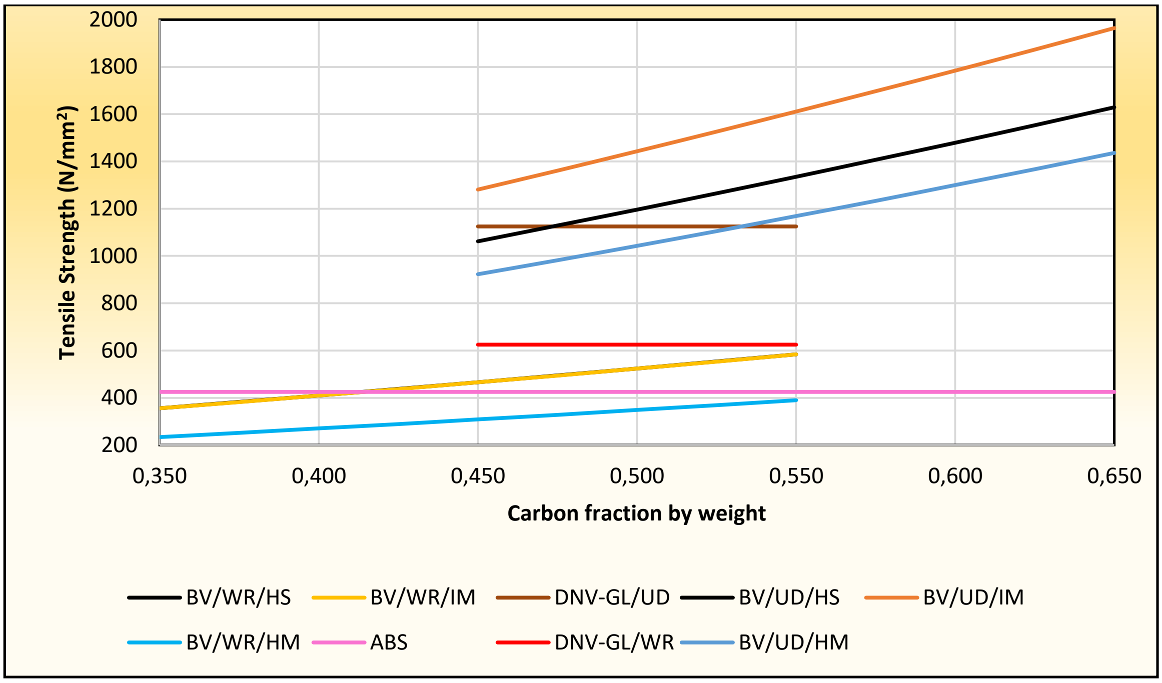


Figure 3.5. 15 Tensile Strength of carbon reinforced layers

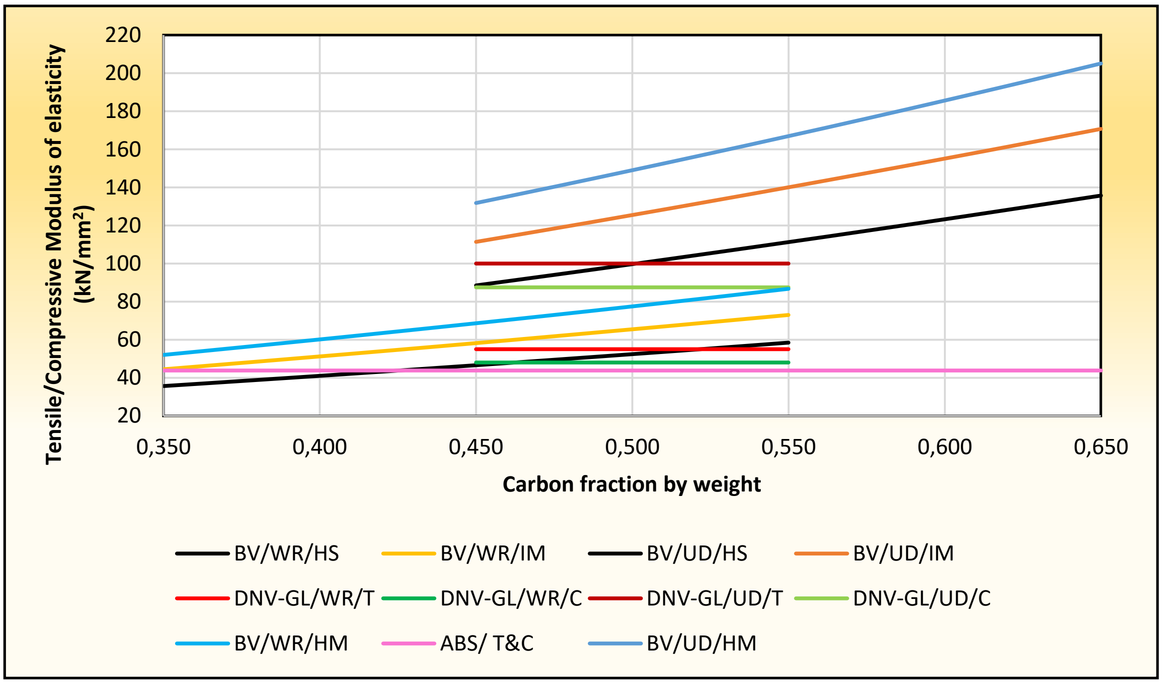


Figure 3.5. 16 Tensile/Compressive Modulus of elasticity of carbon reinforced layers

The next diagram refer to the compressive strength of the carbon reinforced layers. As shown in *Figure 3.5. 17 Compressive Strength of carbon reinforced layers*, HS are indeed the strongest layers, but that applies only to UDs, as woven rovings with IM carbon fibres present greater strength than HS for this type of reinforcement. DNV-GL requirements values are quite similar to BV calculated values, especially concerning HM and HS of WR type. ABS minimum property value is the lowest, although it equals BV/WR/HM for lower values of carbon fraction, even surpass it.

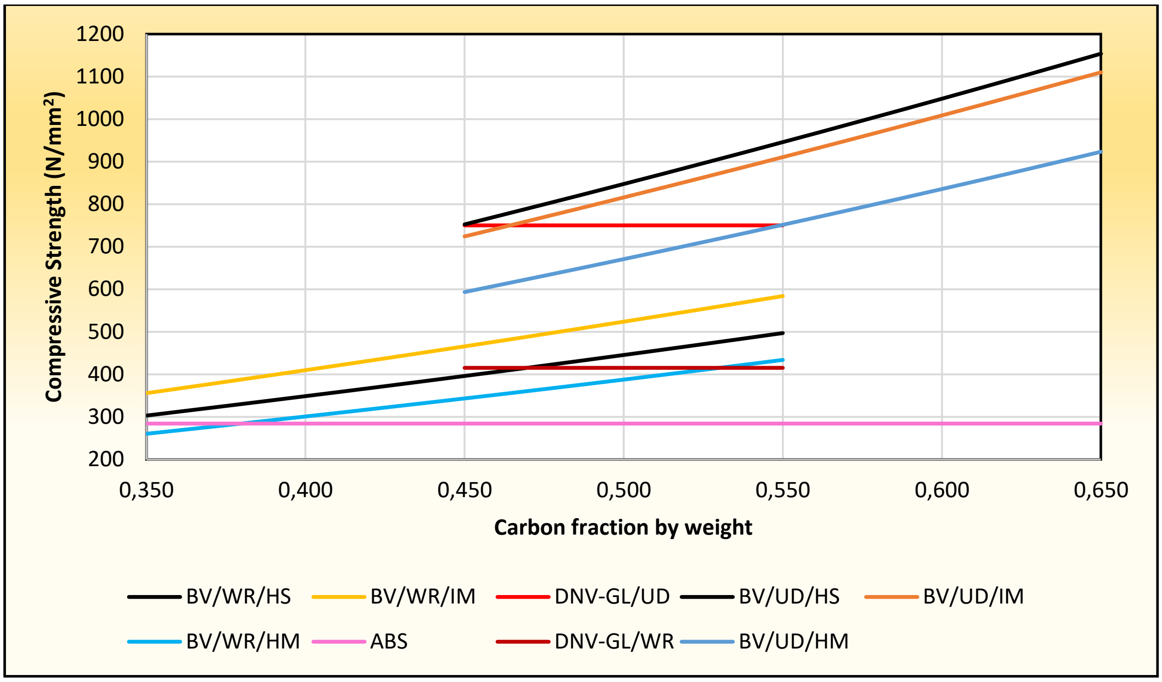


Figure 3.5. 17 Compressive Strength of carbon reinforced layers

In *Figure 3.5. 18 Shear Strength of carbon reinforced layers,* the gradation among BV materials is similar for WR and UD, as the shear strength of HM is greater than IM and IM is greater than HS. Interesting is the fact WR/HM presents greater strength than UD/HM for equal carbon fraction by weight values, while this does not apply to IM and HS types of fibre.

As mentioned before, the computations, given in of *Hull in Composite Materials and Plywood, Material Approval, Design Principles, Construction and Survey* (November 2018), Sec. 5, indicate same shear moduli of elasticity for WR and UD. In terms of fibre type, layers with HM fibres have the greatest shear modulus of elasticity and IM the lowest.

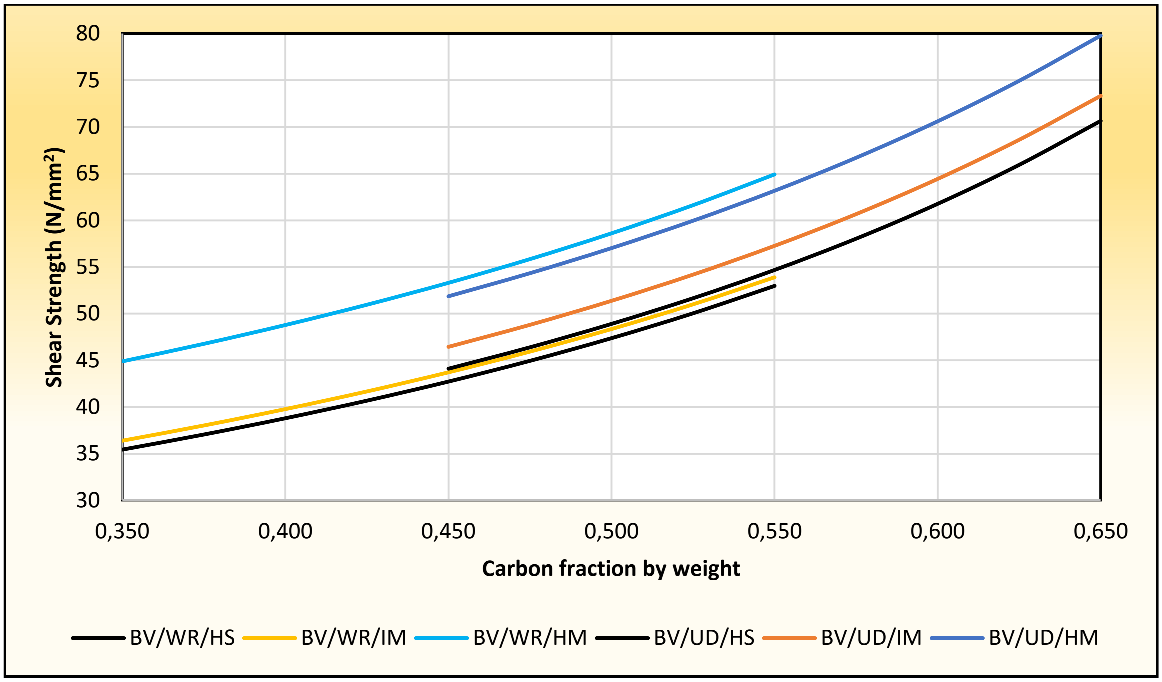


Figure 3.5. 18 Shear Strength of carbon reinforced layers

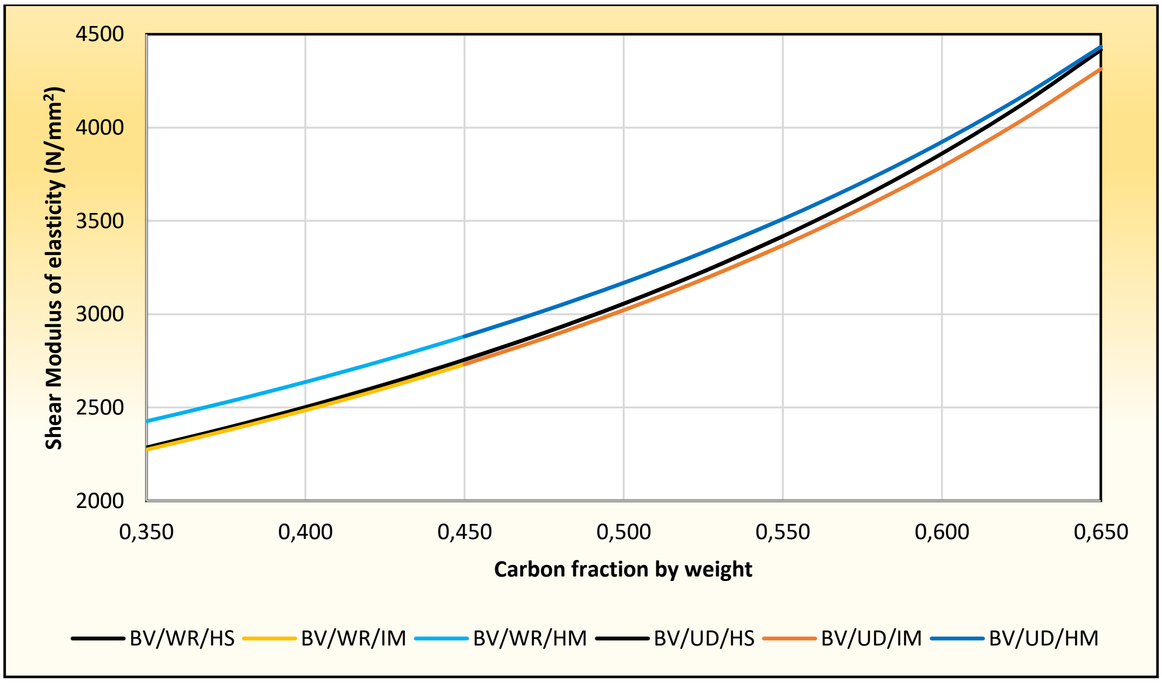


Figure 3.5. 19 Shear Modulus of elasticity of carbon reinforced layers

The final graph, reveals that carbon reinforced woven roving has in general better interalminar strength qualities, according to BV, as the least strong WR, HS, has greater interlaminar shear strength than the strongest UD, HS. Note also that WR/IM the interlaminar shear strength values is about 80% higher than the second strongest woven roving, WR/IM.

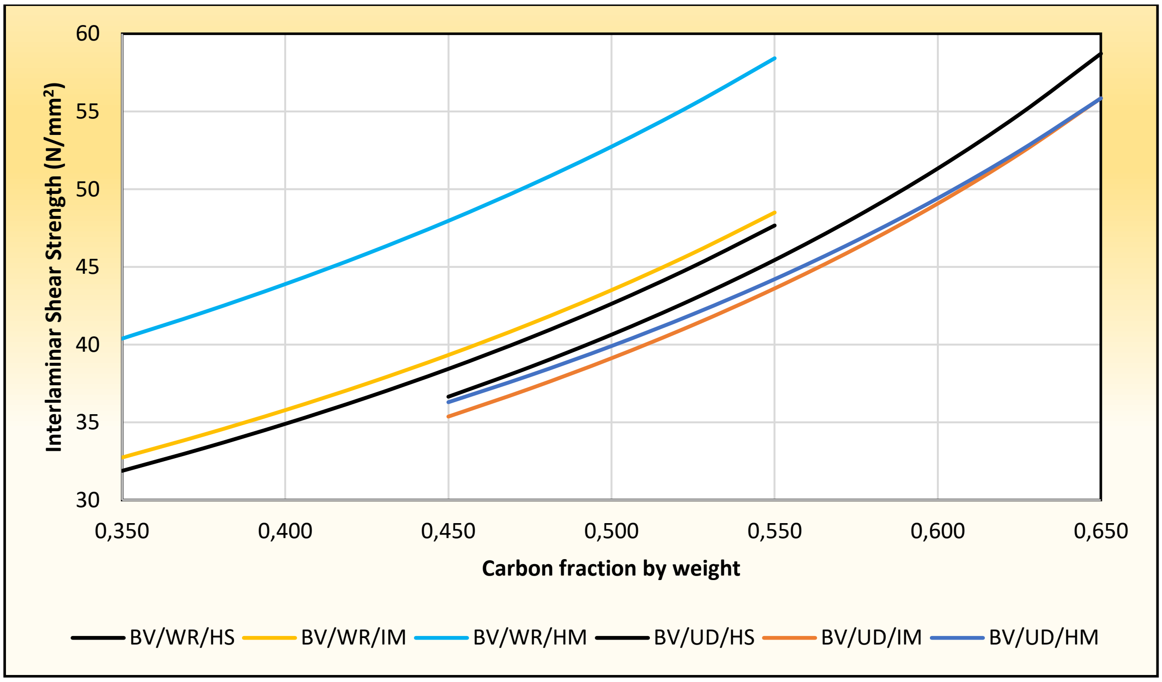


Figure 3.5. 20 Interlaminar Shear Strength of carbon reinforced layers

Chapter

4 Design Loads of Small Crafts

Section

4.1 Introduction

4.1.1 Scope

The ability to estimate the loads that are going to act on various regions of a craft is a valuable tool in the hands of a naval engineer as it would assist the construction planning during design. By knowing, even approximately, the design loads, the engineer could make adjustments, such as changing the thickness plating or the material to be used, in order for his designs to result in a structure that serve better its purpose.

The present chapter has as purpose to explore the design loads of High-Speed Crafts (HSC) and Yachts as given by the five classification societies; LR, ABS, BV, DNV-GL and RINA. The rules and regulations presented by each society are compared, not only regarding the regions included, but also regarding the parameters that are depended on. Furthermore the similarities and differentiations among them will be investigated and an attempt will be made in order to conclude on which society provides the most conservative results.

Apart from one section dedicated to HSC, there will be two sections that divide yachts in two categories: Planing/Semi-Planing Yachts and Displacement/Sailing Yachts. The reason lies on the fact that the same distinction is made by most of the classification societies by presenting common or similar requirements for each category.

Moreover it is worth noticing that throughout this thesis the notation of planing and semi-planing crafts apply to a general category of crafts operating in the non-displacement mode, in which the normal operational regime of the craft when non-hydrostatic forces substantially or predominantly support the weight of the craft. On the contrary sailing and displacement crafts requirements apply to the category of crafts operating in the displacement mode, in which, whether at rest or in motion, the weight of the craft is fully or predominantly supported by hydrostatic forces. Similar definitions are given by some of the classification societies as they are presented in the following sub-section.

4.1.2 Definitions (D)

Here are listed definitions of parameters, symbols and principal particulars, as specified by each classification society in their respective documents. The definitions included in this sub-section are only the ones that find application to relevant requirements and equations of this thesis and are missing from the following sections.

If a definition is missing from a following section, a proper reference will direct the reader to the corresponding sub-section.

4.1.2.1 Lloyd's Register (D)

High Speed Craft. A high speed craft is a craft capable of maximum speed, V as defined below, not less than

$$V = 7{,}19 \cdot \nabla^{1/6} \quad knots$$

where, ∇ = moulded displacement, in m^3, of the craft corresponding to the design waterline.

Yachts. A yacht is a recreational craft used for sport or pleasure and may be propelled mechanically, by sail or by a combination of both. LR's rules are applicable to Yachts of overall length, L_{OA}, 24 metres or greater.

High speed craft's and yacht's definition have been extracted from LR's *Rules and Regulations for the Classification of Special Service Craft (July 2018)*[80]*.* The following definitions belong also to Pt. 1, Ch.2 and Pt. 5, Ch. 2 of the referenced document and are referring to both yacht and high speed craft.

Air gap. The air gap, G_A, is the minimum vertical distance, in metres, from the static waterline to the point considered in an operational condition. In no case is G_A, to be taken greater then G_{Amax}, as indicated in *Figure 4.1.1 Definition of air gap (LR).*

Allowable speed V. The allowable speed used in the computation of environmental loads is the design speed, in knots, associated with a nominated operational environment in which the craft is certified at corresponding operational displacement.

Block coefficient, C_b, is the moulded block coefficient at draught *T* corresponding to summer load waterline, based on Rule length L_R and moulded breadth *B*, as follows:

$$C_b = \frac{mouldeddisplacement(m^3)\ at\ draught\ T}{L_R \cdot B \cdot T}$$

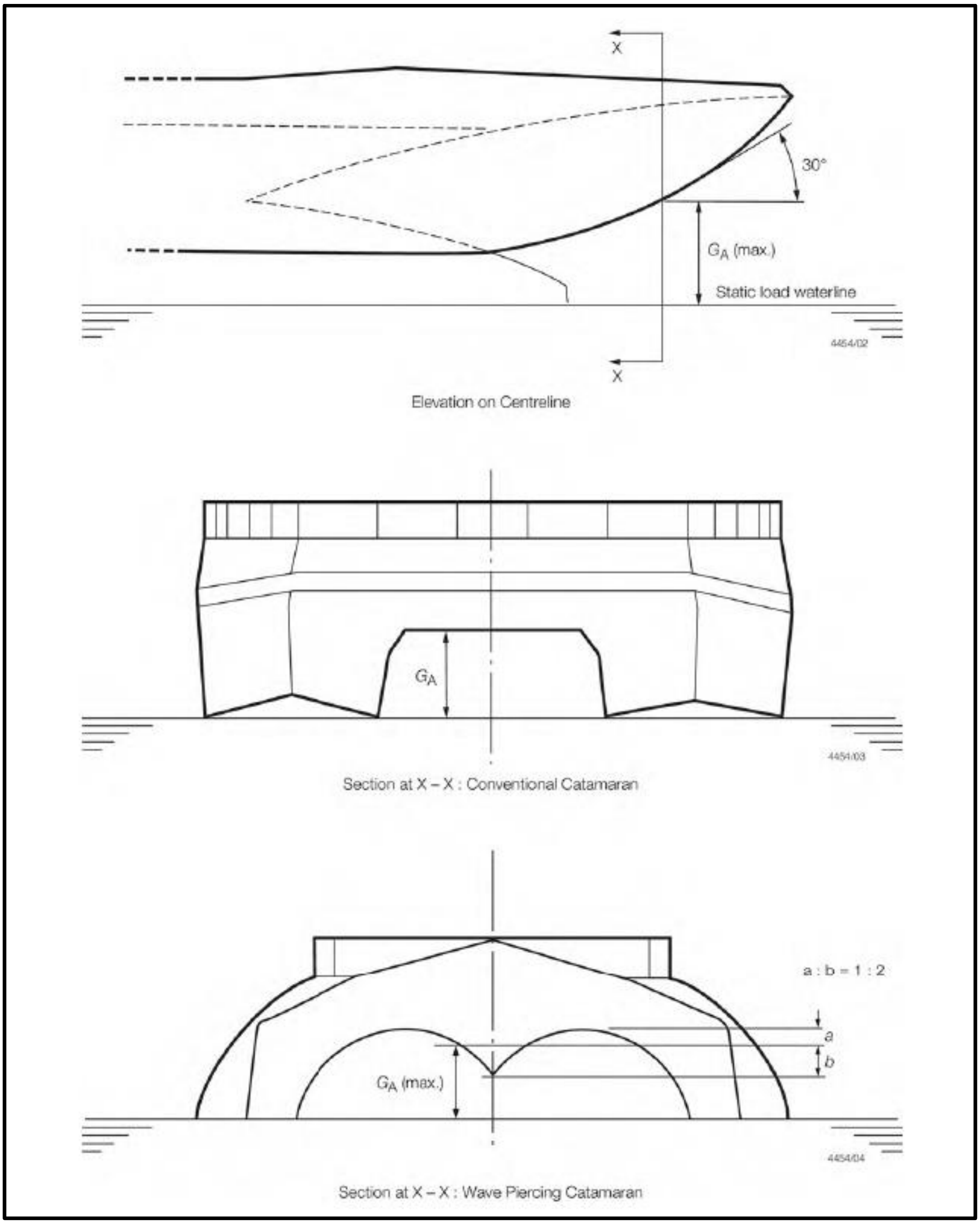


Figure 4.1. 1 Definition of air gap (LR)

Breadth, *B*, is the greatest moulded breadth, in metres, or, for craft of composite construction, the extreme breadth excluding rubbing strakes or other projections. For multi-hull craft it is to be taken as the sum of the breadths of the individual hulls.

Deadrise angle. For craft with no clearly defined deadrise angle at the LCG, the angle, in degrees, to the horizontal of the line at the LCG formed by joining the lowest point of the hull or underside of keel and the bilge tangential point is to be taken as the deadrise angle θ_D, see *Figure 4.1.2 Definition of bilge tangential point and* G_s *for craft with partially submerged hulls*

(LR). For craft with hulls of asymmetric section, where the inner and outer deadrise angles differ, the smaller of the two angles is to be used. For craft with fully submerged hull with circular sections, the deadrise angle is to be taken as 30°.

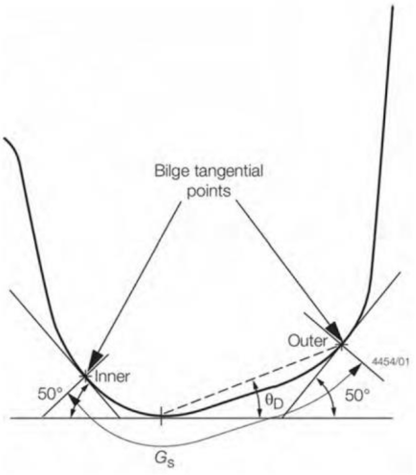


Figure 4.1. 2 Definition of bilge tangential point and G_s for craft with partially submerged hulls (LR)

Depth, D, is measured, in metres, at the middle of the Rule length, L_R, from top of keel to top of the deck beam at side on the uppermost continuous deck, or as defined in appropriate Chapters. When a rounded gunwale is arranged, the depth D is to be measured to the continuation of the moulded deck line at side.

Displacement mode. Displacement mode means the regime, whether at rest or in motion, where the weight of the craft is fully or predominantly supported by hydrostatic forces.

- Applies to craft designed to operate in the displacement mode.
- Applies to all other craft where they are not operating in the non-displacement mode, e.g. at lower speed in severe weather.

Draught, *T*, is the summer draught, in metres, measured from top of keel.

Froude Number F_n. The Froude Number is a non-dimensional speed parameter and is defined as:

$$F_n = \frac{0{,}515 \cdot V_m}{\sqrt{g \cdot L_{WL}}} \qquad (4.1.1)$$

Where,

g = is the acceleration due to gravity and is taken to be 9,81 m/s^2
L_{WL} = Length waterline, in m, as defined below
V_m = is the appropriate speed in knots

Length waterline, L_{WL}, is the distance, in metres, measured on the static load waterline from the foreside of the stem to the after side of the stern or transom.

Non-displacement mode. Non-displacement mode means the normal operational regime of a craft when non-hydrostatic forces substantially or predominantly support the weight of the craft.

- Applies to craft operating in full planing or semi planing modes.
- Applies to craft in foil borne mode.
- Applies to craft where other lifting devices are actively supporting some or all of the craft's weight.
- Typically this applies to craft with a Taylor Quotient, Γ, greater than 3. Γ is defined below. However, the following is to be noted:
    - Some craft are not designed to plane, but have Γ greater than 3, e.g. SWATHs, fast displacement yachts, wave piercing and low wash catamarans. These craft are to be considered as only operating in the displacement mode.
    - Some craft are designed to plane with Γ less than 3 and these should be considered as operating in the non-displacement mode.

Protected structure. *See Figure 4.1.3 Definition of wet-deck protected and unprotected structure (LR)*. A protected structure is one in which the wet-deck component under consideration is enclosed by port and starboard side inboard structure.

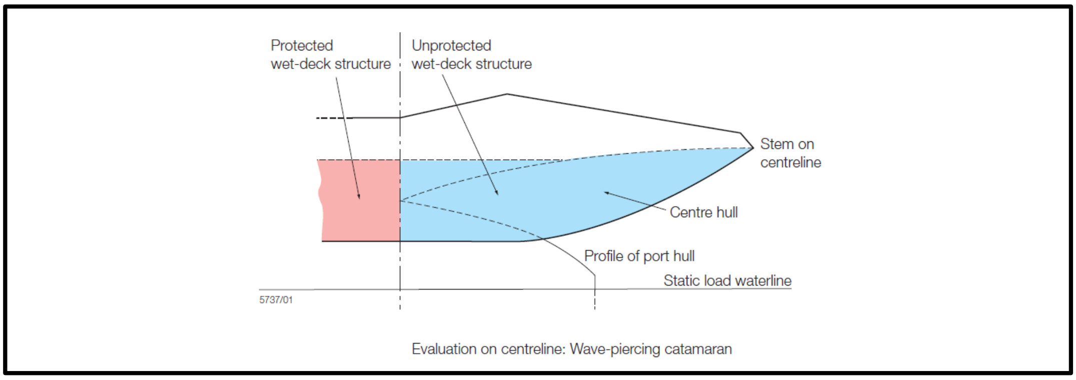


Figure 4.1. 3 Definition of wet-deck protected and unprotected structure (LR)

Relative vertical motion. The relative vertical motion is to be taken as:

$$H_{rm} = C_{w,min} \cdot \left(1 + \frac{k_r}{(C_b + 0{,}2)} \cdot \left(\frac{x_{wl}}{L_{WL}} - x_m\right)^2\right) \quad m \qquad (4.1.2)$$

Where,

k_r = see *Table 4.1.1 Hull form wave pressure factor (LR)*

$C_{w,min}$ = $\frac{C_W}{k_m}$

k_m = $1 + \frac{k_r \cdot (0{,}5 - x_m)^2}{(C_b + 0{,}2)}$

x_m = 0,45-0,6 F_n but not less than 0,2

C_w = Wave head, in metres

= $0{,}0771 \cdot L_{WL} \cdot (C_b + 0{,}2)^{0{,}3} \cdot e^{(-0{,}0044 \cdot L_{WL})}$

x_{wl} = Distance from aft end of L_{WL}, in metres, as defined below

L_{WL} = Waterline length, in m, as defined above

C_b = Block coefficient as defined above
F_n = Froude Number, as defined above, where $V_m = 2/3 \cdot V$
V = Allowable speed as defined above

Table 4.1. 1 Hull form wave pressure factor (LR)

Craft type	k_r
Mono-hull craft in the non-displacement mode	2,25
Mono-hull craft in the displacement mode	1,95
Catamarans and multi-hull craft with partially submerged hulls	2,55
Swaths and multi-hull craft with fully submerged hulls	2,10
Craft supported by hydrodynamic lift provided by foils or other lifting devices	1,50
Note Where multiple craft types apply, the higher value of k_r is to be used.	

Rule length, L_R, is the distance, in metres, on the summer load waterline from the forward side of the stem to the after side of the rudder post or to the centre of the rudder stock if there is no rudder post. L_R is to be not less than 96 per cent, and need not be greater than 97 per cent, of the extreme length on the summer load waterline. In craft without rudders, the Rule length, L_R, is to be taken as 97 per cent of the extreme length on the summer load waterline. In craft with unusual stem or stern arrangements the Rule length, L_R, will be specially considered by LR.

Significant wave height $\boldsymbol{H_{1/3}}$. The wave height, in metres, used in the determination of craft motions and loads is a significant wave height, H 1/3, defined as the average of the one third highest waves in a short term wave measurement record.

Support girth. The support girth, G_s, is the girth distance, in metres, measured around the circumference of the shell plate between the tangential points or chines, as appropriate, of the hull for a mono-hull craft. For multi-hull craft it is to be taken between the inner and outer bilge tangential points or chines of the individual hulls. See *Figure 4.1.2 Definition of bilge tangential point and G_s for craft with partially submerged hulls (LR).*

Surviving wave height $\boldsymbol{H_{03}}$. The wave height, in metres, used in the determination of the structural integrity of a craft and is defined as the wave height with three per cent probability of exceedance. If this value is unknown, the following equation is to be used to determine H_{03}:

$$H_{03} = 1{,}29 \cdot H_{1/3} \quad m \tag{4.1.3}$$

Where,

$H_{1/3}$ = Significant wave height, as defined above

Taylor Quotient $\boldsymbol{\Gamma}$. The Taylor Quotient is defined as:

$$\Gamma = \frac{V}{\sqrt{L_{WL}}} \quad knots \cdot m^{-1/2} \tag{4.1.4}$$

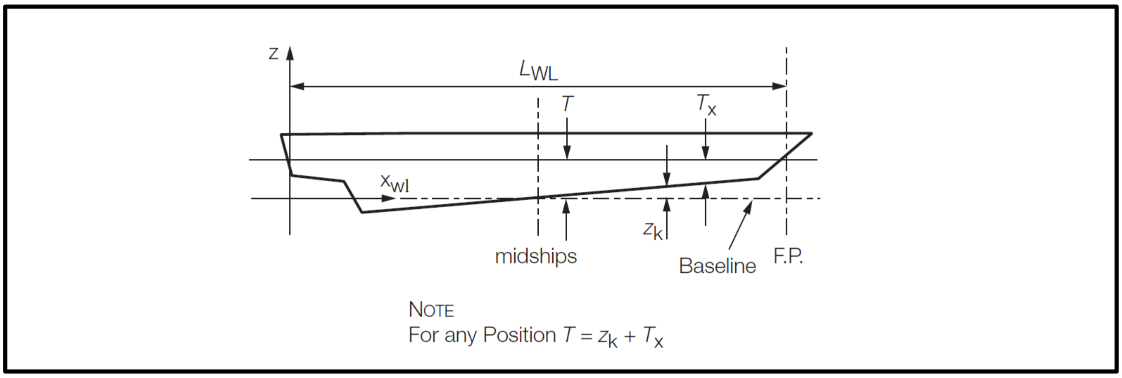
Where,

L_{WL} = Waterline length, in m, as defined above
V = Allowable speed as defined above

Unprotected structure, see *Figure 4.1.3 Definition of wet-deck protected and unprotected structure (LR)*. An unprotected structure is one in which the wet-deck component under consideration is not enclosed by port and starboard side inboard structure.

Below are defined symbols that are used in following sections

$\boldsymbol{x_{wl}}$ = is the longitudinal distance, in metres, measured forwards from the aft end of the L_{WL} to the position or centre of gravity of the item being considered.
$\boldsymbol{z}$ = vertical distance, in metres, from the baseline to the position of centre of gravity of the item being considered, z is positive above the baseline
= Normally the following definitions are to be applied:
= z is to be taken at one third of the panel or strake height
= For short stiffener members: z is to be taken at the stiffener mid position
= For long stiffener members: z is generally to be taken at the stiffener mid position, but may need to be specially considered, especially when there is a significant pressure variation along its length
$\boldsymbol{z_k}$ = is the vertical distance of the underside of the keel above the baseline, in metres, see *Figure 4.1.4 Definition of symbols (LR)*
$\boldsymbol{T_x}$ = local draught to operating waterline at longitudinal position under consideration measured above the baseline is to be taken as the horizontal plane passing through the bottom of the moulded hull at midships, see *Figure 4.1.4 Definition of symbols (LR)*



NOTE
For any Position $T = z_k + T_x$

Figure 4.1. 4 Definition of symbols (LR)

4.1.2.2 American Bureau of Shipping (D)

Definitions extracted from *Rules for Building and Classing High Speed Craft (October 2018)*[81] are given below and are applicable to ***high-speed craft*** having $V/\sqrt{L}$ not less than $2{,}36$, where L is as defined below.

Displacement, *Δ*, is the mass displacement of the craft in the design condition in metric tons, unless otherwise specifically noted.

Scantling Length, *L*, is the distance in meters on the summer load line from the fore side of the stem to the centerline of the rudder stock. For use with the Rules, L is not to be less than 96% and need not be greater than 97% of the extreme length on the summer load line. The forward end of L is to coincide with the fore side of the stem on the waterline on which L is measured.

Definitions extracted from *Rules for Building and Classing Yacht (October 2018)*[82] are given below and are applicable to pleasure ***yachts*** 24 meters or greater in length overall to 90 meters in length as defined below.

Depth (Motor yachts), D, is the moulded depth, in meters, measured at the middle of the length L, from the moulded keel line to the top of the freeboard deck beams at the side of the yacht. On yachts 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

Depth (Sailing and motor sailing yachts) D is the moulded depth, in meters, measured at the middle of the length L, from the bottom of the canoe hull at its lowest point at centerline to the top of the freeboard deck beams at the side of the yacht. For motor sailing yachts with more of a chined, semi-planing or planing hull shape, D is to be measured in accordance with the above definition.

Draft (Motor yachts)**,** *d*, in metres, is measured at the middle of the length *L* from the moulded keel or the rabbet line at its lowest point to the estimated summer load waterline or the design load waterline in the displacement mode.

Draft (Sailing and motor sailing yachts)**,** measured at the middle of the length L, from the bottom of the canoe hull at its lowest point at centerline to the maximum estimated displacement waterline. See *Figure 4.1.5 Transverse Section at D (ABS)*. For motor sailing yachts with more of a chined, semi-planning or planning hull shape, d is to be measured in accordance with above definition.

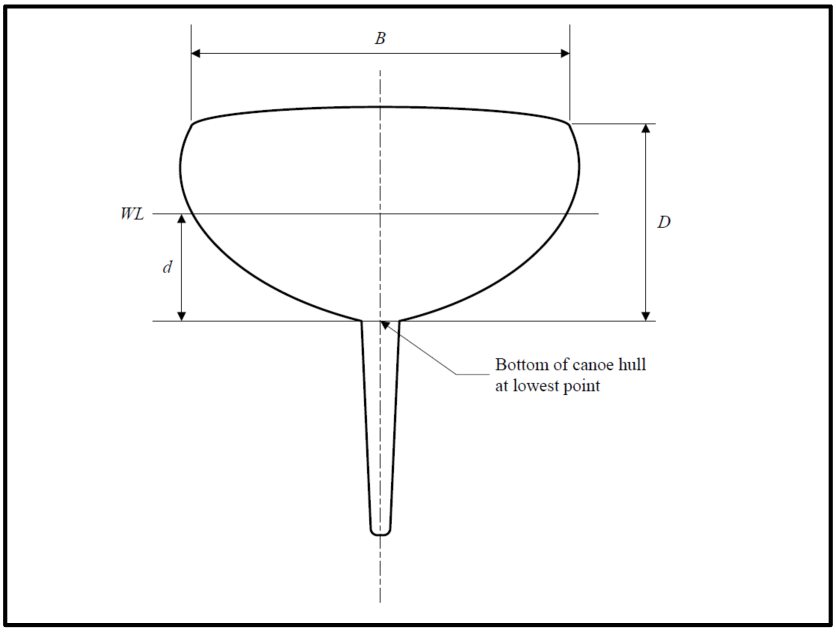


Figure 4.1. 5 Transverse Section at D (ABS)

Scantling Length, *L,* as ABS' definition for high-speed crafts. For sailing and motor sailing yachts, the *L* value to be used for the determination of local scantlings, is given by the following equation:

$$L = \frac{L_{OA} + L_{WL}}{2} \ m \tag{4.1.5}$$

Where,

L_{WL} = length on the maximum estimated displacement waterline, see *Figure 4.1.6 Profile at Centerline (ABS)*

L_{OA} = overall length of the hull, see *Figure 4.1.6 Profile at Centerline (ABS)*

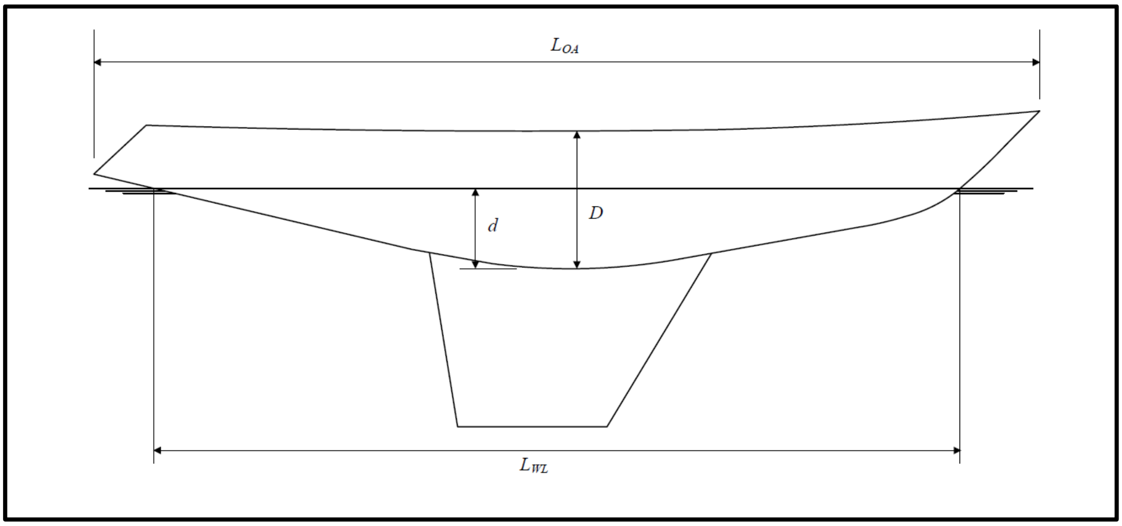


Figure 4.1. 6 Profile at Centerline (ABS)

4.1.2.3 Bureau Veritas (D)

High Speed Craft. A high speed craft is a craft capable of maximum speed, in metres per second (m/s), equal to or exceeding:

$$V = 3{,}7 \cdot \nabla^{0{,}1667} \quad m/s$$

where, ∇ = moulded displacement, in m^3, of the craft corresponding to the design waterline.

excluding craft the hull of which is supported completely clear above the water surface in non-displacement mode by aerodynamic forces generated by ground effect.

High speed craft's definition have been extracted from BV *Rules for the Classification of High Speed Craft (July 2002)*[83]*.* The following definitions belong also to segment C.1.4.7 of the referenced document and are referring to high speed craft.

Breadth, B_W, the greatest moulded breadth, in m, measured on the waterline at draught T; for catamarans, B_W is the breadth of each hull.

Design waterline, means the waterline corresponding to the maximum operational weight of the craft with no lift or propulsion machinery active

Displacement mode means the regime, whether at rest or in motion, where the weight of the craft is fully or predominantly supported by hydrostatic forces.

Draught, T, of the craft, in m, measured vertically on the transverse section at the middle of length L, from the moulded base line of the hull(s) to the full load waterline, with the craft at rest in calm water and, for SESs, in the off-cushion condition

Rule length, L, in m, equal to L_{WL} where L_{WL} is the waterline measured with the craft at rest in calm water and, for SESs, in the off-cushion condition

Non-displacement mode means the normal operational regime of a craft when non-hydrostatic forces substantially or predominantly support the weight of the craft.

In BV rules, the service notation ***yacht*** (or charter yacht, when the ship is engaged in trade) is assigned to ship intended for pleasure cruising. The requirements of BV's *Rules for the Classification and the Certification of Yachts(March 2012)*[84] cover sailing yachts and motor yachts, of monohull type or catamaran type, built in steel, aluminium, composite materials or plywood, definitions referring to them are given below.

Breadth, B_{WL}, in m, is the greatest moulded breadth of the hull at full load waterline. For catamarans, B_{WL} is the breadth of each hull.

Depth, D, in m, is the distance measured vertically on the midship transverse section, from the moulded base line to the top of the deck beam at side on the uppermost continuous deck.

Displacement, Δ, is the full load displacement, in tonnes, at draught T, in sea water (density ρ = 1,025 t/m^3)

Freeboard deck is normally the uppermost complete deck exposed to weather and sea, which has permanent means of closing all openings in the weather part thereof, and below which all openings in the sides of the ship are fitted with permanent means of watertight closing.

Interpretation:

This deck noted freeboard deck$^{(m)}$ in BV's rules is to be considered as the deck exposed to greenseas, and granting the necessary weathertightness of the hull to prevent any water ingress.

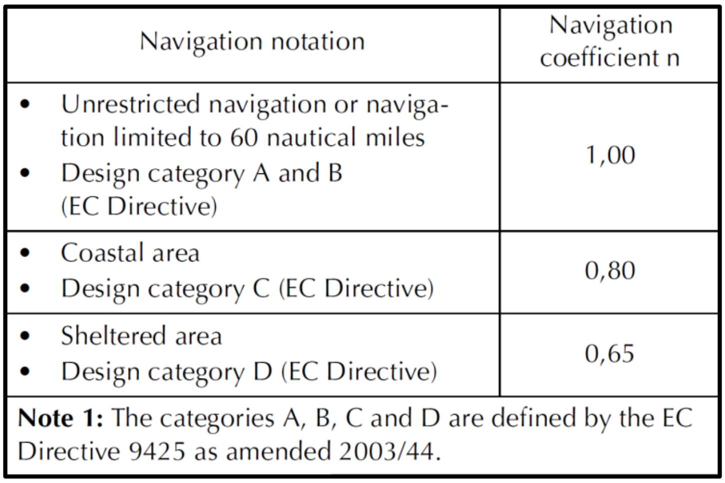
Full load Draught, *T,* in m, is the distance, measured vertically on the midship transverse section, from the moulded base line to the full load waterline.

Hull length, L_{HULL}, is equal to the total hull length, from the extreme forward part of the hull, excluding any outfitting outside, to the extreme aft part.

Moulded base line is the horizontal reference line tangent to the upper face of bottom plating at midship. In the case of yacht with a solid bar keel, the moulded base line is to be taken at the intersection between the upper face of the bottom plating and the solid bar keel at the middle of length L.

Navigation coefficient, n, is a reduction coefficient as defined in *Table 4.1.2 Navigation Coefficient (BV)*, is considered on global and local loads to take into account the navigation area and the notation of the yacht within the scope of classification and/or certification as defined within the scope of EC certification.

Table 4.1. 2 Navigation Coefficient (BV)



Navigation notation	Navigation coefficient n
• Unrestricted navigation or navigation limited to 60 nautical miles • Design category A and B (EC Directive)	1,00
• Coastal area • Design category C (EC Directive)	0,80
• Sheltered area • Design category D (EC Directive)	0,65
Note 1: The categories A, B, C and D are defined by the EC Directive 9425 as amended 2003/44.	

Rule length, L, in m, equal to L_{WL} where L_{WL} is the waterline measured with the craft at rest in calm water, at the full load displacement.

Total block coefficient, C_B, equals to $C_B = \frac{\Delta}{1{,}025 \cdot L \cdot B_{WL} \cdot T}$, for catamarans, C_B is to be calculated for a single hull, assuming Δ equal to one half of the yacht's displacement

Wave length, L_W, in m, is the distance between two consecutive crests of the wave.

4.1.2.4 Det Norske Veritas – Germanischer Lloyd (D)

A ***high speed light craft***, is defined as a craft, is capable of a maximum speed in knots equal to or exceeding:

$$V = 7{,}19 \cdot \nabla^{1/6} \quad knots$$

where, ∇ = moulded displacement, in m^3, of the craft corresponding to the design waterline.

High speed craft's definition have been extracted from DNV-GL's *Rules for classification: High speed and light craft (January 2018)*[85]*.* The following definitions belong also to segment Pt. 3, Ch. 1, Sec. 1 of the referenced document and are referring to high speed craft.

Block coefficient, given by the formula: $c_B = \frac{\Delta}{1{,}025 L B_{WL} T}$

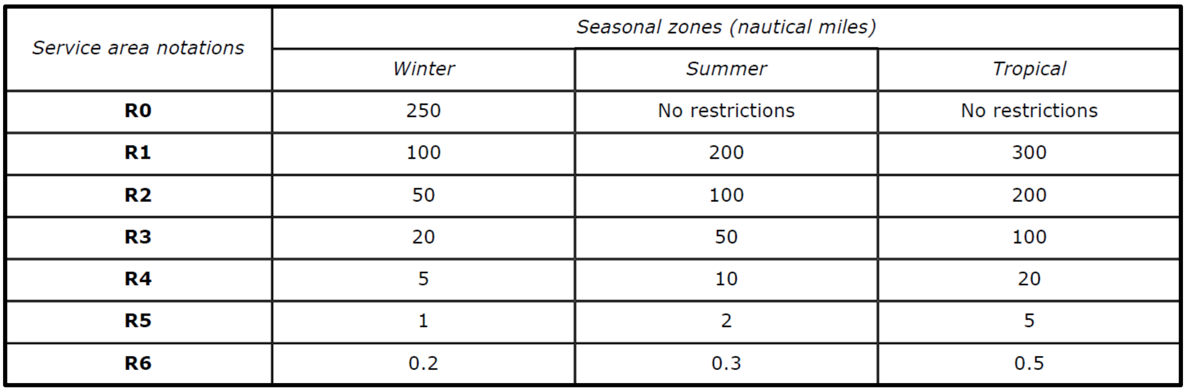
Draught, *T*, in m, is the fully loaded draught in m at L/2 with the craft floating at rest in calm water.

Length, in m, of the craft defined as the length on design waterline. Amidships is defined as the middle of L

Service area restrictions, given in nautical miles and representing the maximum distance from nearest port or safe anchorage, are given in *Table 4.1.3 Service area restrictions (DNV-GL)*. For the various service area notations the restrictions are related to the zones, areas and seasonal periods as defined in the *International Convention on Load Lines*, 1966, Annex II.

The service area notation **R** followed by a number or a letter will be assigned to all high speed, light craft. The service area notations **R5** and **R6** are limited to enclosed waters such as fjords, ports, rivers and lakes

Table 4.1. 3 Service area restrictions (DNV-GL)



Service area notations	*Seasonal zones (nautical miles)*		
	Winter	*Summer*	*Tropical*
R0	250	No restrictions	No restrictions
R1	100	200	300
R2	50	100	200
R3	20	50	100
R4	5	10	20
R5	1	2	5
R6	0.2	0.3	0.5

Significant wave height, H_s, in m, is the average of the 1/3 highest waves within a wave spectrum.

Wave coefficient, C_W, is given by below equation:

$$C_W = 0{,}08 \cdot L \cdot f_r$$

- For $L \leq 100$ m

$$C_W = (6 + 0{,}02 \cdot L) \cdot f_r \qquad (4.1.6)$$

- For $L > 100$ m

Where,

L = Length of the craft, in m
f_r = Reduction factor of C_W for restricted service as given *Table 4.1.4 Reduction of C_W (DNV-GL)*

Table 4.1. 4 Reduction of C_W (DNV-GL)

Class notation	f_r
R0	1
R1	0.9
R2	0.8
R3	0.7
R4	0.6
R5	0.5
R6	0.4

Sailing yachts are yachts that use sails as primary means of propulsion and are used for pleasure, having a length L ≥ 24 m and carrying not more than 12 passengers.

Motor yachts are yachts that are engine powered and are used for pleasure, having a length L ≥ 24 m and carrying not more than 12 passengers.

High Speed motor yacht is a yacht capable of maximum speed equal or exceeding to the maximum speed of a high speed craft as defined above.

Yacht's definition have been extracted from DNV-GL *Rules for classification: Yachts craft (October 2016)*[86]. The following definitions belong also to segment Pt. 3, Ch. 1, Sec. 1 of the referenced document and are referring to all types of yacht.

Rule Length, *L,* is the distance, in m, measured on the design waterline at displacement Δ.

Service area restrictions, given in nautical miles and representing the maximum distance from nearest port or safe anchorage, are given in Table 1. For the various service area notations the restrictions are related to the zones, areas and seasonal periods as defined in the International Convention on Load Lines,1966, Annex II.

The service area notation **R** followed by a number or a letter will be assigned to vessels with modified requirements to arrangement, equipment or scantlings, in relation to vessels built for unrestricted trade. The service area notation **RE** is limited to enclosed waters such as fjords, ports, rivers and lakes.

4.1.2.5 Registro Italiano Navale (D)

Rules for the Classification of High Speed Craft (2002) was established along by BV, RINA and Germanischer Lloyd, hence rules that apply to ***high-speed crafts*** have already been presented in *4.1.2.3 Bureau Veritas (D).*

According to RINA *Rules for the Classification of Yachts Designed for Commercial Use (January 2019)*[87] **yacht** means:

1) a vessel engaged in commercial use for sport or pleasure, not carrying cargo and not carrying more than 12 passengers;

2) a vessel of less than 500 GT mainly propelled by sails, engaged in commercial use for sport or pleasure, not carrying cargo and not carrying more than 36 passengers

A vessel mainly propelled by sails is a vessel that has sails as main means of propulsion, which may also be propelled by internal combustion engines enabling the navigation of the vessel without sails if necessary, and that has a nominal sail area.

The vessel may be propelled mechanically, by sail or by a combination of both.

Definitions for the type of yacht are also applied as given below:

Displacement yacht. A yacht whose weight is fully supported by the hydrostatic forces. In general, for the purposes of this Section, a displacement yacht is a craft having $V/L^{0,5} \leq 4$.

Semi-planing yacht. A yacht that is supported partially by the buoyancy of the water it displaces and partially by the dynamic pressure generated by the bottom surface running over the water.

Planing yacht. A yacht in which the dynamic lift generated by the bottom surface running over the water supports the total weight of the yacht.

The following definitions belong also to segment Pt. B, Ch. 1, Sec. 5 and Sec. 5 of the referenced document and are referring to all types of yacht.

Aft perpendicular, P_{PAD}, is the perpendicular at the intersection of the full load waterline plane (with the yacht stationary in still water) and the aft side of the sternpost or transom.

B is the maximum outside breadth, in metres.

Block coefficient, C_B, equals to $C_B = \frac{\Delta}{1{,}025 \cdot L \cdot B_{WL} \cdot T}$

Depth, D, in metres in metres, measured vertically on the transverse section at the middle of length L, from the lower side of the bar keel, if any, or of the fixed ballast keel, if any, or of the drop keel, to the top of the deck beam at side on the weather deck.

Draught, T in metres, measured at the middle of length L, in metres, between the full load waterline and the lower side of the keel. In the case of hulls with a drop or ballast keel, the lower side of the keel is intended to mean the intersection of the longitudinal plane of symmetry with the continuation of the external surface of the hull.

Forward perpendicular, P_{PAV}, is the perpendicular at the intersection of the full load waterline plane (with the yacht stationary in still water) and the fore side of the stem.

Scantling length, L in m, on the full load waterline, assumed to be equal to the length on the full load waterline with the yacht at rest

Point of reference, Pdr, intended as the lower edge of the plating panel or the centre of the area supported by the stiffener, depending on the case under consideration.

4.1.3 Example of Rules Application

4.1.3.1 Scope

Additionally, this section contains an example of rule application, results of which are presented in relevant sub-sections, in order to aid the comparison process. The purpose of this example is the elaboration of basic rules and regulations that are presented in *Chapter 4*, by applying them on a hypothetical craft. The equations and regulations of each classification society are used to determine the vertical acceleration of the craft and subsequently the design pressures acting on bottom shell, the side shell and the main deck.

Moreover the rules are applied separately on three longitudinal sections of the craft, at 0,25L, 0,5L and 0,75L, in order to primarily examine whether the superiority of one classifications society's results to another's is dependent on the longitudinal position of the load point considered. Vertically the height would be equal to zero for the bottom, equal to the height of chines for the side shell and equal to vessel depth for the deck.

Lastly at the examined load point, a plate with length of 0,75 m and width of 0,50 m would be considered as the structural member under study.

The examined vessel is a mono-hull high-speed craft with a $V/\sqrt{L}$ ratio equal to $4{,}56$, thus the results have been produced using the requirements of *Section 4.2 High-Speed Craft* accordingly and are presented below conclusion in relevant sub-sections.

4.1.3.2 Hypothetical's Ship's Principal Particulars

The vessel used for the comparative study of the results of the regulations is a mono-hull high-speed craft and its main particulars are given in *Table 4.1.5 Craft's Principal Particulars.*

Table 4.1. 5 Craft's Principal Particulars

Particular	Symbol	Value	Unit
Displacement	Δ	40	t
Length overall	L_{OA}	22,65	m
Waterline Length	L_{WL}	19,23	m
Breadth	B	4,62	m
Waterline Breadth	B_{WL}	3,84	m
Breadth between the Chines	B_C	3,42	m
Draught	T	1,08	m
Longitudinal Center of Gravity	LCG	7,905	m
Bottom Deadrise Angle	β	24,5	$degrees$
Chines Deadrise Angle	β_S	80,3	$degrees$
Maximum Speed	V	20	$knots$
Running Trim	τ	3,5	$degrees$
Significant Wave Height	H_S	2,5	m
Block Coefficient	C_B	0,489	
LR's Block Coefficient	C_B	0,407	

LR is using the maximum moulded breadth of the crafts instead of the waterline breadth, for the calculation of block coefficient, see *4.1.2.1 Lloyd's Register (D).*

For some computations the unsupported span (l) and the spacing (s) of the longitudinal stiffeners is required, which for our example they are taken equal to $2{,}45\,m$ and $0{,}63\,m$, respectively. Also the height of chines above the base line is equal to $0{,}62\,m$.

Section

4.2 High-Speed Craft

4.2.1 General (High-Speed Craft: HSC)

In accordance with SOLAS Chapter 10 Reg. 1.3, high-speed craft are craft capable of a maximum speed, in metres per second (m/s), equal to or exceeding:

$$V = 3{,}7x\nabla^{0.1667}\ m/s$$

where ∇ = volume of displacement in cubic metres corresponding to the design waterline, excluding craft of which the hull is supported clear above the water surface in non-displacement mode by aerodynamic forces generated by ground effect.

4.2.2 Vertical Acceleration (HSC/VA: Vertical Acceleration)

4.2.2.1 Lloyd's Register (HSC/VA)

The vertical acceleration of a high-speed craft is to be determined according to the formulae in *Rules and Regulations for the Classification of Special Service Craft (July 2018) Pt. 5, Ch. 2, Sec. 3* by LR. As a high-speed craft usually operates in non-displacement mode or semi-planning mode, its vertical acceleration should be calculated with the corresponding equation of the realtive section.

Lloyd’s Register provides also different formulas depending on the number of hulls of the craft. The vertical acceleration in the non-displacement mode for mono-hull craft is to be taken as:

$$a_V = 1,5 \cdot \theta_B \cdot L_1 \cdot (H_1 + 0,084) \cdot (5 - 0,1\Theta_D) \cdot \Gamma^2 \cdot 10^{-3} \quad g's \qquad (4.2.1)$$

Where,

= a_V is the vertical acceleration at the LCG in terms of g’s
Γ = Taylor Quotient see *4.1.2.1 Lloyd's Register (D)*
g = acceleration due to gravity (9,81 m/sec^2)
L_1 = $\frac{L_{WL}B_c^3}{B_w\Delta}$, but $\frac{L_{WL}}{B_W}$ is not to be taken as less that 3
H_1 = $\frac{H_{1/3}}{B_W}$, but is not to be taken as less than 0,2
B_C = breadth of hull between the chines or bilge tangential points at LCG, as appropriate, in metres
B_W = breadth of hull at the LCG measured at the waterline, in metres
Δ = displacement, in tonnes, as defined in *4.1.2.1 Lloyd's Register (D)*
$H_{1/3}$ = design significant wave height in metres
θ_D = deadrise angle at the LCG, in degrees, but is not to be taken as greater than 30°
θ_B = running trim angle in degrees, but is not to be taken as less than 3°
L_{WL} = waterline length, in metres, see *4.1.2.1 Lloyd's Register (D)*

The vertical acceleration in the non-displacement mode for multi-hull craft is to be taken as:

$$a_V = \frac{f_a \cdot L_{WL}}{\Delta} \cdot (B_M \cdot H_{1/3} + 0,084 \cdot B_M^2) \cdot (5 - 0,1 \cdot \Theta_D) \cdot \Gamma^2 \cdot 10^{-3} \qquad (4.2.2)$$

Where,

= a_V is the vertical acceleration at the LCG in terms of g’s
Γ = Taylor Quotient see *4.1.2.1 Lloyd's Register (D)*
f_a = hull form acceleration factor
= 2,7 for craft supported mainly by hydrodynamic lift provided by foils or other lifting devices
= 3,6 for Swaths and multi-hull craft with fully submerged hulls
= 4,5 for catamarans and multi-hull craft with partially submerged hulls
B_M = total breadth of hulls or struts at LCG at the waterline, in metres, excluding tunnels
Δ = displacement, in tonnes, as defined in *4.1.2.1 Lloyd's Register (D)*
$H_{1/3}$ = design significant wave height in metres
θ_D = deadrise angle at the LCG, in degrees, but is not to be taken as greater than 30°
L_{WL} = waterline length, in metres, see *4.1.2.1 Lloyd's Register (D)*

However, high-speed crafts could be built to operate in displacement mode or to be able to operate in this mode under certain circumstances e.g. severe weather. In such cases, the vertical acceleration in the displacement mode for all craft is to be taken as presented in *Rules and Regulations for the Classification of Special Service Craft (July 2018) Pt. 5, Ch. 2, Sec. 3*:

$$a_V = 0,2 \cdot \Gamma + \frac{34}{L_{WL}} \qquad (4.2.3)$$

Where,

= a_V is the vertical acceleration at the LCG in terms of g's

Γ = Taylor Quotient see *4.1.2.1 Lloyd's Register (D)*

L_{WL} = waterline length, in metres, see *4.1.2.1 Lloyd's Register (D)*

Lastly, LR, in the same section, provides formulae to calculate vertical acceleration, a_x, at any given location distance x_a from the AP along the hull, as follows:

$$a_x = a_V.(0{,}86 - 0{,}32 \cdot \frac{x_a}{L_{WL}} + 1{,}76 \cdot \left(\frac{x_a}{L_{WL}}\right)^2 + \xi_\alpha) \qquad (4.2.4)$$

where,

a_V = is the vertical acceleration at the LCG in terms of g's, as appropriate

a_x = is the vertical acceleration at distance x_a from AP on the static load waterline, in terms of g's

x_a = distance from aft end of the static load waterline, in metres, to the point at which the vertical acceleration is calculated

x_{LCG} = distance from aft end of the static load waterline, in metres, to the LCG

L_{WL} = waterline length, in metres, see *4.1.2.1 Lloyd's Register (D)*

ξ_a= $0{,}14 + 0{,}32\frac{x_{LCG}}{L_{WL}} - 1{,}76(\frac{x_{LCG}}{L_{WL}})^2$

4.2.2.2 American Bureau of Shipping (HSC/VA)

Some postulations are made by ABS on the vertical acceleration of the craft in *Rules for Building and Classing High-Speed Craft (October 2018)* Pt. 3, Ch. 2, Sec. 2, but without distinctions on the operating mode.

According to ABS, the vertical acceleration of the craft is as determined by a model test, theoretical computation, or service experience and 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:

$$n_{cg} = N_2 \cdot \left[\frac{12 \cdot h_{1/3}}{N_h \cdot B_w} + 1{,}0\right] \cdot \tau \cdot \left[50 - \beta_{cg}\right] \cdot \frac{V^2 \cdot (N_h \cdot B_w)^2}{\Delta} \; g's \qquad (4.2.5)$$

where,

= n_{cg} is the vertical acceleration at the LCG in terms of g's

N_2 = 0,0078

Δ = displacement at design waterline, in kg, as *4.1.2.2 American Bureau of Shipping (D)*

B_W = maximum waterline beam, in m (of one hull for multihulls)

$h_{1/3}$ = significant wave height, m, see *Table 4.2.1 Design Significant Wave Heights and Speed (ABS),* below

τ = running trim at V, in degrees, but generally not to be taken less than 4° for craft L < 50 m, nor less than 3° for L > 50 m. Special consideration will be given to designers values predicted from model tests.

β_{cg} = deadrise at LCG, degrees, generally not to be taken less than 10° nor more than 30°

V = craft design speed in knots, see *Table 4.2.1 Design Significant Wave Heights and Speed (ABS),* below

N_h = Number of hulls (for multihulls)

Table 4.2. 1 Design Significant Wave Heights and Speed (ABS)

	Operational Condition	
	$h_{1/3}$	V
High-Speed Craft	4 m	$V_m{}^{(2)}$
Coastal Craft	2,5 m	$V_m{}^{(2)}$
Riverine Craft	0,5 m	$V_m{}^{(2)}$
Note 1: Not to be taken less than L/12 Note 2: V_m=maximum speed for the craft in the design condition		

Furthermore, ABS provides maximum limit of vertical acceleration, by indicating that vertical that it should not be taken greater than the following:

$$n_{cg} = 1{,}39 + k_n \cdot \frac{V}{\sqrt{L}} \quad g's \qquad (4.2.6)$$

Where,

L = Scantling Length as defined in *4.1.2.2 American Bureau of Shipping (D)*
k_n = 0,256
V = craft design speed in knots

Supplementary, ABS specifies maximum values of vertical acceleration depending on the $V/\sqrt{L}$ ratio, the length and type of the craft with the following:

"For speeds greater than 18$\sqrt{L}$ the maximum $\boldsymbol{n_{cg}}$ is 6,0 g (7,0 g for search and rescue type craft). The vertical accelerations are typically not to be taken less than 1,0 g for craft lengths less than 24 m and 2,0 g for craft lengths less than 12 m. Intermediate values can be determined by interpolation. The vertical acceleration will need to be specially considered for craft fitted with seat belts or special shock mitigation seats."

ABS also includes formula to calculate the average of the 1/100 highest vertical accelerations, n_{xx}, at any section clear of LCG, in g's, which correspond to LR's a_x.

$$n_{xx} = n_{cg} \cdot K_v \quad g's \qquad (4.2.7)$$

K_v = vertical acceleration distribution factor given in *Figure 4.2.1 Vertical Acceleration Distribution Factor K_v (ABS)*

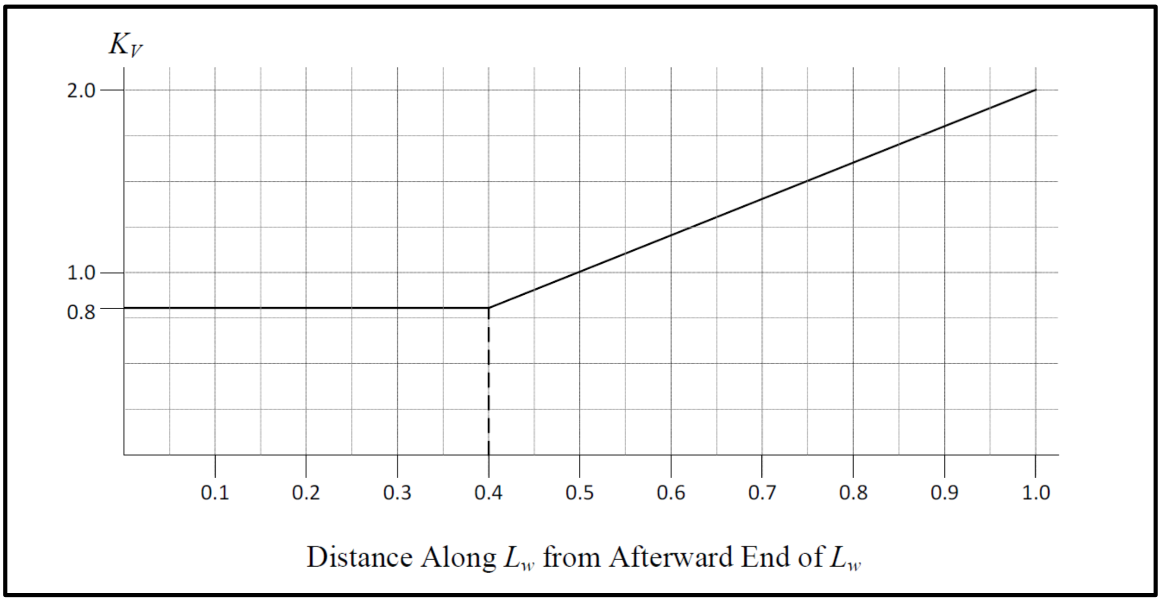


Figure 4.2. 1 Vertical Acceleration Distribution Factor K_v (ABS)

4.2.2.3 Bureau Veritas (HSC/VA)

Provisions are made by BV on HSC, only in *Rules for the Classification of High Speed Craft (February 2002).* Its rules was established along by BV, RINA and Germanischer Lloyd.

Regulations considering vertical acceleration are in the referenced document's segment C3.3. The design vertical acceleration at LCG, a_{cg} (expressed in g's), is defined by the designer and corresponds to the average of the 1 per cent highest accelerations in the most severe sea conditions expected, in addition to the gravity acceleration. According to BV the design vertical acceleration is not to be taken less than:

$$a_{cg} = foc \cdot Soc \cdot \frac{V}{\sqrt{L}} \quad g's \qquad (4.2.8)$$

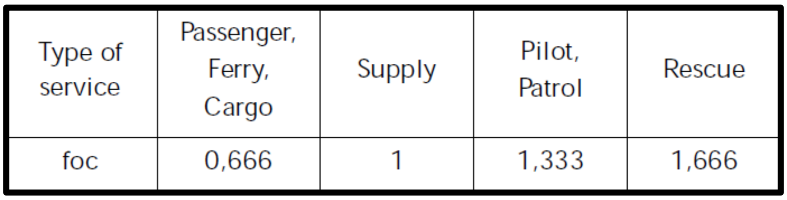
Where,

L = Rule length, in m, equal to L_{WL} where L_{WL} is the waterline measured with the craft at rest in calm water and, for SESs, in the off-cushion condition

V = maximum service speed, in knots

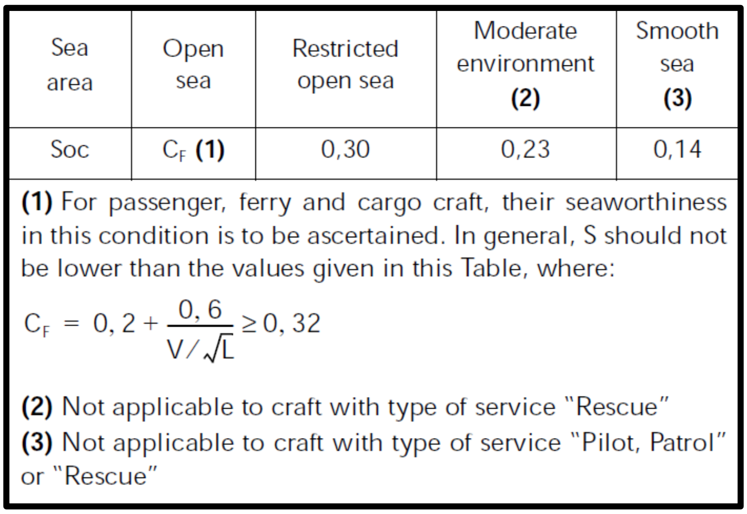
Where foc and Soc values are defined in *Table 4.2.2 foc values (BV)* and *Table 4.2.3 Soc values (BV).*

Table 4.2. 2 foc values (BV)



Type of service	Passenger, Ferry, Cargo	Supply	Pilot, Patrol	Rescue
foc	0,666	1	1,333	1,666

Table 4.2. 3 Soc values (BV)



Sea area	Open sea	Restricted open sea	Moderate environment **(2)**	Smooth sea **(3)**
Soc	C_F **(1)**	0,30	0,23	0,14

(1) For passenger, ferry and cargo craft, their seaworthiness in this condition is to be ascertained. In general, S should not be lower than the values given in this Table, where:

$$C_F = 0,2 + \frac{0,6}{V/\sqrt{L}} \geq 0,32$$

(2) Not applicable to craft with type of service "Rescue"
(3) Not applicable to craft with type of service "Pilot, Patrol" or "Rescue"

Bureau Veritas also adds definitions with reference to significant wave heights, H_s as per BV, of the sea areas referred in *Table 4.2.3 Soc values (BV)*. Significant wave heights are exceeded for an average of not more than 10 percent of the year:

- Open-sea service:

$H_s \geq 4,0$ m

- Restricted open-sea service:

2,5 m $\leq H_s < 4,0$ m

- Moderate environment service:

0,5 m $< H_s < 2,5$ m

- Smooth sea service:

$H_s \leq 0,5$ m.

Similarly to ABS, the longitudinal distribution of vertical acceleration along the hull is given by the product of a_{cg} and k_v, a longitudinal distribution factor (*see Figure 4.2.2 Distribution Factor of Vertical acceleration (BV))*, and is to be taken as:

- k_v = 1 for x/L ≤ 0,5

- $k_v = 2 \cdot x/L$ for $x/L > 0{,}5$

Higher values may be requested based on pitch consideration.

$$a_v = k_v \cdot a_{cg} \tag{4.2.9}$$

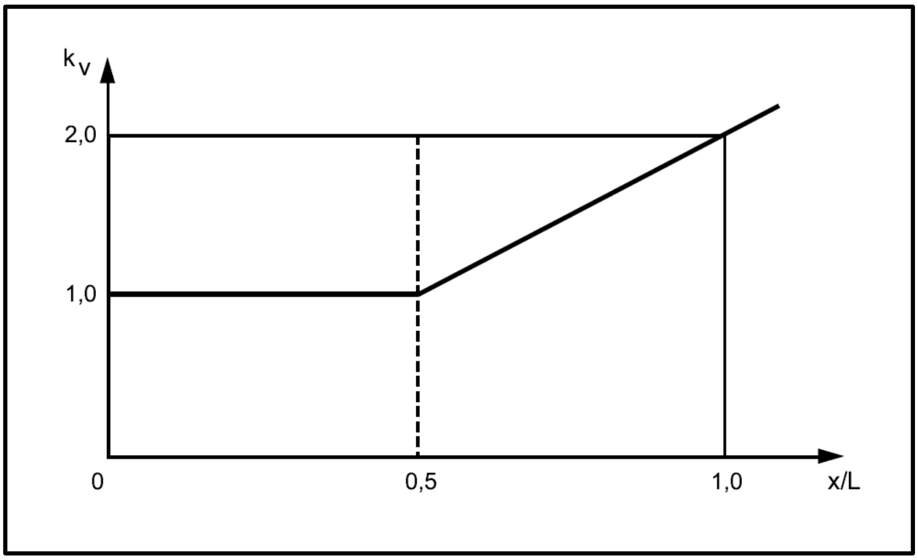


Figure 4.2. 2 Distribution Factor of Vertical acceleration (BV)

According to BV, as the bottom impact pressure, given in C3.5.3, and deck loads, given in C3.5.8 of the referenced document, are explicitly or implicitly depending on the vertical acceleration at LCG, the design values of these loads directly impose limitation on vertical acceleration level at LCG. Therefore, it is the designer's responsibility to provide for relation between the speed and the significant wave height that provides a maximum vertical acceleration less than the design value.

If any model test are to be carried out in irregular sea conditions with significant wave height corresponding to the operating conditions of the craft and a clearly specified sea spectrum, would be acceptable. Where model test results for full-scale measurements are not available, the following formula may be used to define maximum speeds compatible with design acceleration of mono-hulls, depending on sea states having a significant height H_s.

$$a_{cg} = \frac{(50 - a_{dCG}) \cdot (\frac{\tau}{16} + 0{,}75)}{3555 \cdot C_B} \cdot \left(\frac{H_s}{T} + 0{,}084 \cdot \frac{B_w}{T}\right) \cdot K_{FR} \cdot K_{HS} \tag{4.2.10}$$

Where,

for units for which $\frac{V}{\sqrt{L}} \geq 3$ and $\Delta /(0{,}01 \cdot L)^3 \geq 3500$

$K_{FR} = (\frac{V_x}{\sqrt{L}})^2$

$K_{HS} = 1$

for units for which $\frac{V}{\sqrt{L}} < 3$ and $\Delta /(0{,}01 \cdot L)^3 < 3500$

K_{FR} = $0{,}8 + 1{,}6 \cdot \frac{V_x}{\sqrt{L}}$

K_{HS} = $\frac{H_s}{T}$

And

H_s = design significant wave height in metres

a_{dCG} = deadrise angle at the LCG, in degrees, but is not to be taken between 10° and 30°

τ = trim angle during navigation, in degrees, to be taken not less than 4°

V = maximum service speed, in knots

V_x = actual craft speed, in knots

T = Draught of the craft in m, as defined in *4.1.2.3 Bureau Veritas (D)*

B_W = the greatest moulded breadth, in m,as defined in *4.1.2.3 Bureau Veritas (D)*

If V_x is replaced by the maximum service speed *V* of the craft, the previous formula yields the significant height of the limit sea state, H_{sl}. This formula may also be used to specify the permissible speed in a sea state characterised by a significant wave height equal to or greater than H_{sl}.

Finally, BV clarifies that as for catamarans, the relation between speed, wave height and acceleration is to be justified by model test results or full-scale measurements and as for craft, such as SESs, for which a speed reduction does not necessarily imply a reduction in acceleration, the speed is to be modified depending on the sea state according to criteria defined, at the discretion of the Society, on the basis of motion characteristics of the craft.

4.2.2.4 Det Norske Veritas - Germanischer Lloyd (HSC/VA)

DNV-GL rules and regulations on vertical acceleration of a HSC are presented in *Rules for classification: High speed and light craft (January 2018)* Pt. 3, Ch. 1, Sec. 3. The vertical design acceleration at the centre of gravity of the craft, a_{cgi}, shall be estimated for simultaneous values of speed V_i and significant wave height H_{si}, and the largest V_i shall be set equal to V.

DNV-GL provides various formulas of design vertical acceleration depending on the $V_i/\sqrt{L}$ ratio. While BV has got a similar attribute, DNV-GL goes one step further by including a distinct formula for vessels that operate with great $V_i/\sqrt{L}$ ratio, greater than 10,86.

When $V_i/\sqrt{L} \geq 10.86$:

$$a_{cgi} = \frac{8{,}38 \cdot g_0 \cdot k_\tau}{(\frac{L}{\Delta^{1/3}})^{0{,}35}} \cdot \left(\frac{H_{si}}{B_{WL2}} + 0{,}084\right) \cdot \left(50 - \beta_{cg}\right) \cdot \ln(F_{Nv}) \cdot V_i \cdot \sqrt{L} \cdot \frac{{B_{WL2}}^2}{1000 \cdot \Delta} \quad (m/s^2) \tag{4.2.11}$$

When $V_i/\sqrt{L} \geq 3$:

$$a_{cgi} = \frac{g_0 \cdot k_h}{1650} \cdot \left(\frac{H_{si}}{B_{WL2}} + 0{,}084\right) \cdot \left(50 - \beta_{cg}\right) \cdot (\frac{V_i}{\sqrt{L}})^2 \cdot \frac{L \cdot {B_{WL2}}^2}{\Delta} \quad (m/s^2) \tag{4.2.12}$$

When $V_i/\sqrt{L} < 3$:

$$a_{cgi} = 6 \cdot \frac{H_{si}}{L} \cdot \left(0{,}85 + 0{,}35\frac{V_i}{\sqrt{L}}\right) \cdot g_0 (m/s^2) \tag{4.2.13}$$

where,

k_τ = $1{,}5 - 0{,}046 \cdot \frac{V_i}{\sqrt{L}} \geq 0{,}5$

F_{Nv}= $0{,}5144 \cdot \frac{V_i}{\sqrt{g_0 \cdot \Delta^{0.333}}}$

g_0 = standard acceleration of gravity (9,81 m/sec^2)

V_i = Speed in knots

H_{si} = significant wave height according to *Table 4.2.4 Minimum significant wave height Hs in m at maximum speed fully loaded (DNV-GL).* (As DNV-GL note, these minimum values apply only for ship with a speed length ratio ($V/\sqrt{L}$) greater than three)

β_{cg} = deadrise angle in degrees at LCG (minimum 10°, maximum 30°)

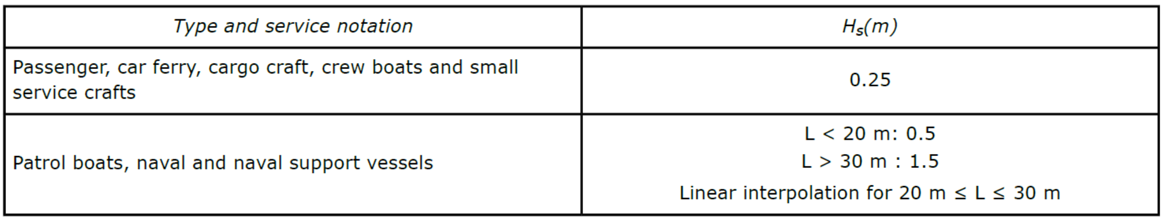
B_{WL2} = greatest moulded breadth of the hull(s) in m at the fully loaded waterline (with the craft at rest) measured at L/2. For multihull craft B_{WL2} is the net sum of the waterline breadths

Δ = displacement, in tonnes, as defined in *4.1.2.4 Det Norske Veritas - Germanischer Lloyd (D)*

k_h = Hull type factor given in *Table 4.2.5 Hull type facto (DNV-GL)*

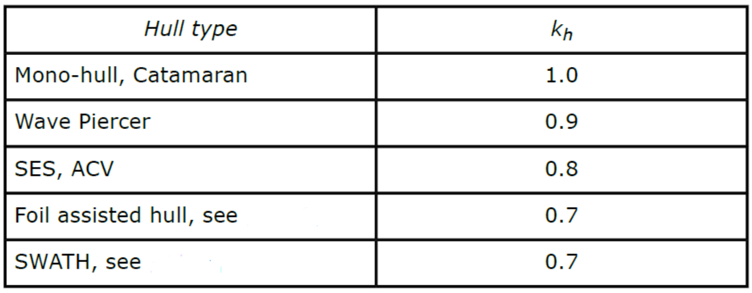
L = length of the craft in metres, see *4.1.2.4 Det Norske Veritas - Germanischer Lloyd (D)*

Table 4.2. 4 Minimum significant wave height Hs in m at maximum speed fully loaded (DNV-GL)



Type and service notation	*H_s(m)*
Passenger, car ferry, cargo craft, crew boats and small service crafts	0.25
Patrol boats, naval and naval support vessels	L < 20 m: 0.5 L > 30 m : 1.5 Linear interpolation for 20 m ≤ L ≤ 30 m

Table 4.2. 5 Hull type facto (DNV-GL)



Hull type	*k_h*
Mono-hull, Catamaran	1.0
Wave Piercer	0.9
SES, ACV	0.8
Foil assisted hull, see	0.7
SWATH, see	0.7

DNV-GL continues by specifying minimum design vertical acceleration that depends on service restriction defined in *4.1.2.4 Det Norske Veritas - Germanischer Lloyd (D)*, a maximum value for all types of craft and the longitudinal distribution of vertical acceleration along the hull, which is calculated as in equation (4.2.9) given in *4.2.2.3 Bureau Veritas (HSC/VA).*

According to DNV-GL the design vertical acceleration shall not be taken less than:

a_{cg} = 1,0g_0 for service restrictions R0-R4
a_{cg} = 0,5g_0 for service restrictions R5-R6
g_0 = standard acceleration of gravity (9,81 m/sec^2)

Or, more analytical for crafts in restricted service areas of R0-R4, the design vertical acceleration shall not be taken less than:

$$a_{cg} = c_{HSLC} \cdot C_{RW} \cdot \frac{V_i}{\sqrt{L}} \; (m/s^2) \qquad (4.2.14)$$

C_{RW} = service range coefficient
= 1,00 for unlimited service range R0
= 0,90 for restricted service area R1
= 0,75 for restricted service area R2
= 0,66 for restricted service area R3
= 0,60 for restricted service area R4

Table 4.2. 6 C-factor (DNV-GL)

Craft character	Passenger, Car Ferry, Cargo Craft, Yacht, Service	Patrol
c_{HSLC}	0.24	0.36

Lastly, the design vertical acceleration a_{cg} needs not be taken greater than 6,0 g's.

4.2.2.5 Registro Italiano Navale (HSC/VA)

As it was mentioned in *4.2.2.3 Bureau Veritas (HSC/VA),* rules and regulations on HSC was established along by BV, RINA and Germanischer Lloyd. Furthermore, RINA singly published *Rules for the Classification of High-Speed Craft (January 2009),* this edition contains a revision of the rules mainly including two set of amendments, effective from 1 July 2006 and 1 July 2008, already published with RINA Circulars 3493/A on 29 June 2006 and 3559/A on 27 June 2008.

However, no changes were made that affect design vertical acceleration, thus no further comments are referred, as the rules are the same as in 4.2.2.3 Bureau Veritas (HSC/VA).

4.2.2.6 Conclusion (HSC/VA)

All classification societies considered have managed to include requirements on the most crucial matter, such as the vertical acceleration of a craft at LCG and how it is distributed along the whole length of the craft.

Parameters for these calculations that are common among the societies are moulded waterline breadth, the significant wave height, the displacement, the velocity and the deadrise angle, while the factor $(\frac{significant\ wave\ height}{waterline\ breadth} + 0{,}084)$ is present on every formula that concerns craft operating in the non-displacement mode or has a ratio of $V/\sqrt{L} \geq 3$. Specifically vertical acceleration is proportional the square of velocity, the square of waterline breadth, the factor $(50 - deaderise\ angle)$ and factor $(\frac{significant\ wave\ height}{waterline\ breadth} + 0{,}084)$. Furthermore it should be mentioned that trim is also applied on these formulas except the one of DNV-GL.

As per inclusions, LR is the only one to provide distinct formula for crafts operating in the displacement mode. However BV (and RINA) and DNV-GL propose equations for crafts with $V/\sqrt{L} < 3$, which is often the case for defining that a craft operates in the displacement mode. On the other hand, while LR makes that distinction clear, does not provide equation or comments on vertical acceleration's minimum value, as other societies.

4.2.2.7 Example Calculations at Longitudinal Center of Gravity (HSC/VA)

The examined vessel is a mono-hull high-speed craft with a $V/\sqrt{L}$ ratio equal to $4{,}56$, thus the results given in *Figure 4.2.3 Vertical Acceleration at LCG* have been produced using the requirements of *Section 4.2 High-Speed Craft* accordingly.

LR vertical acceleration at LCG according to *equation 4.2.1.*

ABS evaluation of vertical acceleration has been taken as in *equation* 4.2.5.

BV and RINA evaluation of vertical acceleration, equation *4.2.10,* was less than the value of equation *4.2.8*, which correspond to BV and RINA minimum value. Hence equation *4.2.8* was used taking *foc* equal to 0,666 and *Soc* equal to 0,3, from *Table 4.2.2 foc values (BV)* and *Table 4.2.3 Soc values (BV)*, respectively.

DNV-GL indications for vertical acceleration at LCG suggest that *equation 4.2.12* is to be used.

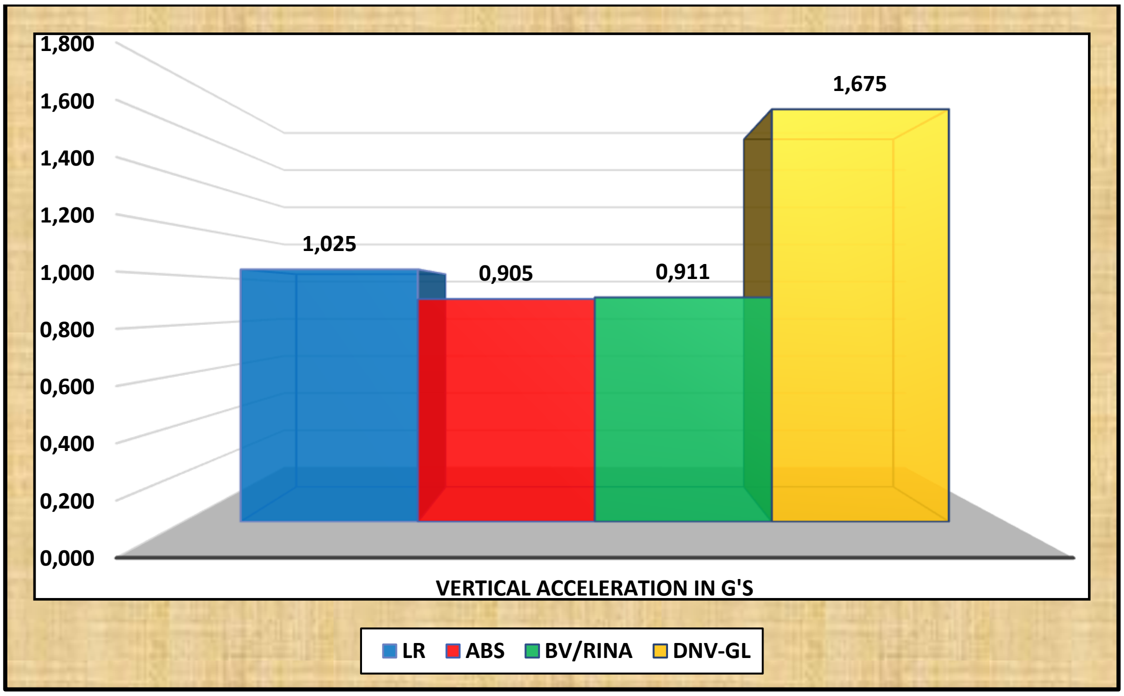


Figure 4.2. 3 Vertical Acceleration at LCG

The aforementioned calculations, as shown also in *Figure 4.2. 3 Vertical Acceleration at LCG,* result to great discrepancies, especially considering the vertical acceleration value of DNV-GL. This differences may be due to safety factors within classification societies' equation. To illustrate that, the equations are rewritten below in a homogenous form, marking with red colour the steady factor and factors that are not used by all societies.

- LR, eq. *4.2.1:* $a_V = 1{,}5 \cdot \Theta_B \cdot {b_c}^3 \cdot 10^{-4} \cdot (\frac{H_{1/3}}{B_W} + 0{,}084) \cdot (50 - \Theta_D) \cdot \frac{V^2 \cdot {B_W}^2}{\Delta}$
- ABS, eq. 4.2.5: $n_{cg} = 0{,}0078 \cdot 12 \cdot \tau \cdot 10^{-3} \cdot (\frac{h_{1/3}}{B_W} + \frac{1}{12}) \cdot (50 - \beta_{cg}) \cdot \frac{V^2 \cdot {B_W}^2}{\Delta}$
- BV & RINA, eq. 4.2.10: $a_{cg} = \frac{1}{3555 \cdot C_b} \cdot (\frac{\tau}{16} + 0{,}075) \cdot (\frac{H_s}{B_W} + 0{,}084) \cdot (50 - \alpha_{dcg}) \cdot \frac{V^2 \cdot {B_W}^2}{\Delta}$
- DNV-GL, eq. 4.2.12: $a_{cgi} = \frac{1}{1650} \cdot (\frac{H_s}{B_W} + 0{,}084) \cdot (50 - \beta_{cg}) \cdot \frac{V^2 \cdot {B_W}^2}{\Delta}$

Where,

V = Speed in knots
$H_{si}, H_{1/3,}\, h_{1/3}$ = significant wave height in m
$\beta_{cg,}\, \Theta_D,\ \alpha_{dcg}$ = deadrise angle in degrees at LCG (minimum 10°, maximum 30°)
B_W = greatest moulded breadth of the hull(s) in m at the fully loaded waterline, in m
Δ = displacement, in tonnes,
Θ_B, τ = Running trim, in m
b_c = $\frac{B_C}{B_W}$, a coefficient made by the author to get the equations in a common form
B_C = breadth of hull between the chines or bilge tangential points at LCG, as appropriate, in metres
C_b = Block coefficient, as defined by BV/RINA

Note also that $\frac{1}{12} \cong 0{,}084$.

It is almost obvious, even without calculation, that the constant factor of DNV-GL is higher the anyone else's. Using the particulars of the hypothetical ship, the marked red factors are calculated and are given below:

- LR, eq. *4.2.1:* $a_V = 3{,}70 \cdot 10^{-4} \cdot (\frac{H_{1/3}}{B_W} + 0{,}084) \cdot (50 - \Theta_D) \cdot \frac{V^2 \cdot {B_W}^2}{\Delta}$
- ABS, eq. 4.2.5: $n_{cg} = 3{,}27 \cdot 10^{-4} \cdot (\frac{h_{1/3}}{B_W} + \frac{1}{12}) \cdot (50 - \beta_{cg}) \cdot \frac{V^2 \cdot {B_W}^2}{\Delta}$
- BV & RINA, eq. 4.2.10: $a_{cg} = 2{,}79 \cdot 10^{-4} \cdot (\frac{H_s}{B_W} + 0{,}084) \cdot (50 - a_{dcg}) \cdot \frac{V^2 \cdot {B_W}^2}{\Delta}$
- DNV-GL, eq. 4.2.12: $a_{cgi} = 6{,}06 \cdot 10^{-4} \cdot (\frac{H_s}{B_W} + 0{,}084) \cdot (50 - \beta_{cg}) \cdot \frac{V^2 \cdot {B_W}^2}{\Delta}$

It is more obvious now, that DNV-GL uses the highest safety factor. Take into consideration that the marked red value of DNV-GL is fixed, while for the rest of the societies depends strongly on trim angle. An interesting study would be to correlate which society gives higher vertical acceleration depending on the trim and the maximum allowable values of it.

To remind, eq. 4.2.10, is not the one that used for *Figure 4.2. 3 Vertical Acceleration at LCG*, see the start of the present sub-section.

4.2.3 Pressures on Bottom Shell (HSC/PBS: Pressure on Bottom Shell)

4.2.3.1 Lloyd's Register (HSC/PBS)

Generally the design pressures that act on the shell envelope are to include effects of static, dynamic and impact loads. In *Rules and Regulations for the Classification of Special Service Craft (July 2018) Pt. 5, Ch. 2, Sec. 4,* by LR, rules concerning both static and dynamic loads are contained, while in the next section, Sec. 5, rules on impact (or slamming) loads are contained.

Firstly, LR makes provision on hydrostatic and hydrodynamic pressures that act on the whole shell plating envelope, without dividing the envelope to individual subparts. Thus, when, later on this thesis, other parts of the craft (e.g. side shell, decks etc.) would be investigated, references would be made to the following regulations concerning this matter.

The pressure, P_h, acting on the shell plating up to the operating waterline due to hydrostatic pressure is to be taken as:

$$P_h = 10\left(T_x - (z - z_k)\right) kN/m^2 \qquad (4.2.15)$$

Where,

T_x = local draught to operating waterline as defined in *4.1.2.1 Lloyd's Register (D)*
z = vertical distance, in metres, as defined in *4.1.2.1 Lloyd's Register (D)*
z_k = vertical distance of the underside of the keel above the baseline, in metres as defined in *4.1.2.1 Lloyd's Register (D)*

Considering hydrodynamic wave pressure due to relative motion, P_w, around the shell envelope up to the operating waterline, i.e. z ≤ T, LR provides two pressure formulas, P_m and P_p, the greater of which is to be taken as P_w. The two formulas are presented below:

$$P_m = 10 \cdot f_z \cdot H_{rm} \;\; kN/m^2 \tag{4.2.16}$$

Where,

f_z = $k_z + (1 - k_z) \cdot (\frac{z - z_k}{T_x})$, the vertical distribution factor
k_z = e^{-u}
u = $(\frac{2\,\pi\,T_x}{L_{WL}})$
H_{rm}= relative motion as defined in *4.1.2.1 Lloyd's Register (D)*
T_x = local draught to operating waterline as defined in *4.1.2.1 Lloyd's Register (D)*
z = vertical distance, in metres, as defined in *4.1.2.1 Lloyd's Register (D)*
z_k = vertical distance of the underside of the keel above the baseline, in metres as defined in *4.1.2.1 Lloyd's Register (D)*
L_{WL}= waterline length, in metres, as defined in *4.1.2.1 Lloyd's Register (D)*

And

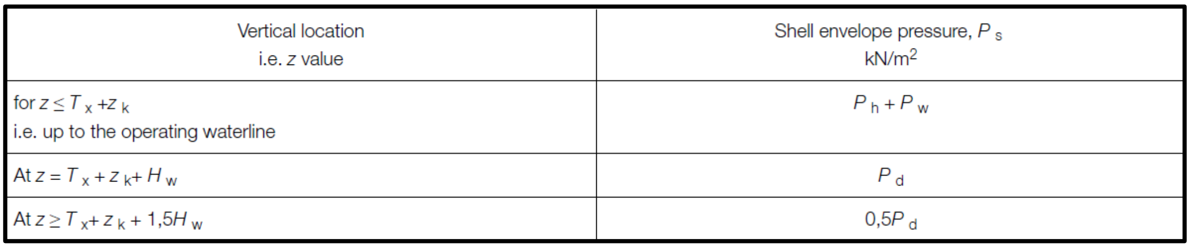
$$P_p = 10 \cdot H_{pm} \;\; kN/m^2 \tag{4.2.17}$$

Where,

H_{pm} = $1{,}1 \cdot (\frac{2 \cdot x_{wl}}{L_{WL}} - 1) \cdot \sqrt{L_{WL}}$, but not less than $f_L \cdot \sqrt{L_{WL}}$
f_L = 0,6 for L_{WL} < 60
= 1,5 - 0,015 L_{WL} for 60 ≤ L_{WL} ≤ 80
= 0,3 for L_{WL} > 80
L_{WL}= waterline length, in metres, see *4.1.2.1 Lloyd's Register (D)*
x_{wl} = longitudinal distance, in metres, measured forwards from the aft end of the L_{WL} to the position or centre of gravity of the item being considered

The total pressure distribution, P_s, in kN/m^2 due to hydrostatic and hydrodynamic pressures is to be taken as in *Table 4.2.7 Combined pressure distribution (LR).* LR also provides an illustrated version of the table presented as in *Figure 4.2.4 Combined pressure distribution (LR).* Pressure values at other z values of the table are to be derived by interpolation.

Table 4.2. 7 Combined pressure distribution (LR)



Vertical location i.e. z value	Shell envelope pressure, P_s kN/m^2
for $z \leq T_x + z_k$ i.e. up to the operating waterline	$P_h + P_w$
At $z = T_x + z_k + H_w$	P_d
At $z \geq T_x + z_k + 1{,}5H_w$	$0{,}5P_d$

Where,

H_w= the nominal wave limit height as defined below
P_d = weather deck pressure as defined *4.2.5.1 Lloyd's Register (HSC/PD)*
P_h = hydrostatic pressure,, as previously defined
P_w = hydrodynamic wave pressure, as previously defined
T_x, z, z_k= As defined in , see *4.1.2.1 Lloyd's Register (D)*

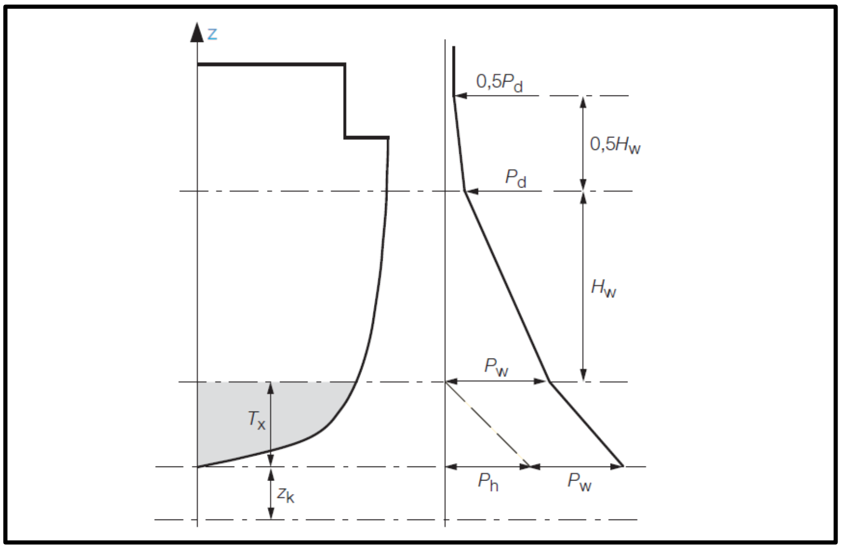


Figure 4.2. 4 Combined pressure distribution (LR)

The nominal wave limit height, H_w, above the design draft T_x is to be taken as:

$$H_w = 2 \cdot H_{rm} \quad m \tag{4.2.18}$$

Where, H_{rm}, relative motion as is defined in *4.1.2.1 Lloyd's Register (D).*

As for impact loads, LR provides common equation for mono-hull and multi-hull crafts on calculating impact pressure, but this is not the case for crafts operating in displacement and non-displacement mode. The bottom shell impact pressure, P_{dh}, due to bottom slamming for displacement mode is to be taken as follows:

$$P_{dh} = \Phi_{dh} \cdot (19 - 2720 \cdot \left(\frac{T_x}{L_{WL}}\right)^2) \cdot \sqrt{L_{WL} \cdot V} \quad kN/m^2 \tag{4.2.19}$$

$$P_{dh} \geq P_m$$

Where,

Φ_{dh} = 0,09 at L_{WL} from aft end of L_{WL}
= 0,18 at 0,9$L_{WL}$from aft end of L_{WL}
= 0,18 at 0,8L_{WL} from aft end of L_{WL}
= 0,0 between aft end of L_{WL} and 0,5L_{WL} from aft end of L_{WL}
Intermediate values to be determined by linear interpolation.
L_{WL} = waterline length, in metres, see *4.1.2.1 Lloyd's Register (D)*
V = allowable speed, in knots, see *4.1.2.1 Lloyd's Register (D)*
T_x = is taken to be the draught T, as defined, but need not be taken greater than 0,08 L_{WL}

P_{dh} at 0,9L_{WL} and 0,8L_{WL} from aft end of L_{WL} need not be taken greater than P_f at L_{WL} from aft end of L_{WL} as defined in *4.2.6.1 Lloyd's Register (HSC/PF).*

As per crafts that operate in the non-displacement mode, the bottom impact pressure due to slamming is given by the following expression, which applies to both mono-hull and multi-hull crafts:

$$P_{dlb} = \frac{f_d \cdot \Delta \cdot \Phi \cdot (1 + \alpha_v)}{L_{WL} \cdot G_o} \quad kN/m^2 \tag{4.2.20}$$

Where,

G_o = support girth or girth distance, in metres, as defined in *Table 4.2.8 Definition of Go for the determination of bottom impact pressure, Pdl for different regions of the hull (LR)*
L_{WL} = waterline length, in metres, see *4.1.2.1 Lloyd's Register (D)*
a_V = is the vertical acceleration, as defined in *Table 2.2.1 Lloyd's Register (HSC/VA)*
Δ = Displacement, in t, as *4.1.2.1 Lloyd's Register (D)*
f_d = hull form pressure factor
= 54 for mono-hull craft
= $\frac{81}{N_H}$ for catamarans and multi-hull craft, where
N_H = is the number of hulls, but it is not to be taken as greater than four
Φ = 0,5 at L_{WL} from aft end of L_{WL}
= 1,0 at 0,75L_{WL} from aft end of L_{WL}
= 1,0 at 0,5L_{WL} from aft end of L_{WL}
= 0,5 at aft end of L_{WL}
Intermediate values to be determined by linear interpolation.
Otherwise, **Φ**= 1,0

Table 4.2. 8 Definition of Go for the determination of bottom impact pressure, Pdl for different regions of the hull (LR)

Bottom shell region	Go	
	Craft with chines	Craft without chines
Between tangential points or chines	Gs	Gs
Between tangential points and design waterline	-	Gwl
Note 1. Gs = support girth, in metres, as defined in *4.1.2.1 Lloyd's Register (D)* Note 2. Gwl = girth distance, in metres, measured between the waterlines on either side of a hull at the LCG.		

Lastly, LR include regulations on impact pressures especially for crafts with foils and lifting devices, a feature inserted in the rules only by LR. Having said that, the bottom impact pressure, P_{fb}, for craft supported by hydrodynamic lift provided by foils or other lifting devices is given by the greater of P_{fba} or P_{fbb}, where:

$$P_{fba} = \frac{16}{L_{WL}} (H_{03} + \sqrt{H_0 \cdot L_{WL}})^2 \; kN/m^2 \tag{4.2.21}$$

$$P_{fbb} = \frac{1}{3} \cdot K_{po} \cdot V_R \cdot V \left(1 - \frac{H_0}{H_{03}}\right)\ kN/m^2 \qquad (4.2.22)$$

Where,

K_{po} = longitudinal distribution factor
= 1,0 between the aft end of the L_{WL} and $0{,}75L_{WL}$
= 2,0 at L_{WL} from the aft end of L_{WL}, intermediate values to be determined by linear interpolation
H_0 = operational height of craft, in metres, measured from the waterline to the top of the keel at LCG
H_{03} = surviving wave height as defined, but is not taken as less than 1,0
L_{WL} = waterline length, in metres, see *4.1.2.1 Lloyd's Register (D)*
V = allowable speed in knots, as defined in *4.1.2.1 Lloyd's Register (D)*
V_R = is the relative vertical speed of the craft at impact, in knots. If this value is unknown, then the following equation is to be used: $V_R = \frac{8 \cdot H_{1/3}}{\sqrt{L_{WL}}} + 2\ knots$

P_{fbb} is not taken less than zero

Regulations presented on this segment are to be used in conjunction with requirements of *4.2.8 Local Design Criteria by Lloyd's Register,* as appropriate.

4.2.3.2 American Bureau of Shipping (HSC/PBS)

In *Rules for Building and Classing High-Speed Craft (October 2018)* Pt. 3, Ch. 2, Sec. 3, ABS indications on design pressures are given. However, rules of ABS are not having the same extent as LR, as they do not include requirements on hydrodynamic pressure, not having special specifications for crafts with hydro foil or other lifting device and neither making distinctions on the formulas based on the operation mode of the crafts. Nevertheless, in hydrostatic pressure's equation 4.2.23, the factor that include wave parameter *H*, $0{,}64N_3 \cdot H$, may express hydrodynamic wave pressure distribution due to relative motion, as LR pressure P_W.

Furthermore, ABS divides the previous referenced section into segments that regulate mono-hulls and multi-hulls and surface effect craft. Despite that, the formulas given on hydrostatic pressure and on impact pressure due to bottom slamming are similar for both categories. This occurs as they only differ on the number of hulls factor, N_h, which appears in the multi and surface effect crafts' bottom slamming pressure equations and when N_h takes the value 1 the equation transpose to the mono-hulls' one. On this thesis they will presented as common rules for mono-hulls and multi-crafts.

According to LR the bottom design pressure is to be the greater of those, as given in the following equations, for the location under consideration.

The hydrostatic pressure is to be taken as follows:

$$p_d = N_3 \cdot (0{,}64 \cdot H + d)\ kN/m^2 \qquad (4.2.23)$$

The bottom slamming pressure acting at LCG and at any section clear of the LCG is to be taken as the following equations, respectively:

$$p_{bcg} = \frac{N_1 \cdot \mathit{\Delta}}{L_w \cdot N_h \cdot B_w}\left[1 + n_{cg}\right]F_D \; kN/m^2 \qquad (4.2.24)$$

$$p_{bxx} = \frac{N_1 \cdot \mathit{\Delta}}{L_w \cdot N_h \cdot B_w}\left[1 + n_{xx}\right]\left[\frac{70 - \beta_{bx}}{70 - \beta_{cg}}\right] \cdot F_D \; kN/m^2 \qquad (4.2.25)$$

Additionally, ABS provides specific equation for craft less than 61 meter, which is similar to equation 4.2.24 times factor F_V as ti is shown below:

$$p_{bxx} = \frac{N_1 \cdot \mathit{\Delta}}{L_w \cdot N_h \cdot B_w}\left[1 + n_{cg}\right]F_D \cdot F_V \; kN/m^2 \qquad (4.2.26)$$

Where,

p_{bcg} = bottom design pressure at LCG

p_{bxx} = bottom design pressure at any section clear of LCG

p_d = bottom design pressure based on hydrostatic forces

n_{cg} = the average 1/100 highest vertical accelerations at LCG, as defined in *4.2.2.2 American Bureau of Shipping (HSC/VA)*

n_{xx} = average of the 1/100 highest vertical accelerations, at any section clear of LCG, as defined in *4.2.2.2 American Bureau of Shipping (HSC/VA)*

N_1 = 0,1

N_3 = 9,8

$\mathit{\Delta}$ = Displacement in kg, as defined in *4.1.2.2 American Bureau of Shipping (D)*

L_W = waterline length, in metres, see *4.1.2.2 American Bureau of Shipping (D)*

B_w = maximum waterline beam, in metres, (of one hull for multi-hulls)

H = wave parameter, 0,0172L + 3,653 m, generally not to be taken less than the maximum survival wave height for the craft

$h_{1/3}$ = significant wave height, m, see *Table 4.2.1 Design Significant Wave Heights and Speed (ABS)*

β_{bx} = deadrise at any section clear of LCG, in degrees, not to be taken less than 10° nor greater than 30°, see *Figure 4.2.5 Deadrise, Flare, and Entry Angles (ABS)*

β_{cg} = deadrise at LCG, degrees, generally not to be taken less than 10° nor more than 30°

V = craft design speed in knots, see *Table 4.2.1 Design Significant Wave Heights and Speed (ABS)*

N_h = Number of hulls

F_D = design area factor given in *Figure 4.2.6 Design Area Factor F_D (ABS),* for given values of A_D and A_R. Generally not to be taken less than 0,4. *Table 4.2.9 Minimum Values for F_D (ABS)* for minimum values of F_D for craft less than 24 m in length.

A_D = design area, cm^2. For plating it is the actual area of the shell plate panel but not to be taken as more than 2,5s^2. 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 0.33l^2

A_R = reference area, cm^2, 6,95Δ/d cm^2

s = spacing of longitudinals or stiffeners, in cm

l = unsupported span of internals, in cm.

d = stationary draft, in m, 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.

F_V = vertical acceleration distribution factor given in *Figure 4.2.7 Vertical Acceleration Distribution Factor Fv (ABS)*

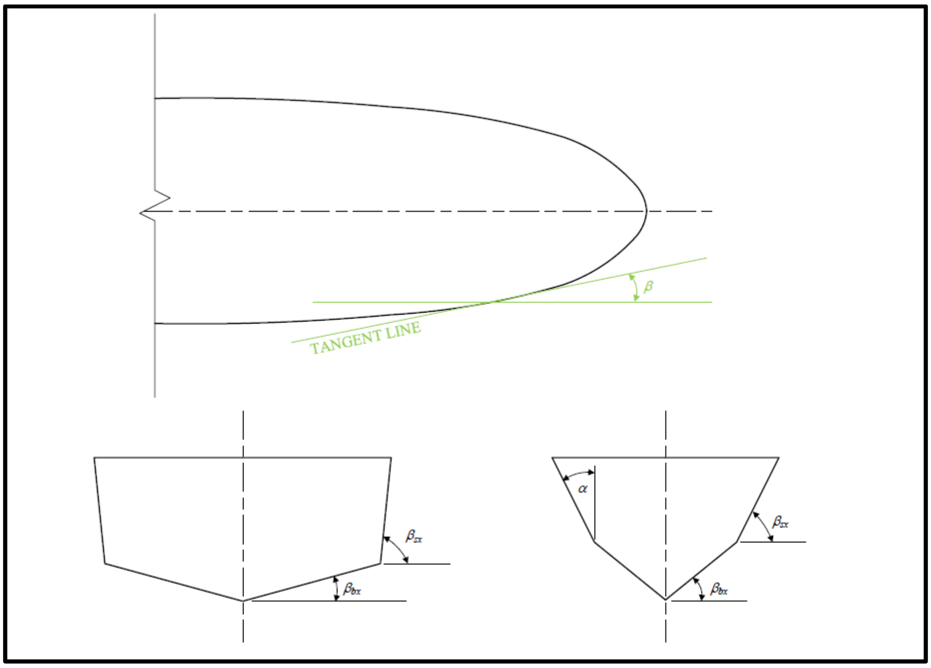


Figure 4.2. 5 Deadrise, Flare, and Entry Angles (ABS)

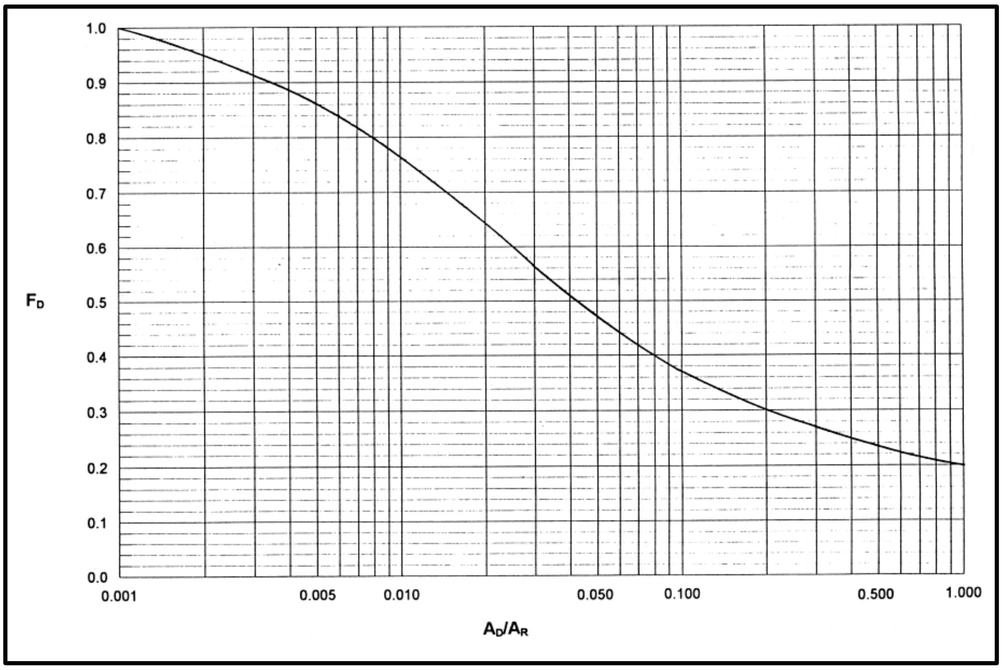


Figure 4.2. 6 Design Area Factor FD (ABS)

Table 4.2. 9 Minimum Values for FD (ABS)

s mm (in.)	F_D
250 (9.75)	0.85
500 (16.75)	0.75
750 (29.5)	0.60
1000 (39.25)	0.50
1250 (49.25)	0.40

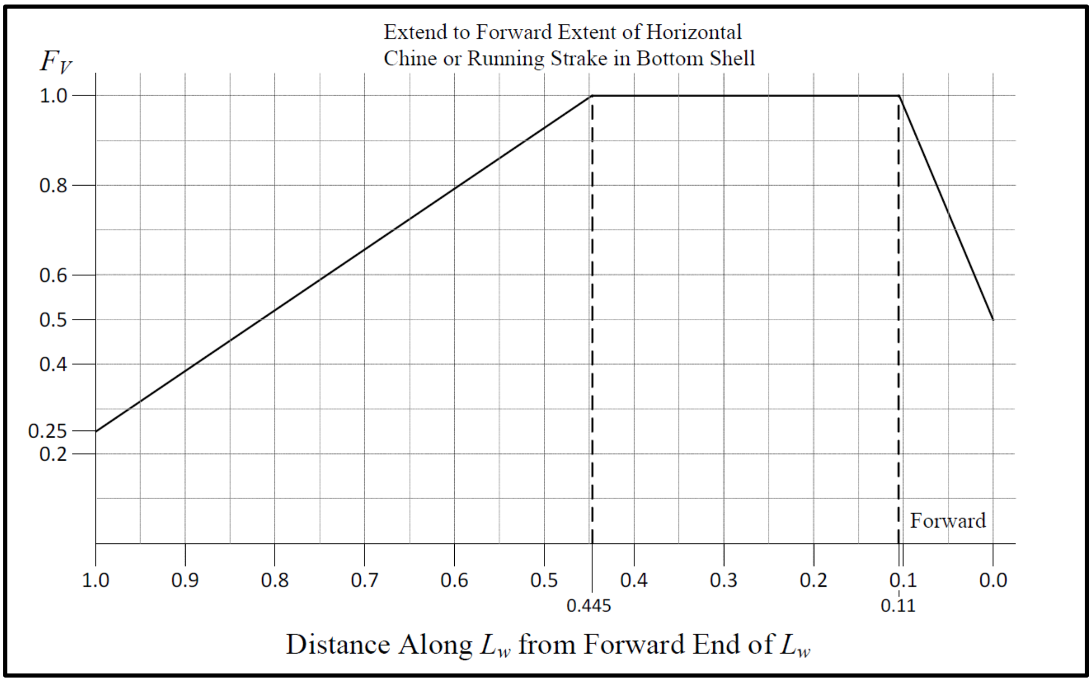


Figure 4.2. 7 Vertical Acceleration Distribution Factor F_V (ABS)

4.2.3.3 Bureau Veritas (HSC/PBS)

In *Rules for the Classification of High Speed Craft (February 2002)* segment C3.5 rules on the design pressures of the craft, by BV are given. Firstly the impact pressures due to bottom slamming are presented and then the sea pressures due to hydrostatic heads and wave loads.

Concerning the sea pressures, BV does not indicate distinct formulas on hydrostatic pressures and wave load as LR, but implements a combined formula, whose value the sea pressure should exceed. So, according to BV, the sea pressure, in kN/m^2, considered as acting on the bottom and side shell is not to be less than p_{smin}, defined in *Table 4.2.10 S and* p_{smin} *minimum value (BV)*, nor less than:

$$\begin{gathered} for\ z \leq T: \\ p_s = 10 \cdot \left(T + 0{,}75 \cdot S - \left(1 - 0{,}25 \cdot \frac{S}{T}\right) \cdot z\right)\ kN/m^2 \\ for\ z\ > T \\ p_s = 10 \cdot (T + S - z)\ kN/m^2 \end{gathered} \tag{4.2.27.a}$$

Where,

z = Vertical distance, in m, from the moulded base line to load point. z is to be taken positively upwards

S = As given, in m, in *Table 4.2.10 S and p$_{smin}$ minimum value (BV)* with C_B, taken not greater than 0,5

Table 4.2. 10 S and psmin range value (BV)

	S	p$_{smin}$
x/L ≥ 0,9	$T \leq 0,\ 36 \cdot a_{CG} \cdot \frac{\sqrt{L}}{C_B} \leq 3,\ 5 \cdot T$	$20 \leq \frac{L + 75}{5} \leq 35$
x/L ≤ 0,5	$T \leq 0,\ 60 \cdot a_{CG} \cdot \sqrt{L} \leq 2,\ 5 \cdot T$	$10 \leq \frac{L + 75}{10} \leq 20$

Where

a_{cg} = vertical acceleration at LCG as defined in *4.2.2.3 Bureau Veritas (HSC/VA), equation 4.2.8*
C_B = Block coefficient, as defined in *4.1.2.3 Bureau Veritas (D)*
L = Rule length, in m as defined in *4.1.2.3 Bureau Veritas (D)*
T = Draft as defined in *4.1.2.3 Bureau Veritas (D)*

BV supplements on the matter that between midship area and fore end (0,5 < x/L < 0,9), p_s varies in a linear way. At this region the p_s should be taken as in equation *4.2.27.b*, where p_{sFP} is the sea pressure at fore end and p_{sM} at midship area.

$$p_s = p_{sFP} - \left(2{,}25 - 2{,}5 \cdot \frac{x}{L}\right) \cdot (p_{sFP} - p_{sM})\ kN/m^2 \tag{4.2.28.b}$$

More over the impact pressure due to bottom slamming acting on the bottom of the hull is to be taken not less than:

$$p_{si} = 70 \cdot \frac{\Delta}{S_r} \cdot K_1 \cdot K_2 \cdot K_3 \cdot a_{cg}\ kN/m^2 \tag{4.2.29}$$

Where,

Δ = Displacement, in tonnes as defined, For catamaran, Δ in the above formula is to be taken as half of the craft displacement
S_r = Reference area, in m^2, equal to $S_r = 0{,}7 \cdot \frac{\Delta}{T}$
For catamaran, Δ in the above formula is to be taken as half the craft displacement
K_1 = longitudinal bottom impact pressure distribution factor, see *Figure 4.2.8 Longitudinal Bottom Impact Pressure Distribution Factor (BV)*

= for x/L < 0,5: K_1 = 0,5 + x/L

= for 0,5 ≤ x/L ≤ 0,8: K_1 = 1,0

= for x/L > 0,8: K_1 = 3,0 − 2,5 · x/L

where x is the distance, in m, from the aft perpendicular to the load point

K_2 = factor accounting for impact area, equal to:

$K_2 = 0{,}455 - 0{,}35 \cdot \frac{u^{0{,}75} - 1{,}7}{u^{0{,}75} + 1{,}7}$, with:

= K_2 ≥ 0,50 for plating,

= K_2 ≥ 0,45 for stiffeners,

= K_2 ≥ 0,35 for girders and floors,

$u = 100 \cdot \frac{s}{S_r}$

where s is the area, in m^2, supported by the element (plating, stiffener, floor or girder). For plating, the supported area is the spacing between the stiffeners multiplied by their span, without taking for the latter more than three times the spacing between the stiffeners

K_3 = factor accounting for shape and deadrise of the hull, equal to:

$K_3 = (70 - a_d)/(70 - a_{dCG})$

where a_{dCG} is the deadrise angle, in degrees, measured at LCG and a_d is the deadrise angle, in degrees, between horizontal line and straight line joining the edges of respective area measured at the longitudinal position of the load point; values taken for a_d and a_{dCG} are to be between 10° and 30°

a_{cg} = vertical acceleration at LCG as defined in *4.2.2.3 Bureau Veritas (HSC/VA), equation 4.2.8*

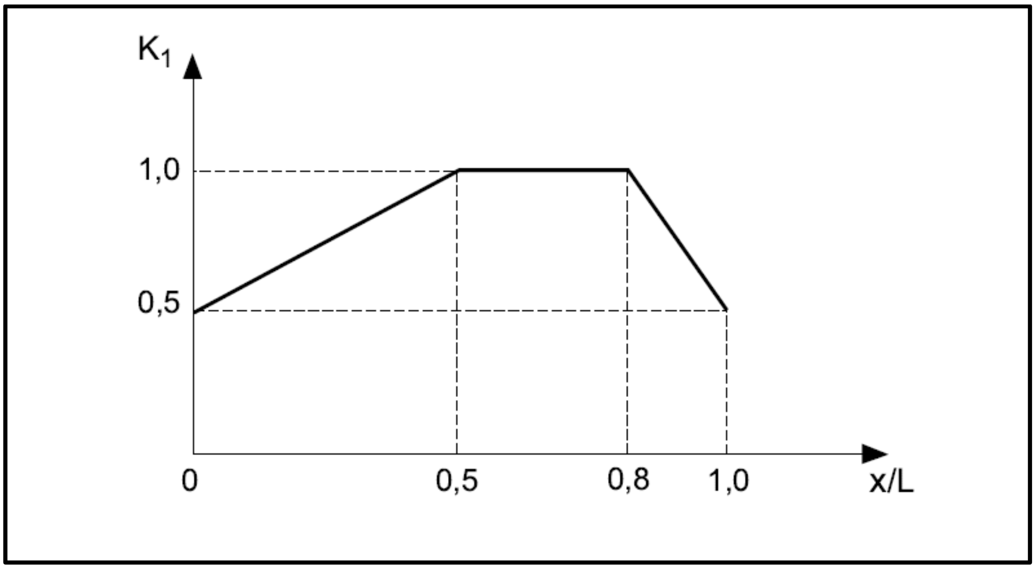


Figure 4.2. 8 Longitudinal Bottom Impact Pressure Distribution Factor (BV)

4.2.3.4 Det Norske Veritas - Germanischer Lloyd (HSC/PBS)

Alike BV, in *Rules for Classification: High speed and light craft (January 2018),* Pt. 3, Ch. 1, Sec. 3, DNV-GL suggests a formula that corresponds generally to sea pressures and does not make distinctions on hydrostatic pressure and wave load. In this case though, DNV-GL formula may relate more to hydrostatic pressures, as its variables mainly express the hull's morphology and the draught of the craft, also the factor of vertical acceleration is absent.

Moreover, DNV-GL equation concerns not only bottom and side shell, but applies to superstructure side, deckhouse side and weather decks. Sea pressure shall be taken as:

for load point below design waterline:

$$p = a\left(10 \cdot h_0 + \left(k_s - 1{,}5 \cdot \frac{h_0}{T}\right) \cdot C_w\right) \quad kN/m^2$$

for load point above design waterline:

$$p = a \cdot k_s \cdot (C_w - 0{,}67 \cdot h_0) \qquad kN/m^2 \tag{4.2.30}$$

Where,

h_0 = vertical distance in m from the waterline at draught T to the load point. Always to be given a positive value.

k_s = 7,5 aft of amidships

= 5/*C_B* forward of FP.

Between specified areas k_s shall be varied linearly, see *Figure 4.2.9 Sea load distribution factor (DNV-GL)*

a = *load intensity factor according to Table 4.2.11 Load intensity factors (a) for weather exposed areas (DNV-GL)*

C_w = wave coefficient, as defined in *4.1.2.4 Det Norske Veritas - Germanischer Lloyd (D)*

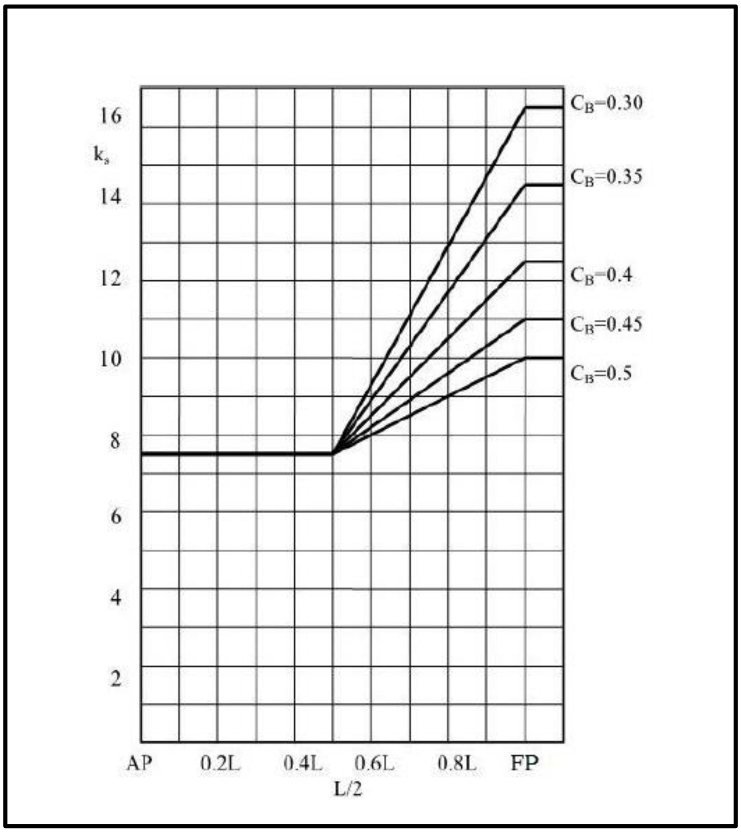


Figure 4.2. 9 Sea load distribution factor (DNV-GL)

Table 4.2. 11 Load intensity factors (a) for weather exposed areas (DNV-GL)

Location		*General (all types of crafts)*
Bottom, side and transom		1.0
Deck	Weather deck	1.0
	Weather deck higher than 0.1 *L* above WL	0.8
Deckhouse side		0.8
Front bulkhead	1st tier	2.0
	Other fronts	0.8
End bulkhead		0.8

Minimum sea pressure for each counterpart are given by DNV-GL as in *Table 4.2.12 Minimum sea pressures (kN/m^2) (DNV-GL).*

Table 4.2. 12 Minimum sea pressures ($\mathrm{kN/m^2}$) (DNV-GL)

Location		*Service restriction notation*		
		Unrestricted – R0	*R1 – R3*	*R4 – R6*
Bottom, side and transom		6.5	5.0	3.0
Deck	Weather deck	5.0	4.0	3.0
	Weather deck higher than 0.1 L above WL	3.0	3.0	3.0
Deckhouse side		5.0	4.0	3.0
Front bulkhead	1st tier	5 + (5 + 0.05L) sin α		5.0
	Other fronts	5 + 0.025L sin α		5.0
End bulkheads		5.0	4.0	3.0
Where α is the angle between the bulkhead and the deck.				

In the referenced section there are inclusions on the design slamming pressure on the bottom of the craft. The formula provided by DNV-GL is quite similar to BV's, as it would be discussed in following paragraph. According to DNV-GL, only for crafts with speed $V/\sqrt{L} \geq 3$, the design slamming pressure shall be taken as follows:

$$p_{sl} = \frac{a_{CG} \cdot \mathit{\Delta}}{0{,}14 \cdot A_{ref}} \cdot K_{red} \cdot K_l \cdot K_\beta \qquad kN/m^2 \tag{4.2.31}$$

Where,

A_{ref} = reference area from impact loads, $A_{ref} = 0{,}7 \cdot \frac{\mathit{\Delta}}{T}$

K_{red} = reduction factor for design load area

$K_{red} = 0{,}445 - 0{,}35 \cdot \frac{u^{0{,}75}-1{,}7}{u^{0{,}75}+1{,}7}$, with:

$u = 100 \cdot \frac{n \cdot A}{A_{ref}}$

n = number of hulls, 1 for mono hull, 2 for catamaran, trimaran and other multi hulls will be specially considered

A = design load area for element considered in m^2

= For plates, stiffeners and girders A shall be taken as spacing x span (*sl*)

= For plates A shall not be taken greater than 2.5 s^2

A need not for any structure be taken less than 0,002 $\frac{\Delta}{T}$

K_l = longitudinal distribution factor from *Figure 4.2.10 Longitudinal slamming pressure distribution factor for high speed mode slamming (DNV-GL)*

K_β = correction factor for local deadrise angle

$$K_\beta = \frac{50 - \beta_x}{50 - \beta_{cg}}$$

β_x = deadrise angle in degrees at transverse section considered (minimum 10°, maximum 30°), not to be taken less than β_{cg} aft of LCG

DNV-GL also indicates that β_x shall be determined as the angle of the tangent of the hull shell at the centre of the loaded element as shown in *Figure 4.2.11 Panel angle β$_x$ (DNV-GL)* a) to b).

β_{cg} = deadrise angle in degrees at LCG (minimum 10°, maximum 30°).

For transverse sections with no pronounced dead-rise angle, β_{cg} shall be determined as shown in *Figure 4.2.12 Dead-rise angle β$_{cg}$ (DNV-GL)* a) to c).

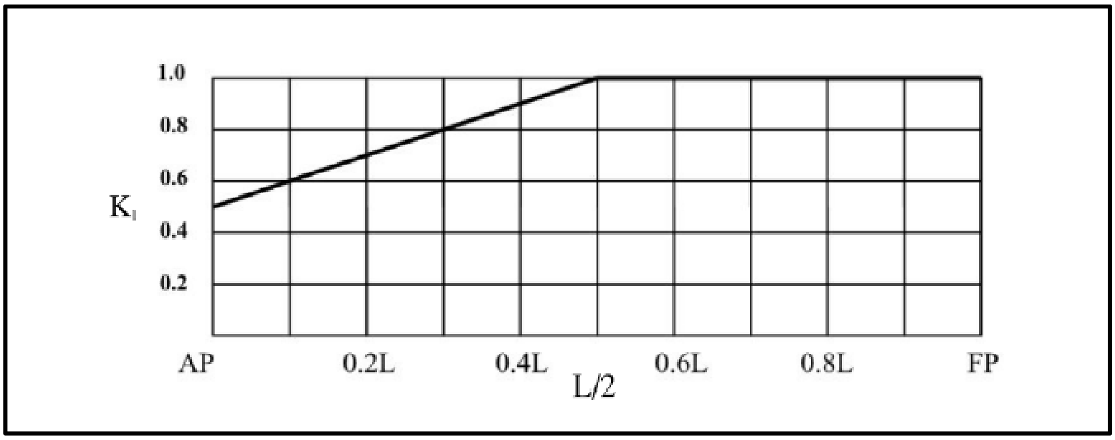


Figure 4.2. 10 Longitudinal slamming pressure distribution factor for high speed mode slamming (DNV-GL)

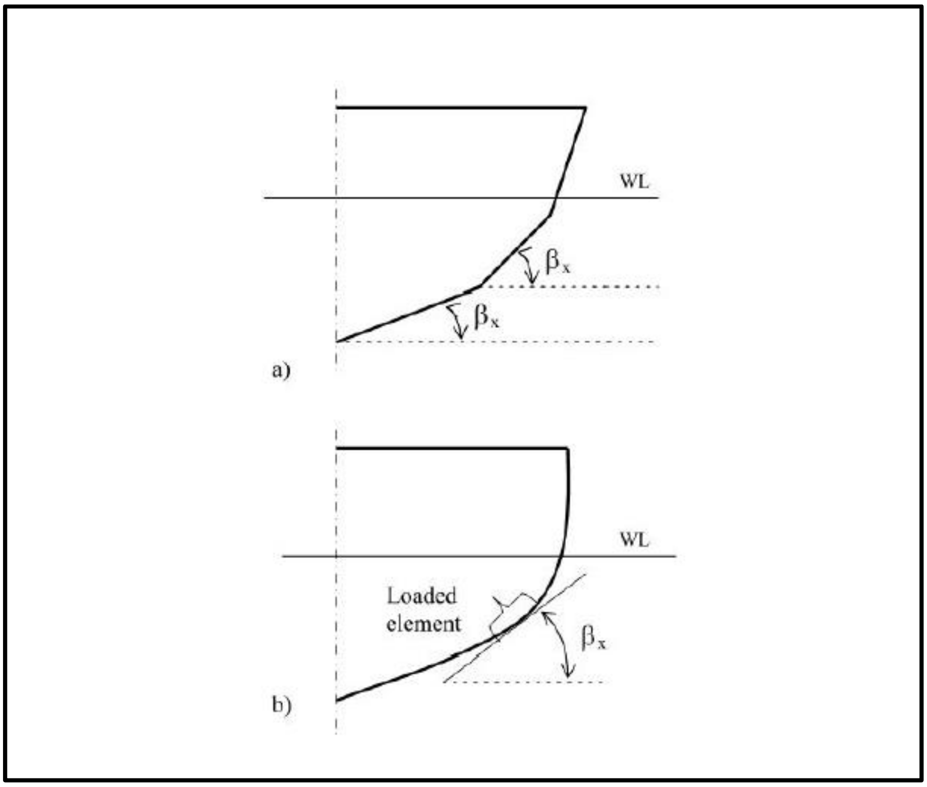


Figure 4.2. 11 Panel angle βx (DNV-GL)

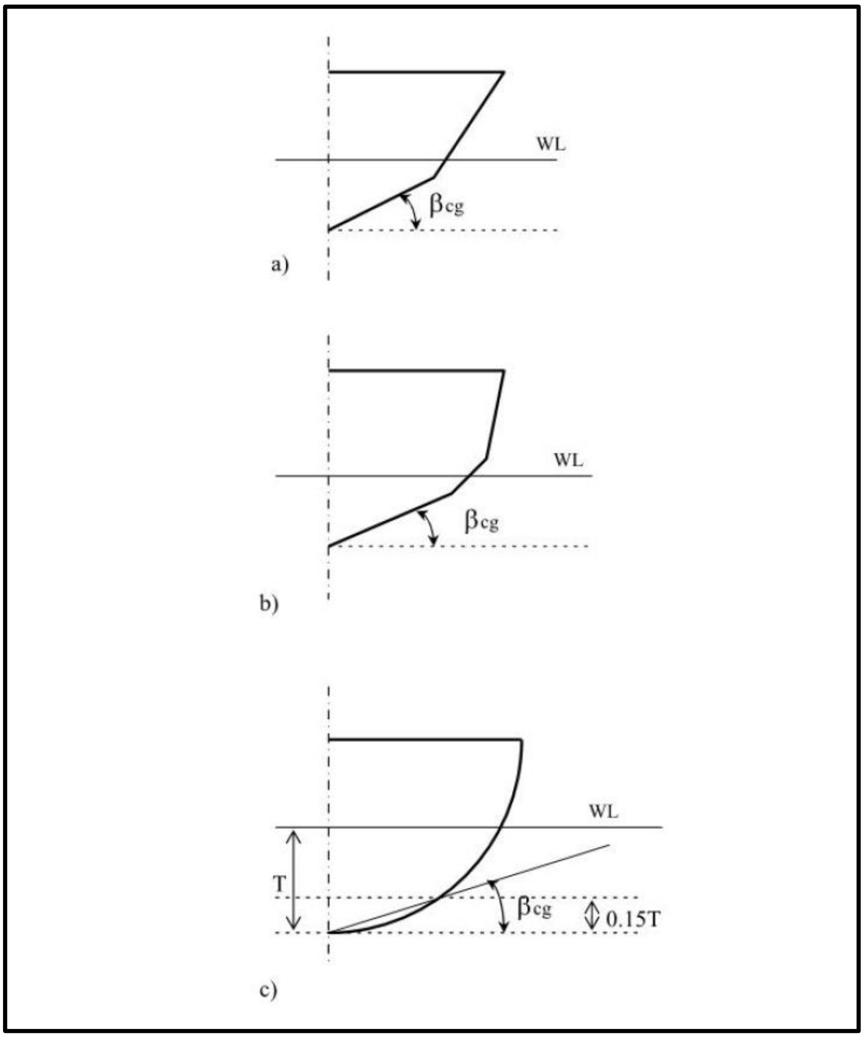


Figure 4.2. 12 Dead-rise angle βcg (DNV-GL)

As it was mentioned, equation 4.2.28 by BV is almost identical to DNV-GL's equation 4.2.30, divided by 9.8, due to the fact of a_{cg} is in g's while in the latter equation is inserted in m/s^2. Another difference lies on factor K_β, which is equal to $\frac{50-\beta_x}{50-\beta_{cg}}$ and the corresponding BV factor K_3 is equal to $\frac{70-a_d}{70-a_{dcg}}$.

However the biggest difference occurs comparing factor K_l and BV factor K_1, see *Figure 4.2.10 Longitudinal slamming pressure distribution factor for high speed mode slamming (DNV-GL)* and *Figure 4.2.8 Longitudinal Bottom Impact Pressure Distribution Factor (BV).* In BV figure a reduction of K_1 at the fore part of the craft which may result to reduction of the pressure is implemented. DNV-GL disagrees and its regulation state that fore part's K_l should be equal to the amidships.

A unique insertion on the matter by DNV-GL is the pitching slamming pressure, which as per DNV-GL all crafts shall be designed for, and is equal to equation 4.2.31. According to DNV-GL, pitching slamming pressure shall extend within a length from FP of $(0{,}1 + 0{,}15 \cdot V/\sqrt{L}) \cdot L$

metres. Furthermore DNV-GL states $V/\sqrt{L}$ need not to be taken greater than 3 and p*sl* may be gradually reduced to zero at 0,175 L aft of the above length. Pitching slamming pressure shall be exposed on elements within the area extending from the keel line to chine, upper turn of bilge or pronounced sprayrail.

$$p_{sl} = \frac{21}{\tan(\beta_x)} \cdot k_a . k_b \cdot C_w \cdot (1 - \frac{20 \cdot T_{FP}}{L}) \cdot (\frac{0,3}{A})^{0,3} \quad kN/m^2 \tag{4.2.32}$$

Where,

β_x = deadrise angle in degrees, as defined above
k_a = 1 for plating
= 1,1 – 20 l_A/L; maximum 1,0 and minimum 0,35 for stiffeners and girders
l_A = longitudinal extent in m of load area
k_b = 1 for plating and longitudinal stiffeners and girders
= L/40 l + 0,5 (maximum 1,0) for transverse stiffeners and girders (l = span in m of stiffener or girder)
T_{FP} = as given in *Figure 4.2.13 Definition of T_{FP} (DNV-GL)*
A = A need not for any structure be taken less than 0,002 Δ/T, or otherwise as defined in equation *4.2.30*
C_w = Wave coefficient, as *4.1.2.4 Det Norske Veritas - Germanischer Lloyd (D)*

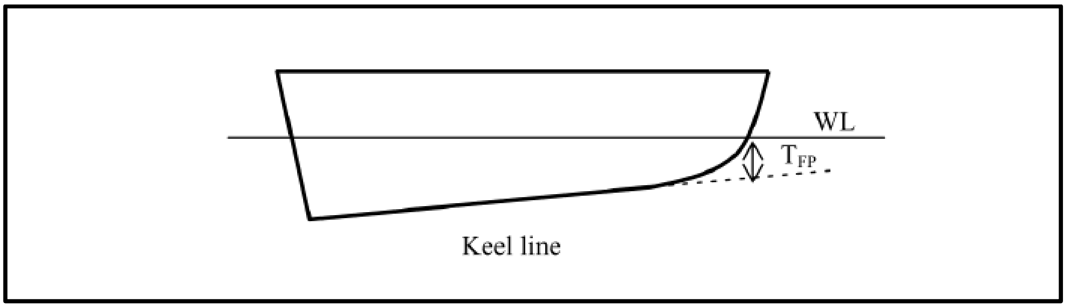


Figure 4.2. 13 Definition of TFP (DNV-GL)

4.2.3.5 Registro Italiano Navale (HSC/PBS)

As it was mentioned in *4.2.2.3 Bureau Veritas (HSC/PBS),* rules and regulations on HSC was established along by BV, RINA and Germanischer Lloyd. Furthermore, RINA single published *Rules for the Classification of High-Speed Craft (January 2009),* this edition contains a revision of the rules mainly including two set of amendments, effective from 1 July 2006 and 1 July 2008, already published with RINA Circulars 3493/A on 29 June 2006 and 3559/A on 27 June 2008.

However, no changes were made that affect design vertical acceleration, thus, no further comments are referred, as the rules are the same as in *4.*2.3.3 Bureau Veritas (HSC/PBS).

4.2.3.6 Conclusion (HSC/PBS)

Even though all the societies include equations that express the effect of the sea along the shell envelope, LR regulations explicitly refer to hydrostatic and hydrodynamic pressure, providing two distinct equations. The other societies either refer generally to sea pressures or only to hydrostatic pressures. Nevertheless there are parameters in relevant equation that express hydrodynamic or wave effects.

Pressure acting to the bottom shell due to bottom slamming is also a design load that is regulated by all societies. The previous paragraphs confirm the fact that vertical acceleration directly affects the impact pressure acting on the bottom shell of a HSC as it is an integral part of every classification society's formula. BV and DNV-GL bottom slamming pressures are proportional to the vertical acceleration, while LR and ABS bottom slamming pressure is proportional to the factor $(1 + vertical\ acceleration)$. Also every classification society's bottom slamming pressure is proportional to the displacement.

As regards longitudinal bottom pressure distribution along the hull, LR, ABS (for crafts with length less than 61 metres) and BV/RINA agree to a reduction at a region near the fore peak, while the DNV-GL suggests that the distribution factor's values at the fore peak is equal to the amidships.

Concerning sea pressures, ABS equation, which is named as hydrostatic pressure, has resemblance to LR sea pressure equation, which is a sum of LR hydrostatic and hydrodynamic wave pressure. The rest set completely different requirements.

Exclusivity occurs in three cases as LR sets specific requirements for crafts supported by hydrodynamic lift by foils or other devices, ABS gives modified equation for craft with length less than 61 metres and DNV-GL suggests that pitching slamming, as in equation 4.2.21, shall be taken into consideration.

4.2.3.7 Example Calculations at 0,25L (HSC/PBS)

LR bottom design pressures calculation:

According to *4.2.8.2 Craft operating in non-displacement mode*, to determine scantlings the pressure for bottom plating, P_{BP}, is to be the greater of:

$H_f S_f P_s\ (P_{BP1})$

$H_f S_f C_f P_{dl}\ (P_{BP2})$

$H_f S_f G_f C_f P_f\ (P_{BP3})$

Where,

P_{dl} = impact pressure *see 4.2.3.1 Lloyd's Register (HSC/PBS)* and *4.2.4.1 Lloyd's Register (HSC/PSS)*

P_s = shell envelope pressure, see *4.2.3.1 Lloyd's Register (HSC/PBS)* and *4.2.4.1 Lloyd's Register (HSC/PSS)*

P_f = forebody impact pressure, see *4.2.6.1 Lloyd's Register (HSC/PF)*

Since P_f does not act on the bottom shell (*see 4.2.6.1 Lloyd's Register (HSC/PF)*) and the impact pressure is listed as P_{dl} and not as P_{dlb}, which is LR symbol of bottom slamming pressure, it is assumed that the intention of LR is to check the higher pressures acting on the shell envelope and set the plating according to the highest. This also explains that the corresponding pressure for side plating, P_{SP}, is to be taken equal to P_{BP}, *see 4.2.8.2 Craft operating in non-displacement mode.*

The pressures have been calculated according to the following:

- P_s is taken as the sum of P_h and P_w, see *equations 4.2.15, 4.2.16* and *4.2.17*, with $T_x = T$, $z = 0$ (bottom) and $z_k = 0$
- P_{dlb} is taken as in *equation 4.2.20,* where support girth $G_o = 3{,}74\,m$ and $\Phi = 0{,}75$ taken via linear interpolation between $0{,}5$ (aft end of L_{WL}) and 1 (at $0{,}5L_{WL}$)
- P_f is taken equal to 0, *see equation 3.2.45, for* $x/L < 0{,}5$.
- H_f equal to 1, as HSC, *see 4.2.8.1 Character of classification and class notations*
- S_f equal to 1, as Passenger Type, *see 4.2.8.1 Character of classification and class notations*
- C_f equal to 1, as Mono-hull, *see 4.2.8.1 Character of classification and class notations*
- G_f equal to 0,8, as Service area G2A, *see 4.2.8.1 Character of classification and class notations*

ABS bottom design pressures calculation:

According to ABS the bottom design pressure is to be the greater of those given in *4.2.3.2 American Bureau of Shipping (HSC/PBS).* The pressure that refer to the examined craft is bottom slamming pressure for craft less than 61 meters P_{bxx} and hydrostatic pressure P_d.

The pressures have been calculated according to the following:

- p_{bxx}, is taken as in *equation 4.2.26,* where $F_D = 0{,}72$ and $F_V = 0{,}60$
- p_d is taken as in *equation 4.2.23*

BV and RINA bottom design pressures calculation:

While is not clearly mentioned in the relevant regulation, sea pressure P_s and bottom slamming pressure P_{sl} are examined separately, as BV and RINA propose distinct calculations for the thickness plating.

The pressures have been calculated according to the following:

- p_s, is taken as in *equation 4.2.27.a*, where $z = 0\,m$ and $S = 2{,}40$ calculated as indicated by *Table 4.2.10 S and p_{smin} range value (BV)* for $x/L \leq 0{,}5$
- p_{sl}, is taken as in *equation 4.2.28*, $K_1 = 0{,}75,\ K_3 = 1$ and $K_2 = 0{,}5$

DNV-GL bottom design pressures calculation:

Similarly to BV and RINA, DNV-GL suggest either sea pressure, p, either bottom slamming pressure, p_{sl}, to be used for thickness plating calculations. To remind, DNV-GL suggest that all craft shall be designed for a pitching slamming pressure, which, for the purpose of calculations, is signified as p_{psl}, in order to not be confused with bottom slamming pressure.

The pressures have been calculated according to the following:

- p, is taken as in *equation 4.2.29,* where C_w is for service area restriction **R0**, *see 4.1.2.4 Det Norske Veritas - Germanischer Lloyd (D),* and $h_0 = 1{,}08\,m$. In addition $k_s = 7{,}5$ according to *Figure 4.2.9 Sea load distribution factor (DNV-GL)*
- p_{sl}, is taken as in *equation 4.2.30*, $K_l = 0{,}75$, $K_\beta = 1$ and $K_{red} = 0{,}36$
- p_{psl}, is taken as in *equation 4.2.31*, where $T_{FP} = 0$ and C_w is calculated for service area restriction **R0**

The results of the above calculations are presented in *Figure 4.2.14 Bottom Design Pressures at 0,25·L.*

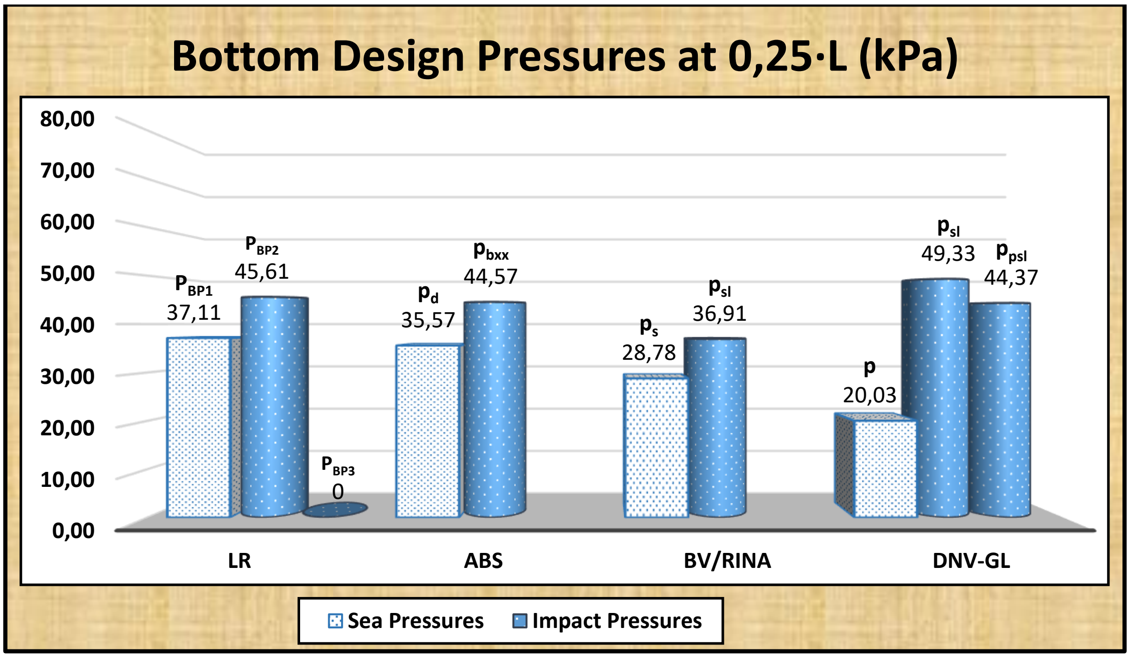


Figure 4.2. 14 Bottom Design Pressures at 0,25·L

DNV-GL and BV/RINA sea pressures have a quite lower value that LR and ABS, whose results are very close. As mentioned in *4.2.3.6 Conclusion (HSC/PBS),* LR and ABS use similar equation, which may explain that the discrepancy between them is small.

In terms impact pressures, the used equations are rewritten in a homogenous form, in order to assist the comparison process, as in *4.2.2.7 Example Calculations as Longitudinal Centre of Gravity (HSC/VA).*

- LR: $P_{dlb} = \frac{f_d \cdot \Delta}{L_{WL} \cdot G_O} \cdot (1 + a_v) \cdot \Phi$
- ABS: $P_{bxx} = \frac{100 \cdot \Delta}{L_W \cdot B_W} \cdot (1 + n_{cg}) \cdot F_D \cdot F_V$
- BV/RINA: $P_{sl} = \frac{100 \cdot \Delta}{L_W \cdot B_W} \cdot a_{cg} \cdot K_1 \cdot K_2 \cdot K_3 \cdot \frac{1}{\rho \cdot C_b}$
- DNV-GL: $P_{sl} = \frac{100 \cdot \Delta}{L_W \cdot B_W} \cdot a_{cg} \cdot K_{red} \cdot K_l \cdot K_\beta \cdot \frac{1}{\rho \cdot C_b}$

Where,

B_w = maximum waterline beam
L_{WL}, L_W = waterline length, in metres, see *4.1.2.1 Lloyd's Register (D)*
a_V, n_{cg}, a_{cg}= is the vertical acceleration, in g's, as defined by each classification society
Δ = Displacement, in t
C_B = Block coefficient
K_{red}, K_2, F_D = reduction factor for design load area, as defined by each classification society
K_l, K_1, F_V, Φ = longitudinal distribution factor , as defined by each classification society
K_β, K_3 = correction factor for local deadrise angle , as defined by each classification society
G_o = support girth or girth distance, in metres, as defined in *Table 4.2.8 Definition of Go for the determination of bottom impact pressure, Pdl for different regions of the hull (LR)*
f_d = hull form pressure factor, equals to 54, for mono-hull crafts

Observing the homogenous pressure equations, it is expected that LR and ABS would provide the highest pressure values, since the vertical acceleration factor is increased by one unit. However, the fact that DNV-GL suggest the highest vertical acceleration, *see 4.2.2.7 Example Calculations at Longitudinal Center of Gravity (HSC/VA)*, and its pressure is counter proportional to the block coefficient, at least in the homogenous equation, makes the DNV-GL bottom slamming pressure even greater than ABS and LR. This does not apply to BV, because BV suggests one of the lowest values of vertical acceleration.

4.2.3.8 Example Calculations at 0,50L (HSC/PBS)

The calculations of this sub-section are based on the same assumptions as in *4.2.3.7 Example Calculations at 0,25L (HSC/PBS)*, thus only differentiations or further assumptions are reported.

LR bottom design pressures calculation:

- P_f is taken as in equation *3.2.45.* P_f is to be taken equal to P_m, *see equation 3.2.16,* at 0,5L. And as P_f does not act on the bottom, P_m is calculated at the height of chines
- P_{dlb} is taken as in *equation 4.2.20,* where $\Phi = 1$

ABS bottom design pressures calculation:

- p_{bxx}, is taken as in *equation 4.2.26,* where $F_D = 0{,}72$ and $F_V = 0{,}925$

BV and RINA bottom design pressures calculation:

- p_{sl}, is taken as in *equation 4.2.28*, $K_1 = K_3 = 1$ and $K_2 = 0{,}5$

DNV-GL bottom design pressures calculation:

- p_{sl}, is taken as in *equation 4.2.30*, $K_l = K_\beta = 1$ and $K_{red} = 0{,}36$

The results of the above calculations are presented in *Figure 4.2.15 Bottom Design Pressures at 0,50·L.*

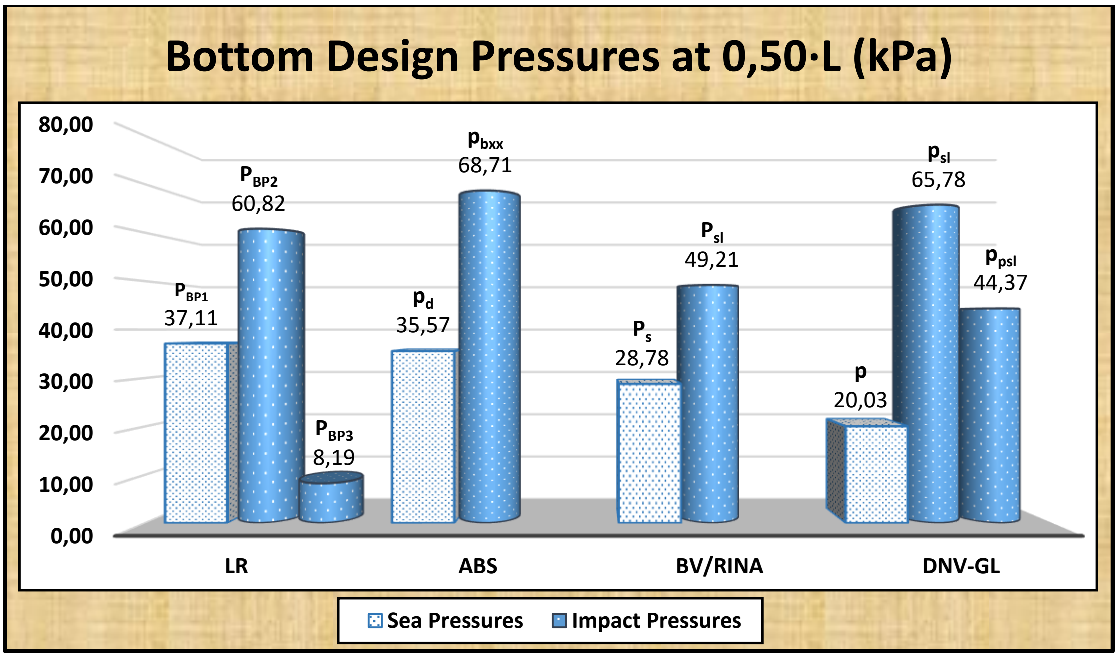


Figure 4.2. 15 Bottom Design Pressures at 0,50·L

The results bear a resemblance to *4.2.3.7 Example Calculations at 0,25L (HSC/PBS),* as LR, ABS and DNV-GL impact pressure values are similar and significantly higher than BV computations, as in the previous example, while also the sea pressure are identical to the previous calculations. Thus, relevant comments in *4.2.3.7 Example Calculations at 0,50L (HSC/PBS)* apply here as well.

Nonetheless, the fact that ABS requirements, instead of DNV-GL as in previous example calculation, lead to the greatest bottom pressure due to slamming, it is not go unnoticed. This is explained by the difference that exist amongst the classification societies' longitudinal distribution factors. In the previous calculations the values of every longitudinal distribution factor was 0,75, except for ABS, whose value was equal to 0,6. Now the value difference of relevant factors is decreased (for ABS the distribution factor equals to 0,925 and for the rest equals to 1) and the factor $(1 + vertical\ acceleration)$ of ABS equation prevails over the great vertical acceleration value of DNV-GL.

4.2.3.9 Example Calculations at 0,75L (HSC/PBS)

The calculations of this sub-segment are based on the same assumptions as in *4.2.3.7 Example Calculations at 0,25L (HSC/PBS)*, thus only differentiations or further assumptions are reported.

LR bottom design pressures calculation:

- P_f is taken as in equation *4.2.45.* P_f is to be taken as P_{dsl} at 0,75L , *see equation 4.2.16*. Note that P_{dsl} is the side shell impact pressure due to bottom slamming.
- P_{dlb} is taken as in *equation 4.2.20,* where $\Phi = 1$

ABS bottom design pressures calculation:

- p_{bxx}, is taken as in *equation 4.2.26,* where $F_D = 0{,}72$ and $F_V = 1$

BV and RINA bottom design pressures calculation:

- p_s, is taken as in *equation 4.2.27.b*. Usage of equation 4.2.27.a is necessary to determine sea pressure at midship area and the fore end.
- p_{sl}, is taken as in *equation 4.2.28*, $K_1 = K_3 = 1$ and $K_2 = 0{,}5$

DNV-GL bottom design pressures calculation:

- p, is taken as in *equation 4.2.29,* where $k_s = 8{,}8$ according to *Figure 4.2.9 Sea load distribution factor (DNV-GL)*. Linear interpolation between $7{,}5$ (aft of amidships) and $5/C_b$ (forward of F.P.).
- p_{sl}, is taken as in *equation 4.2.30*, $K_l = K_\beta = 1$ and $K_{red} = 0{,}36$

The results of the above calculations are presented in *Figure 4.2.16 Bottom Design Pressures at 0,75·L.*

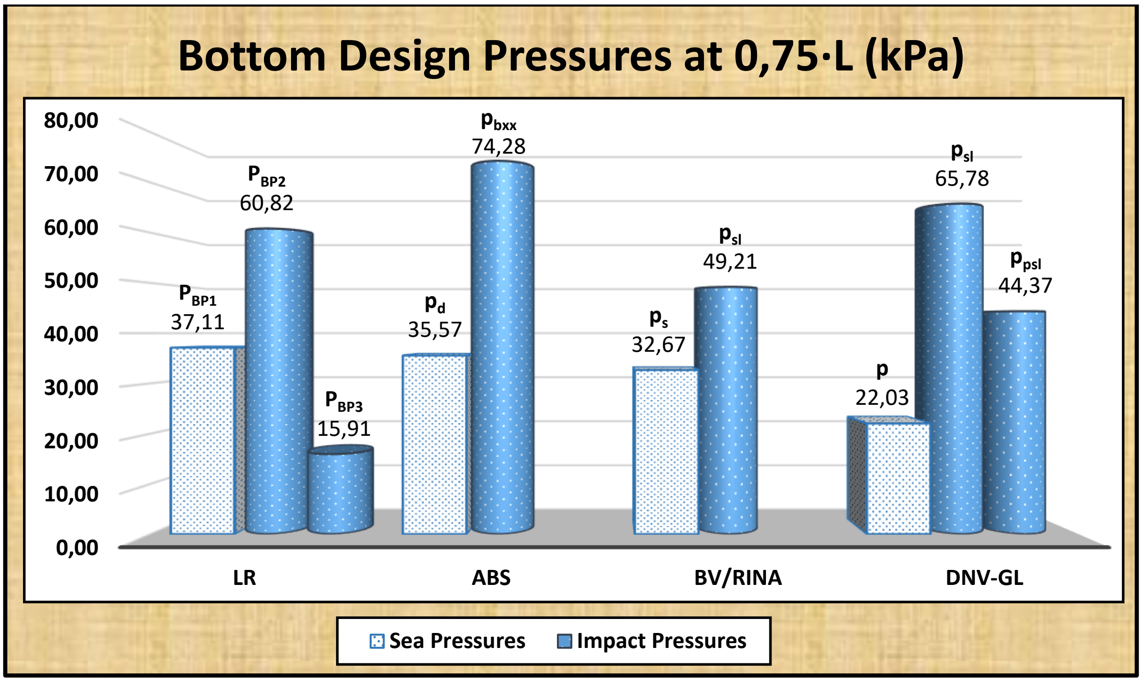


Figure 4.2. 16 Bottom Design Pressures at 0,75·L

Conclusion that are drawn from *4.2.3.7 Example Calculations at 0,25L (HSC/PBS)* and *4.2.3.8 Example Calculations at 0,50L (HSC/PBS)* apply here as well. Although, the sea pressures of BV/RINA and DNV-GL are not the same as before as they depend on the longitudinal position of the load point. LR and ABS sea pressure are equal to the previous calculations.

In addition bottom slamming pressure of ABS is further increased as the longitudinal distribution factor is equal to 1. The rest of the societies suggest same impact pressure as in *4.2.3.8 Example Calculations at 0,50L (HSC/PBS).*

4.2.4 Pressures on Side Shell (HSC/PSS: Pressure on Side Shell)

4.2.4.1 Lloyd's Register (HSC/PSS)

As in the case of bottom shell pressures, side shell pressures' regulations are shown in *Rules and Regulations for the Classification of Special Service Craft (July 2018)* Pt. 5, Ch. 2, 4th and 5th section, by LR.

In section 4 of the referenced Chapter, are indicated the hydrostatic and hydrodynamic pressures on the shell plating. Formulas on calculating hydrostatic pressure, hydrodynamic wave pressure and a combined pressure of which are common for the whole shell. Hence, as in *4.2.3.1 Lloyd's Register (HSC/PBS)* LR's method has been described, equations *4.2.15, 4.2.16, 4.2.17* and *4.2.18* of this segment shall be used for sea pressure calculations of side shell as appropriate.

Concerning impact loads due to bottom slamming provisions made by LR for both crafts operating in displacement and in non-displacement mode, as well as for crafts with foils and lifting devices.

Regarding crafts operating in displacement mode, as stated by LR, the side shell impact pressure shall be taken as P_{dh} , see *equation 4.2.19* in *2.3.1 Lloyd's Register (HSC/PBS),* at the operating waterline, reducing to 0,4P_{dh} at the weather deck. Intermediate values between the weather deck at side and operating waterline, are to be determined by linear interpolation.

In term of non-displacement mode, the side shell impact pressure due to bottom slamming is resulting from P_{dlb}, see *equation 4.2.20,* but corrected by a factor as it is presented below:

$$P_{dls} = P_{dlb} \frac{\tan(40 - \theta_B)}{\tan(\theta_S - 40)} \; kN/m^2 \qquad (4.2.33)$$

but is not to be taken greater than P_{dlb}.

Where,

θ_B = mean deadrise angle of bottom plating, in degrees at local section, see *Figure 4.2.17 Angles used in determination of side shell pressure for planing craft (LR)*

θ_S = mean deadrise angle of side plating, in degrees at local section, see *Figure 4.2.17 Angles used in determination of side shell pressure for planing craft (LR)*

Also, $(40 - \theta_B)$ and $(\theta_S - 40)$ are not to be taken as less as 10°.

LR supplements with the following: *"P_{dls} is to be taken as constant from the chine or operating waterline to a point half Go from the chine, or the weather deck if this is reached first. Multiple chines will be subject to special consideration based on the above principle."*

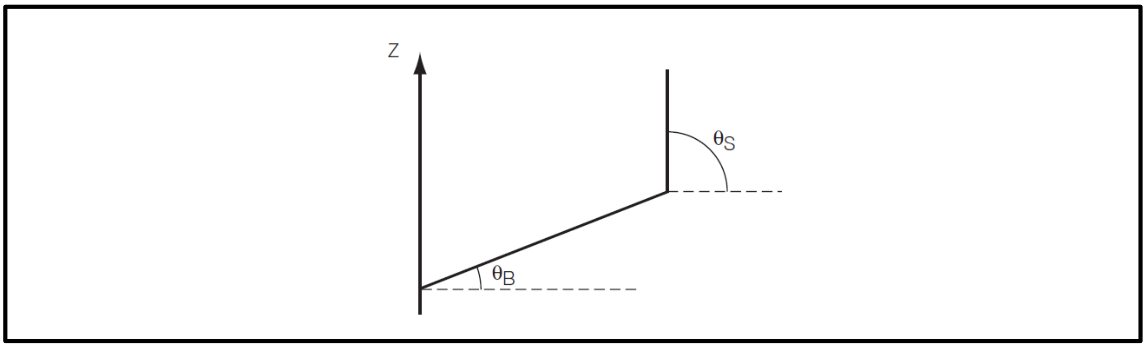


Figure 4.2. 17 Angles used in determination of side shell pressure for planing craft (LR)

Lastly, similarly to the crafts operating in displacement mode, the side shell impact pressure shall be taken as P_{fb}, see *equations 4.2.21* and *4.2.22*, at the chine or at the operating waterline for round bilge hullforms as appropriate reducing to 0,3P_{fb} at the weather deck, concerning craft with foils and lifting devices. Intermediate values between the weather deck at side and the chine or operating waterline, as appropriate, to be determined by linear interpolation.

Regulation presented on this segment are to be used in conjunction with requirements of *4.2.8 Local Design Criteria by Lloyd's Register,* as appropriate.

4.2.4.2 American Bureau of Shipping (HSC/PSS)

Alike pressures on the bottom shell, ABS provides formula only for hydrostatic forces in *Rules for Building and Classing High Speed Craft (October 2018),* excluding hydrodynamic loads. As referenced in Pt. 3, Ch. 2, Sec. 2 of ABS; rulebook the hydrostatic pressure on the side shell is to be taken as follows:

$$p_s = N_3 \cdot (H_s - y) \quad kN/m^2 \tag{4.2.34}$$

Where,

H_S = 0,083L + d in metres, but it is not to be taken less than D + 1,22 for craft less than 30 m
= 0,64H + d in meters for craft over 30 m; where H is defined in *4.2.3.2 American Bureau of Shipping (HSC/PBS)*
d = Stationary draft, in m, as defined in *4.2.3.2 American Bureau of Shipping (HSC/PBS)*
y = distance above base line of location being considered, in m
N_3 = 9,8

Furthermore, referring to the region aft of 0,125L from the stem, ABS states that in any case side design pressure due to hydrostatic forces is not to be taken less than 0,05$N_3L\ kN/m^2$ at or below $L/15$ above the base line and less than 0,033$N_3L\ kN/m^2$ above $L/15$ above the baseline.

The impact load due to bottom slamming on the side shell is given in the same section and is quite similar to the bottom shell's, at any section clear of the LCG, see *equation 4.2.25.* Thus the side design pressure, according to ABS, is to be not less than given by the equations:

$$p_{sxx} = \frac{N_1 \cdot \Delta}{L_w \cdot N_h \cdot B_w}[1 + n_{xx}][\frac{70 - \beta_{sx}}{70 - \beta_{cg}}] \cdot F_D \quad kN/m^2 \tag{4.2.35}$$

Where,

n_{xx} = average of the 1/100 highest vertical accelerations, at any section clear of LCG, as defined in *4.2.2.2 American Bureau of Shipping (HSC/VA)*
β_{sx} = deadrise of side at any section clear of LCG, in degrees, not to be taken greater than 55°, see *Figure 4.2.5 Deadrise, Flare, and Entry Angles (ABS)*
N_1, Δ, L_w, N_h, B_w, β_{cg} and F_D as defined in 4.2.3.2 American Bureau of Shipping (HSC/VA)

According to ABS, craft greater than 24 m in length, the side design slamming pressure applies both along the entire length below L/12 above baseline and to the region forward of 0,125L.

4.2.4.3 Bureau Veritas (HSC/PSS)

As it was mentioned in *4.2.3.3 Bureau Veritas (HCS/PBS),* BV suggests a formula to be used for both bottom and side shell and is presented in that segment, see *equations 4.2.27.*a and *4.2.27.b.* It should be remarked that similar practice was indicated by LR concerning crafts operating in the displacement mode.

Moreover and surprisingly enough, in *Rules for the Classification of High Speed Craft (February 2002)* there are no provisions on impact loads acting on the side shell of the crafts.

4.2.4.4 Det Norske Veritas - Germanischer Lloyd (HSC/PSS)

In segment *4.2.3.4 Det Norske Veritas - Germanischer Lloyd (HSC/PBS)* it was noticed that, as per sea pressures, DNV-GL, via *Rules for Classification: High speed and light craft (January 2018),* Pt. 3, Ch. 1, Sec. 3 suggests common formula for craft's bottom, side, superstructure side, deckhouse side and weather decks. Therefore, according to DNV-GL, sea pressure at the side shell should be taken as *equation 4.2.29.*

DNV-GL's indications on impact pressure concern forebody side and bow, as the pressure calculation of each part arise from the following equation:

$$p_{sl} = \frac{0{,}7C_L C_H}{A^{0{,}3}}(0{,}6 + 0{,}4\frac{V}{\sqrt{L}}\sin(\gamma)\cos(90-\alpha) + \frac{2{,}1\alpha_0}{C_B}\sin(90-a)(\frac{x}{L} - 0{,}4)\sqrt{0{,}4\frac{V}{\sqrt{L}} + 0{,}6)}^2\ kN/m^2 \qquad (4.2.36)$$

Where,

$V/\sqrt{L}$ need not be taken greater than 3

A = design load area for element considered in m^2
For plating *A* shall not be taken greater than = 2,5 s^2 (m^2)
For stiffeners and girders A need not be taken smaller than e^2 (m^2)
In general A need not be taken smaller than LB_{wl}/1000 (m^2)

e = vertical extent of load area, measured along shell perpendicular to the waterline

x = distance in m from AP to position considered

C_L = $\frac{250 \cdot L - L^2}{15000}$, correction factor for length of craft

C_H = $1 - \frac{0.5}{C_w} \cdot h_0$ correction factor for height above waterline to load point

C_w = Wave coefficient, as *4.1.2.4 Det Norske Veritas – Germanischer Lloyd (D)*

h_0 = vertical distance in m from the waterline at draught *T* to the load point

a = flare angle taken as the angle between the side plating and a horizontal line, measured at the point considered. See *Figure 4.2.18 Flare angle* α *(DNV-GL)*

γ = angle between the waterline and a longitudinal line measured at the point considered. See *Figure 4.2.19 Waterline angle* γ *(DNV-GL)*

a_0 = $3 \cdot \frac{C_w}{L} + C_V \cdot \frac{V}{\sqrt{L}}$, acceleration parameter
$C_V = \frac{\sqrt{L}}{50}$, maximum 0,2

V = maximum speed in knots

L = length of the craft, in m, as defined in *4.1.2.4 Det Norske Veritas – Germanischer Lloyd (D)*

Nevertheless, the above regulation do not refer to the whole hull, the impact pressure according to *4.2.35* shall be calculated for longitudinal positions between 0,4 L from AP and bow.

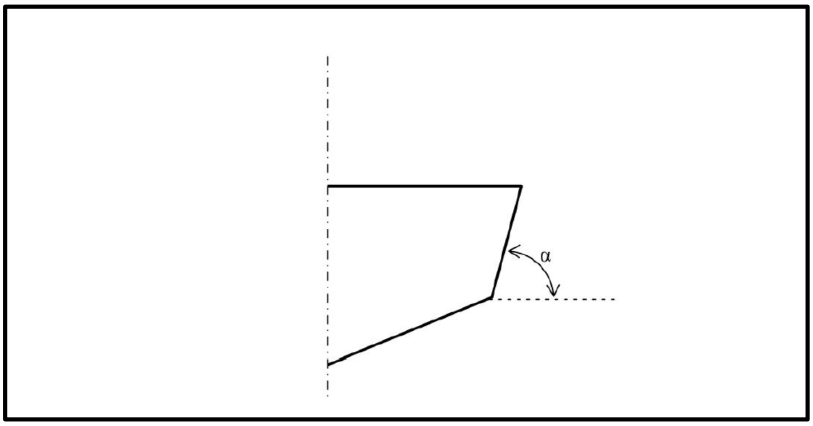


Figure 4.2. 18 Flare angle a (DNV-GL)

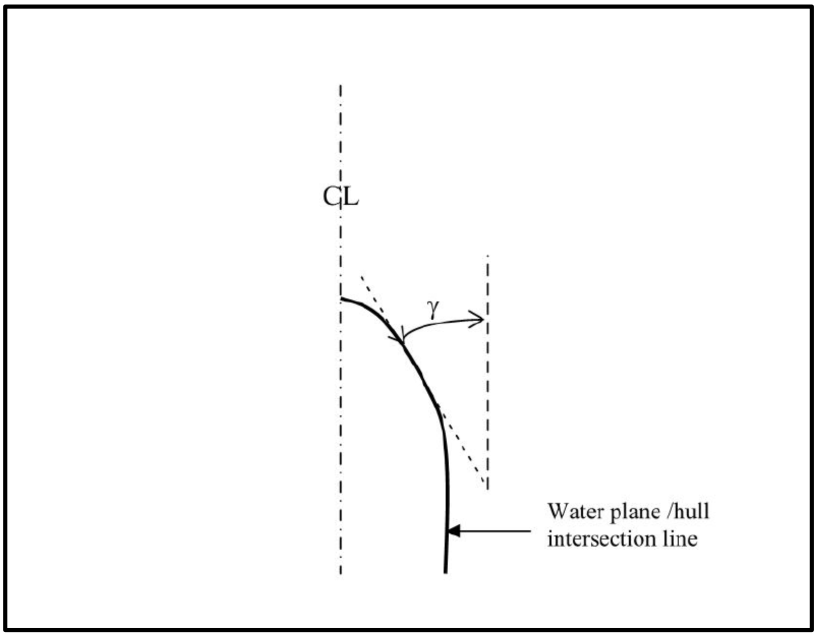


Figure 4.2. 19 Waterline angle γ (DNV-GL)

4.2.4.5 Registro Italiano Navale (HSC/PSS)

As it was mentioned in *4.2.2.3 Bureau Veritas (HSC/PSS),* rules and regulations on HSC was established along by BV, RINA and Germanischer Lloyd. Furthermore, RINA single published *Rules for the Classification of High-Speed Craft (January 2009),* this edition contains a revision of the rules mainly including two set of amendments, effective from 1 July 2006 and 1 July 2008, already published with RINA Circulars 3493/A on 29 June 2006 and 3559/A on 27 June 2008.

However, no changes were made that affect design vertical acceleration, thus no further comments are, as the rules are the same as in 4.2.4.3 Bureau Veritas (HSC/PSS).

4.2.4.6 Conclusion (HSC/PSS)

The differences between the calculations of sea pressure have already been discussed in the previous conclusions section, *see 4.2.3.6 Conclusions (HSC/PBS),* and also apply for the pressures acting on the side shell, as each classification society suggests general equation to be used accordingly, depending on the location of the load point considered. ABS may give distinct requirements for side shell but it is a modified equivalent equation.

Nevertheless evident discrepancies arise concerning the matter of impact pressures acting on the side shell, mainly because LR and ABS acknowledge that impact pressure due to slamming are affecting the side shell along the hull. DNV-GL impact loads requirements refer only to longitudinal positions between 0,4 L from AP and bow, while BV and RINA do not include relevant regulations.

It should be mentioned that, supplementarily to the parameters affecting bottom slamming and also apply to side shell calculations, important part on LR and ABS calculations is the change of deadrise angle from bottom to shell plating, though is expressed differently by both.

4.2.4.7 Example Calculations at 0,25L (HSC/PSS)

LR side design pressures calculation:

As it was mentioned in *4.2.3.7 Example Calculations at 0,25L (HSC/PBS)* the side plating pressure, P_{SP}, is to be taken equal to the corresponding bottom plating pressure, P_{BP}, according to *4.2.8 Local Design Criteria by Lloyd's Register*. However pressures acting on the side shell according to section *4.2 High-Speed Craft* are going to be calculated for theoretical comparison purposes, without taking into consideration factors given by *4.2.8.1 Character of classification and class notations.*

The pressure acting on the side shell are the shell envelope pressure, P_s (*hydrostatic and hydrodynamic pressure)*, side impact pressure due to bottom slamming, P_{dls} and forebody impact pressure, P_f, which acts on the side from 0,5L and forward.

The pressures are calculated according to the following:

- P_{SP}, equal to P_{BP}, as calculated in *4.2.3.7 Example Calculations at 0,25L (HSC/PBS)*
- P_s is taken as the sum of P_h and P_w, see *equations 4.2.15, 4.2.16* and *4.2.17*, with $T_x = T$, $z = 0{,}62\ m$ (chines) and $z_k = 0$
- P_{dls} is taken as in *equation 4.2.32,* in conjunction with *equation 4.2.20,* where support girth $G_o = 3{,}74\ m$ and $\Phi = 0{,}75$, taken via linear interpolation between $0{,}5$ (aft end of L_{WL}) and 1 (at 0,5L_{WL})
- P_f to be taken equal to 0, *see equation 3.2.45,* for $x/L < 0{,}5$.

ABS side design pressures calculation:

In ABS rules and regulations it is indicated that the pressure acting on the side shell is not to be taken less than those given *4.2.4.2 American Bureau of Shipping (HSC/PSS)*. The pressure to be considered are the hydrostatic pressure, p_s and side design slamming pressure, p_{sxx}.

The pressures are calculated according to the following:

- p_{sxx}, is taken as in *equation 4.2.34,* where $F_D = 0{,}72$ and $\beta_{sx} = 55°$ (not 80,3, since β_{sx} is not be taken greater than $55°$) and n_{xx}, the vertical acceleration at any section clear of LCG, as in equation *4.2.7.* where $K_V = 0{,}8$
- p_d has been taken as in *equation 4.2.33,* where $y = 0{,}62$.

BV and RINA side design pressures calculation:

Sea pressure, p_s, is the only pressure acting at the side shell according to BV and RINA.

The pressure has been calculated according to the following:

- p_s, has been taken as in *equation 4.2.27.a*, where $z = 0{,}62\ m$ and $S = 2{,}40$ calculated as indicated by *Table 4.2.10 S and p$_{smin}$ range value (BV)* for $x/L \leq 0{,}5$

DNV-GL side design pressures calculation:

Forebody side impact pressure, p_{sl}, and sea pressure, p are to be taken into consideration for side plating.

The pressures are calculated according to the following:

- p, is taken as in *equation 4.2.29,* where C_w has been calculated for service area restriction **R0**, *see 4.1.2.4 Det Norske Veritas - Germanischer Lloyd (D),* and $h_0 = 0{,}46\ m$. In addition $k_s = 7{,}5$ according to *Figure 4.2.9 Sea load distribution factor (DNV-GL)*
- p_{sl}, has been taken as in *equation 4.2.35*, where $a = 80{,}3°$, $\gamma = 0°$ and C_w as referenced above.

The results of the above calculations are presented in *Figure 4.2.20 Side Design Pressures at 0,25·L.*

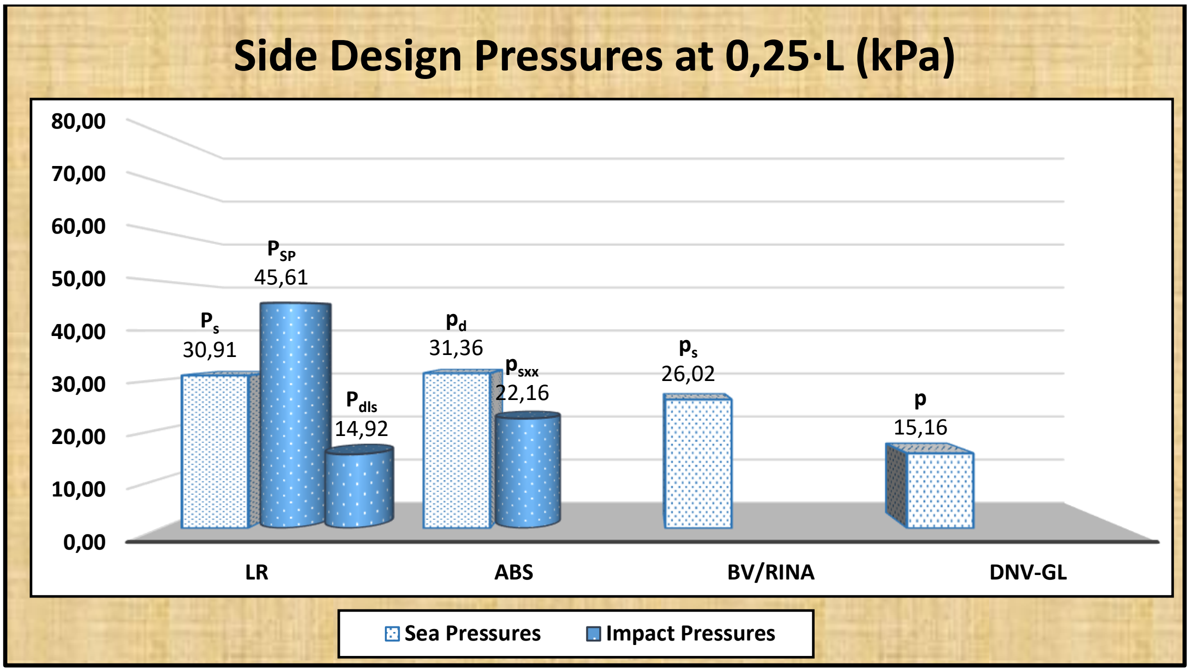


Figure 4.2. 20 Side Design Pressures at 0,25·L

LR policy of suggesting same design pressure for bottom and sell plating leads to the side shell requirements of LR being 50% higher the estimations of all the other classification societies. If the requirements of *4.2.8 Local design criteria by Lloyd's Register* were ignored, the side design pressure requirements of LR would indeed be similar to those of ABS, as were the equation of the two classification societies.

Comparing to the other societies, the underestimation of side design pressure by DNV-GL is also impressive, as DNV-GL value is even 50% lower than ABS suggestions. Especially if taken into account that DNV-GL guidelines indicated the greater bottom design pressure at 0,25L, *see 4.2.3.7 Example Calculations at 0,25L (HSC/PBS).*

4.2.4.8 Example Calculations at 0,50L (HSC/PSS)

The calculations of this sub-section are based on the same assumptions as in *4.2.4.7 Calculations at 0,25L (HSC/PSS)*, thus only differentiations or further assumptions are reported.

LR side design pressures calculation:

- P_f is taken as in equation *3.2.45* where it is reported that P_f equals to P_m, *see equation 3.2.16,* at 0,5L
- P_{dls} is taken as in *equation 4.2.32,* in conjunction with *equation 4.2.20,* P_{dlb}, where $\Phi = 1$

ABS side design pressures calculation:

- p_{sxx}, is taken as in *equation 4.2.34*, where $F_D = 0{,}72$ and $\beta_{sx} = 55°$ (not 80,3, since β_{sx} is not be taken greater than $55°$) and n_{xx}, the vertical acceleration at any section clear of LCG, as in equation *4.2.7.* where $K_V = 1$

BV and RINA side design pressures calculation:

As in *4.2.4.7 Example Calculations at 0,25L (HSC/PSS)*

DNV-GL side design pressures calculation:

As in *4.2.4.7 Example Calculations at 0,25L (HSC/PSS)*. The value of p_{sl} is lower due to the dependency of equation *4.2.35* to x/L factor.

The results of the above calculations are presented in *Figure 4.2.21 Side Design Pressures at 0,50·L.*

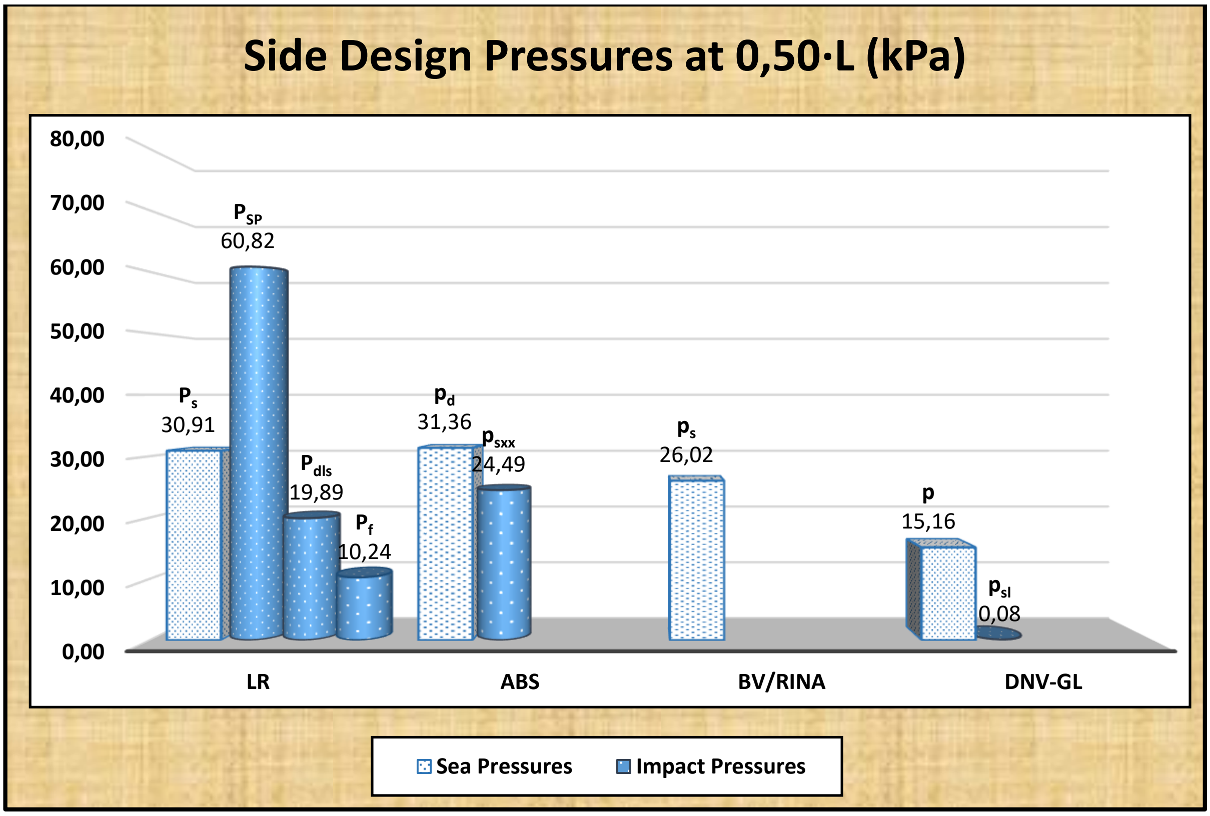


Figure 4.2. 21 Side Design Pressures at 0,50·L.

Comment made in *4.2.4.7 Example Calculation at 0,25L (HSC/PSS)*, also apply here as there are no great value discrepancies between 0,25L and 0,50L, in terms of side design pressure. However, is should be underlined that LR requirements on side shell design pressure lead to over conservative rules, as the use of same side and bottom design pressure for plating further increases the difference with the other societies.

4.2.4.9 Example Calculations at 0,75L (HSC/PSS)

The calculations of this sub-segment are based on the same assumptions as in *4.2.4.7 Example Calculations at 0,50L (HSC/PSS)*, thus only differentiations or further assumptions are reported.

LR side design pressures calculation:

- P_f is taken as in equation *4.2.45,* where it is indicated that P_f is to be taken as P_{dsl} at 0,75L , *see equation 4.2.16*.
- P_{dls} is taken as in *equation 4.2.32,* in conjunction with *equation 4.2.20,* P_{dlb}, where $\Phi = 1$

ABS side design pressures calculation:

- p_{sxx}, is taken as in *equation 4.2.34,* where $F_D = 0{,}72$ and $\beta_{sx} = 55°$ (not 80,3, since β_{sx} is not be taken greater than $55°$) and n_{xx}, the vertical acceleration at any section clear of LCG, as in equation *4.2.7.* where $K_V = 1{,}5$

BV and RINA side design pressures calculation:

- p_s, is taken as in *equation 4.2.27.b*. Usage of equation 4.2.27.a is necessary in order to determine sea pressure at midship area and the fore end.

DNV-GL side design pressures calculation:

- p, is taken as in *equation 4.2.29,* where $k_s = 8{,}8$ according to *Figure 4.2.9 Sea load distribution factor (DNV-GL)*. Linear interpolation between $7{,}5$ (aft of amidships) and $5/C_b$ (forward of F.P.).
- p_{sl}, is taken as in *equation 4.2.35*, where $a = 80{,}3°$, $\gamma = 15°$ and C_w has been calculated for service area restriction **R0**, *see 4.1.2.4 Det Norske Veritas - Germanischer Lloyd (D)*

The results of the above calculations are presented in *Figure 4.2.22 Side Design Pressures at 0,75·L.*

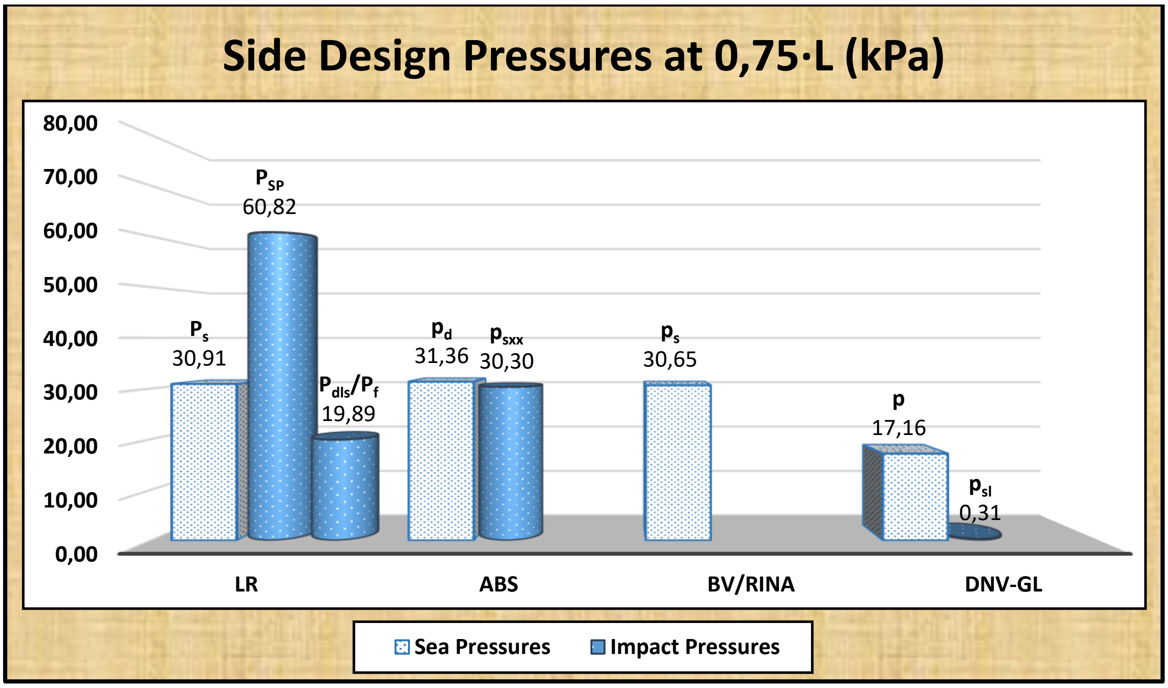


Figure 4.2. 22 Side Design Pressures at 0,75·L

Comment made in *4.2.4.8 Example Calculation at 0,50L (HSC/PSS)*, also apply here as there are no great value discrepancies between 0,25L and 0,50L, in terms of side design pressure. Although note that BV/RINA and DNV-GL sea pressures acting on side calculation dependency on longitudinal position is obvious comparing results of *4.2.4.9 Example Calculations at 0,75L (HSC/PSS)* with those of *4.2.4.7 Example Calculations at 0,25L (HSC/PSS)* and *4.2.4.8 Example Calculations at 0,50L (HSC/PSS)*. LR and ABS suggested side shell impact calculation dependency on the longitudinal position is also evident.

4.2.5 Pressures on Weather/Interior/Wet Decks (HSC/PD: Pressure on Decks)

4.2.5.1 Lloyd's Register (HSC/PD)

Lloyd's Register gives information on several aspects of this matter in *Rules and Regulations for the Classification of Special Service Craft's (July 2018)* Pt. 5, Ch. 2, 4th and 5th section. As in previous referenced regions of the shell envelope, LR divides the rules in two categories, into crafts operating in the displacement mode and in the non-displacement.

LR defines as P_d the pressure acting on weather deck and interior decks, superstructure decks are included, which is to be taken as described in the following two equations as appropriate.

First are presented the local design loads acting on weather and interior decks, which in terms of displacement mode is to be taken as follows:

$$P_{wh} = f_L \cdot (6 + 0{,}01 \cdot L_{WL})(1 + 0{,}05 \cdot \Gamma) + E \;\; kN/m^2 \qquad (4.2.37)$$

Where,

f_L = the location factor for weather decks
= 1,0 from aft end to 0,88L_R
= 1,25 from 0,88L_R to 0,925L_R
= 1,50 from 0,925L_R to forward end
= 1,0 for interior decks
E = $\frac{0{,}7+0{,}08\cdot L_{WL}}{D-T}$ kN/m^2 for exposed decks but need not be taken greater than 3 kN/m^2
= 0,0 for interior decks and superstructure decks aft of the forward quarter
Γ = Taylor Quotient as defined in 4.1.2.1 Lloyd's Register (D)
Δ = displacement, as defined in 4.1.2.1 Lloyd's Register (D)
L_{WL} = Waterline length as defined in 4.1.2.1 Lloyd's Register (D)

Concerning non-displacement mode, the pressure acting on the weather and interior decks is to be taken as:

$$P_{wl} = f_L \cdot (5 + 0{,}01 L_{WL})(1 + 0{,}5 a_v) + E \quad kN/m^2 \qquad (4.2.38)$$

Where,

f_L = the location factor for weather decks, as defined in previous equation
E = As defined in previous equation
a_V= Vertical acceleration as defined in *4.2.2.1 Lloyd’s Register (HSC/VA)*
= is not to be taken less than 1,0, but need not be taken greater than 4,0 for weather decks.
= need not be taken greater than 1,0 for interior decks
L_{WL} = Length Waterline as defined in 4.1.2.1 Lloyd's Register (D)

Pressure on weather deck is increasing from aft to fore of the ship, as it is signalized by the f_L factor.

Additionally, LR make provisions in for craft with multi hulls linked by cross deck structure, in *Rules and Regulations for the Classification of Special Service Craft‘s (July 2018)* Pt. 5, Ch. 2, Sec. 6. According to this section the impact pressure acting on the underside of the cross deck (`wet deck') is to be taken as:

$$P_{pc} = \nabla_{pc} \cdot K_{pc} \cdot V_R \cdot V \cdot \left(1 - \frac{G_A}{H_{03}}\right) kN/m^2 \qquad (4.2.39)$$

Where,

K_{pc} = longitudinal distribution factor
= 1,0 between the aft end of the L_{WL} and 0,75L_{WL}
= 2,0 at the L_{WL} from the aft end of L_{WL}, intermediate values to be determined by linear interpolation
∇_{pc} = cross-deck Impact Factor
= 1/6 for protected structures, as defined in *4.1.2.1 Lloyd's Register (D)*
= 1/3 for unprotected structures, as defined in *4.1.2.1 Lloyd's Register (D)*
G_A = air gap, as defined in *4.1.2.1 Lloyd's Register (D)*
H_{03} = surviving wave height, as defined in *4.1.2.1 Lloyd's Register (D)*
V = allowable speed, as defined in *4.1.2.1 Lloyd's Register (D)*
V_R = is the relative vertical speed of the craft at impact, in knots. If this value is unknown, then the following equation is to be used:
$V_R = \frac{8\cdot H_{1/3}}{\sqrt{L_{WL}}} + 2\ knots$

The last insertion made by LR, is presented in the 7th section of the referenced rulebook, and refers to the area designed for cargo or stores or equipment. For plating the area’s deck design pressure is to be taken as:

$$P_{cd} = W_{CDP} \cdot (1 + 0{,}5 \cdot a_x) \ \ kN/m^2 \qquad (4.2.40)$$

Where,

a_x = Vertical acceleration on any section clear of LCG, as defined in *4.2.2.1 Lloyd’s Register (HSC/VA)*

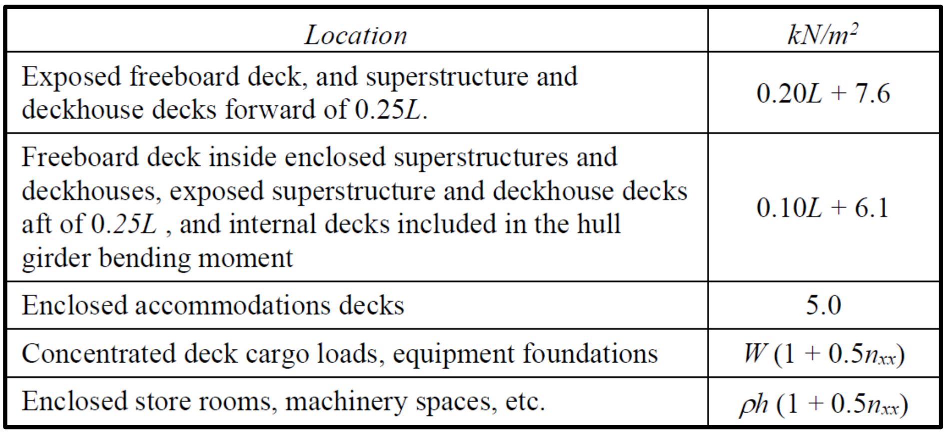
W_{CDP} = the pressure exerted by the cargo on deck specified by the designer in kN/m^2

Regulation presented on this segment are to be used in conjunction with requirements of *4.2.8 Local Design Criteria by Lloyd’s Register,* as appropriate.

4.2.5.2 American Bureau of Shipping (HSC/PD)

In comparison with LR, ABS’s *Rules for Building and Classing High Speed Craft (October 2018)* presents deck pressure, Pd, in more compact way, collecting them in a table in Pt. 3 Ch. 2 Sec.2. Unlike LR indications, this table contains distinctive indications concerning certain locations of the craft, such as enclosed deck and room as given in *Table 4.2.13 Deck Design Pressures (ABS).* Where the various deck locations are described by *Figure 4.2.23 Decks, Superstructures, and Deckhouse Pressures (ABS).*

Table 4.2. 13 Deck Design Pressures, *Pd* (ABS)



Location	kN/m^2
Exposed freeboard deck, and superstructure and deckhouse decks forward of $0.25L$.	$0.20L + 7.6$
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	$0.10L + 6.1$
Enclosed accommodations decks	5.0
Concentrated deck cargo loads, equipment foundations	$W(1 + 0.5n_{xx})$
Enclosed store rooms, machinery spaces, etc.	$\rho h(1 + 0.5n_{xx})$

Where,

W = deck cargo load kN/m^2

n_{xx} = average vertical acceleration at the location under consideration as defined in *4.2.2.2 American Bureau of Shipping (HSC/VA)*

ρ = cargo density in kN/m^3, not to be taken less than 7,04

h = height of enclosed store room, machinery space, etc., in m

L_{WL} = craft length as defined in

Note: Where permanently attached equipment are fitted and the live load associated with this equipment is greater than the deck design pressure, the equipment live loads govern

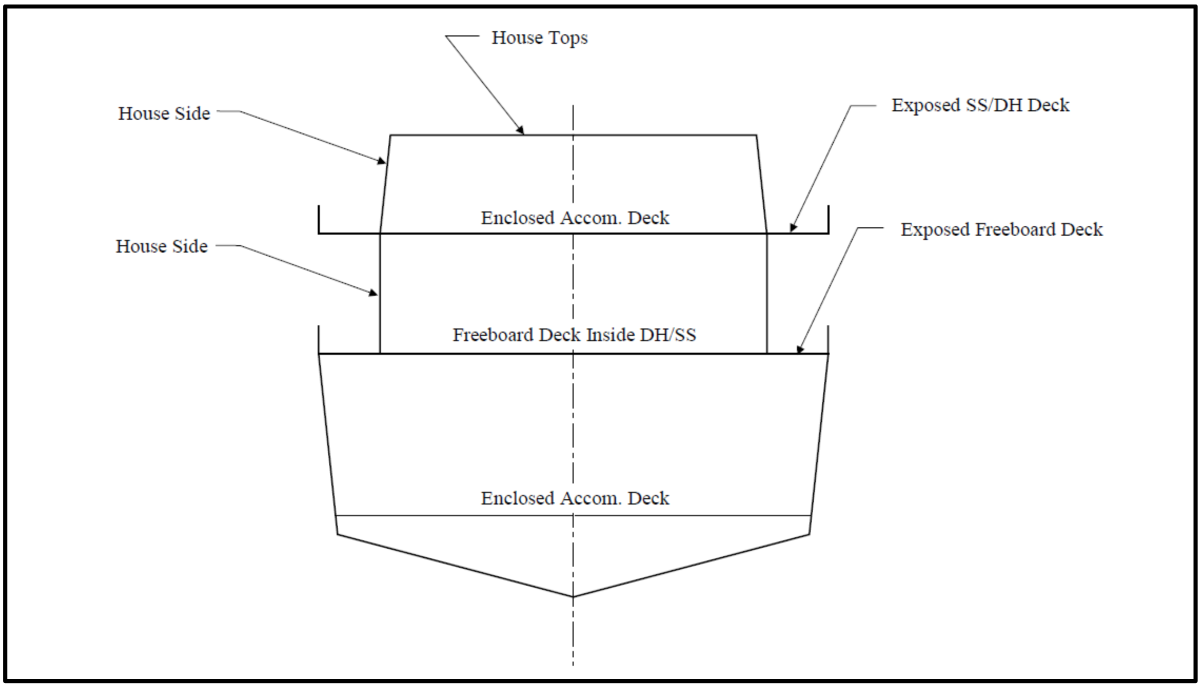


Figure 4.2. 23 Decks, Superstructures, and Deckhouse Pressures (ABS)

Earlier in the same section, ABS provides, alike LR, regulations on 'wet deck' (cross decks) that of course refers to multi hulls. ABS's formula is quite close to LR's but there are some discrepancies due to the societies defining differently the design area and distribution factors. The equation used to determine wet deck design pressure, given by ABS, is the following:

$$p_{wd} = 30 \cdot \mathrm{N}_1 \cdot F_D \cdot F_I \cdot V_I \cdot V \cdot \left(1 - 0{,}85 \cdot \frac{h_a}{h_{1/3}}\right) kN/m^2 \qquad (4.2.41)$$

Where,

N_1 = 0,10

h_a = vertical distance, in m, from lightest draft waterline to underside of wet deck, at design point in question. h_a is not to be greater than 1,176 $h_{1/3}$

F_I = wet deck pressure distribution factor as given in *Figure 4.2.24 Wet Deck Pressure Distribution Factor (ABS)*

V_I = relative impact velocity as given below:

$$V_I = \frac{4 \cdot h_{1/3}}{\sqrt{L_{WL}}} + 1\ m/s$$

F_D = design area factor as defined *4.2.3.2 American Bureau of Shipping (HSC/PBS)*

$h_{1/3}$ = significant wave height, m, see *Table 4.2.1 Design Significant Wave Heights and Speed (ABS)*

V = craft design speed in knots, see *Table 4.2.1 Design Significant Wave Heights and Speed (ABS)*

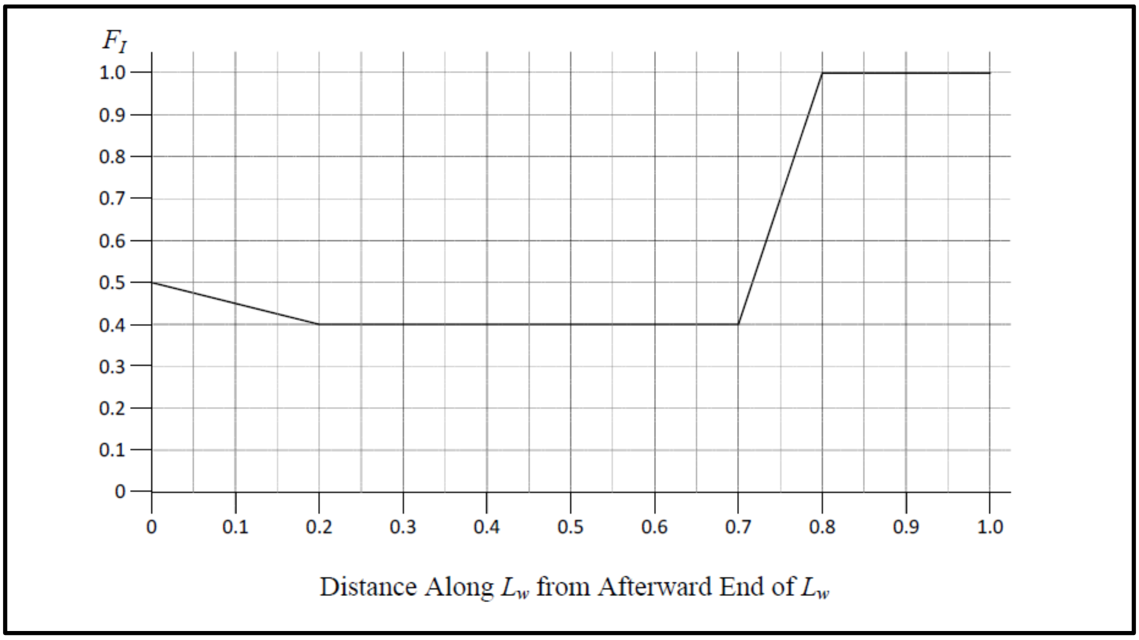


Figure 4.2. 24 Wet Deck Pressure Distribution Factor, F_I (ABS)

4.2.5.3 Bureau Veritas (HSC/PD)

In *Rules for the Classification of High Speed Craft (February 2002),* BV dedicates whole C3.5.8 segment to deck loads, thus including several deck areas of the craft much alike ABS, as it will be presented in the following paragraphs. However, BV presents rules in different fashion.

BV suggests a general equation for all decks, in which factor *p* varies depending on the location of the deck in inspection. The pressure, in kN/m^2, considered as acting on decks is given by the formula:

$$p_d = p \cdot (1 + 0{,}4 \cdot a_v) \ \ kN/m^2 \qquad (4.2.42)$$

Where,

p = uniform pressure due to the load carried, kN/m^2, minimum values are given in the following paragraphs

a_v = Design vertical acceleration as defined in *4.2.2.3 Bureau Veritas (HSC/VA)*

Note: Where decks are intended to carry masses of significant magnitude, including vehicles, the concentrated loads transmitted to structures are given by the corresponding static loads multiplied by (1 + 0,4 a_v)

Bureau Veritas divides deck areas into six locations, providing minimum value of p for every category, except decks carrying vehicles. By that BV is the classification with the most explicit regulations on deck loads, inspecting specifically various part of the craft. The categories that given are weather decks and exposed areas, sheltered decks, enclosed accommodation decks, enclosed cargo decks, platforms of machinery spaces and decks carrying vehicles.

The referenced minimum values for each category are presented below:

- Weather decks and exposed areas: For weather decks and exposed areas without deck cargo:
  - If $z_d \leq 2$:
    $p = 6{,}0\ \ kN/m^2$
  - If 2< z_d < 3:
    $p = (12\ -\ 3 \cdot z_d)\ kN/m^2$
  - If $z_d \geq 3$:
    $p = 3{,}0\ kN/m^2$

  Where z_d is the vertical distance, in m, from deck to waterline at draught T.

  BV adds at this point, that p can be reduced by 20% for primary supporting members and pillars under decks located at least 4 m above the waterline at draught T, excluding embarkation areas.

  For weather decks and exposed areas with deck cargo:
  - If $z_d \leq 2$:
    $p = (p_c +\ 2)\ \ kN/m^2$ with $p_c \geq 4{,}0\ \ kN/m^2$
  - If 2< z_d < 3:
    $p = (p_c + 4\ - z_d)\ \ kN/m^2$ with $p_c \geq (8{,}0 - 2 \cdot z_d)\ \ kN/m^2$
  - If $z_d \geq 3$:
    $p = (p_c +\ 1)\ \ kN/m^2$ with $p_c \geq 4{,}0\ \ kN/m^2$

  Where z_d as defined in this segment and p_c is the uniform pressure due to deck cargo load, in kN/m^2, to be defined by the designer with the limitations indicated above.

- Sheltered decks: They are decks which are not accessible to the passengers and which are not subjected to the sea pressures. Crew can access such deck with care and taking account of the admissible load, which is to be clearly indicated. Deckhouses protected by such decks may not have direct access to ‘tween-deck below.

  $p = 1{,}3\ \ kN/m^2$

- Enclosed accommodation decks: For enclosed accommodation decks not carrying goods:
  - $p = 3\ kN/m^2$, p can be reduced by 20 per cent for primary supporting members and pillars under such decks.

  For enclosed accommodation decks carrying goods:
  - $p = p_c\ \ kN/m^2$, The value of p_c is to be defined by the designer, but taken as not less than 3,0 kN/m^2

- Enclosed cargo decks: For enclosed cargo decks other than decks carrying vehicles:
  - $p = p_c\ \ kN/m^2$, The value of p_c is to be defined by the designer, but taken as not less than 3,0 $\frac{kN}{m^2}$

- Platforms of machinery spaces: For platforms of machinery spaces:
  - $p = 15{,}0\ \ kN/m^2$

Considering decks carrying vehicles, BV may not provide minimum p value, but gives specific instructions on putting through the scantling and can be found on Ch. 3, segment C3.5.8 of the previously referenced document.

Lastly, BV also includes regulation about the pressure acting on the cross deck due to impact loads. According to BV, slamming on bottom of the wet deck is assumed to occur if the air gap H_A, in m, at the considered longitudinal position is less than z_{wd}. BV indicates two different formulas on computing z_{wd} depending on length of the craft, L. When L ≤ 65 m, z_{wd} should be taken as 0,05L, and when L is greater than 65 metres, it should be taken as z_{wd}= 3,25 + 0,0214(L - 65). When this condition is met, pressure on wet deck is not less than:

$$p_{wd} = 3 \cdot K_2 \cdot K_{WD} \cdot V_X \cdot V_{SL} \cdot \left(1 - 0{,}85 \cdot \frac{H_A}{H_s}\right) kN/m^2 \qquad (4.2.43)$$

Where,

H_A = air gap, in m, equal to the distance between the waterline at draught T and the wet deck

K_{WD} = wet deck pressure distribution factor as given in *Figure 4.2.24 Wet Deck Pressure Distribution Factor, F_l (ABS),* where ABS' F_l equals to K_{WD}

V_{sl} = relative impact velocity as given below:
$V_{sl} = \frac{4 \cdot H_S}{\sqrt{L}} + 1\ m/s$

K_2 = design area factor as defined *4.2.3.3 Bureau Veritas (HSC/PBS)*

H_S = significant wave height, m, as defined in *4.2.2.3 Bureau Veritas (HSC/VA)*

V_X = ship's speed, in knots

BV and ABS instructions on impact pressure acting at wet deck are almost identical as the factors that constitute the two equations are equal one by one, except design area factors K_2 and F_D, the first given by a formula and the latter by a figure.

4.2.5.4 Det Norske Veritas - Germanischer Lloyd (HSC/PD)

In segment *4.2.3.4 Det Norske Veritas - Germanischer Lloyd (HSC/PSB)* a common equation on calculating sea pressures acting on the craft's bottom, side, superstructure side, deckhouse side and weather decks is presented. Hence *equation 4.2.29* shall be used when determination of sea pressure on weather deck is needed.

Decks intended to carry cargo are also part of DNV-GL notes but on this thesis indication on estimating relevant pressure is given in *4.2.7.4 Det Norske Veritas – Germanischer Lloyd (HSC/POC)*, by equation *4.2.61*, due to the fact that the referenced equation applies also to other components, such as inner bottom and hatch covers. Note that when weather decks are intended to carry deck cargo the pressure is in general to be taken as the greater of *4.2.29* and *4.2.61.*

Although instructions on design slamming pressure on cross structure are included in *Rules for classification: High speed and light craft* Pt. 3, Ch. 1, Sec. 3, no further regulation on deck pressures are given by DNV-GL.

On the other hand, in Pt. 3, Ch. 1, Sec. 3 of *Rules for classification: High speed and light craft (January 2018)* there are requirements on design slamming pressure on flat cross structures, which is to be taken as follows:

$$p_{sl} = 2{,}6 \cdot k_t \cdot \left(\frac{\Delta}{A}\right)^{0{,}3} \cdot a_{cg} \cdot \left(1 - \frac{H_C}{H_L}\right) \; kN/m^2 \qquad (4.2.44)$$

Where,

A = design load area for element considered, as defined in *4.2.3.4 Det Norske Veritas - Germanischer Lloyd (HSC/PSB)*

H_C = minimum vertical distance in m from WL to load point in operating condition, see *Figure 4.2.25 Flat cross structure (wet deck) subject to slamming (DNV-GL)*

k_t = longitudinal pressure distribution factor according to *Figure 4.2.26 Flat cross structure slamming distribution factor k_t (DNV-GL)*

H_L = necessary vertical clearance in m from WL to load point to avoid slamming

= $0{,}22 \cdot L \cdot k_w \cdot \left(k_c - \frac{0{,}8}{1000} L\right)$

k_w = height coefficient according to *Figure 4.2.27 Flat cross structure height coefficient k_w (DNV-GL)*

L = Length of craft, in metres, see *4.1.2.4 Det Norske Veritas - Germanischer Lloyd (D)*

Δ = Displacement, in tonnes, as defined in *4.1.2.4 Det Norske Veritas - Germanischer Lloyd (D)*

a_{cg} = Vertical acceleration in m/s^2, as defined in *4.2.2.4 Det Norske Veritas - Germanischer Lloyd (HSC/VA)*

k_c = hull type clearance factor

= 0,3 for catamaran, wave piercer

= 0,3 for SES, ACV

= 0,3 for hydrofoil, foilcatamaran

= 0,5 for SWATH.

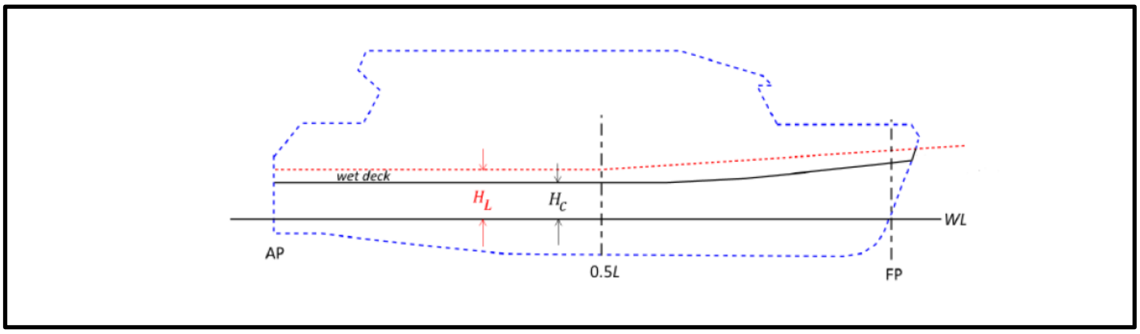


Figure 4.2. 25 Flat cross structure (wet deck) subject to slamming (DNV-GL)

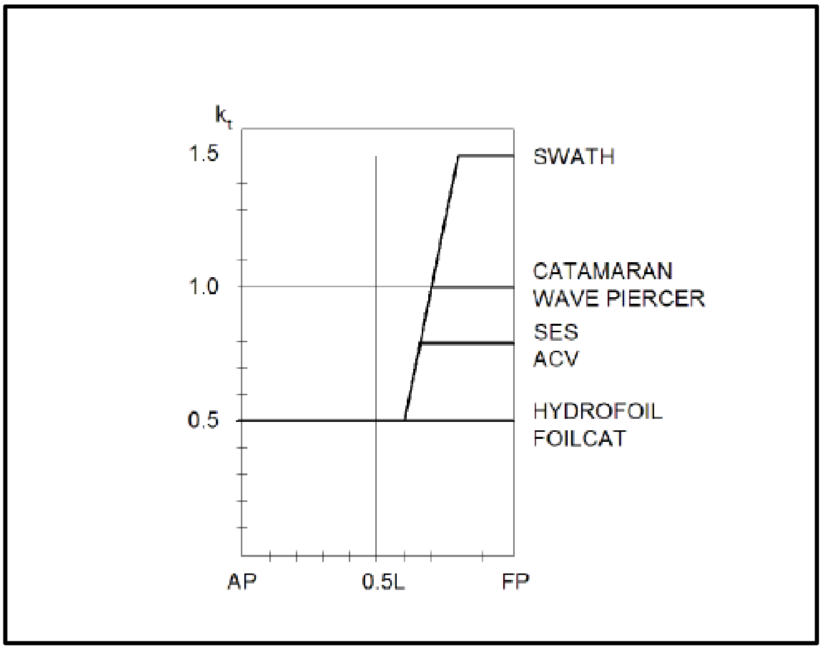


Figure 4.2. 26 Flat cross structure slamming distribution factor k_t (DNV-GL)

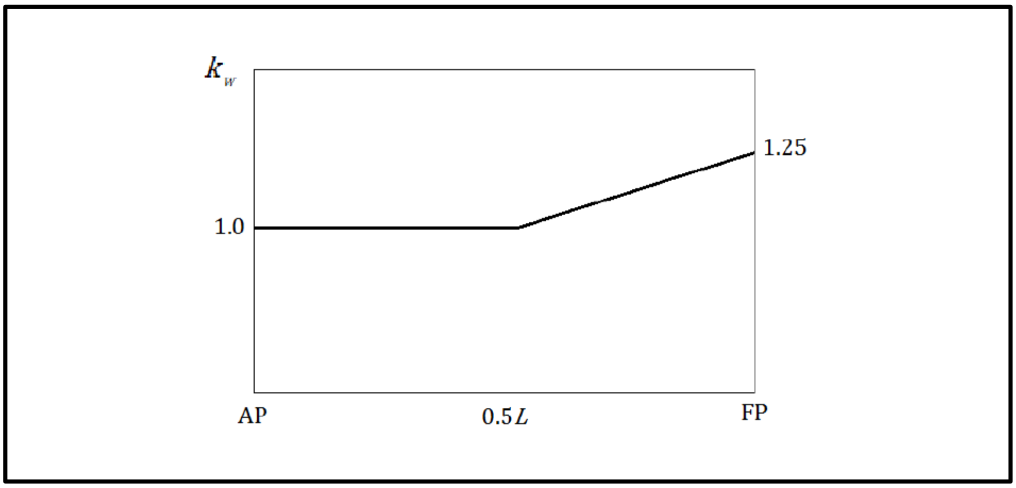


Figure 4.2. 27 Flat cross structure height coefficient k_w (DNV-GL)

DNV-GL regulations do not stop here as it provides minimum values of slamming pressure on the flat cross structure by stating that in no case shall p_{sl} be taken less than shown in *Figure 4.2.28 Minimum slamming pressure on flat cross structures (DNV-GL).*

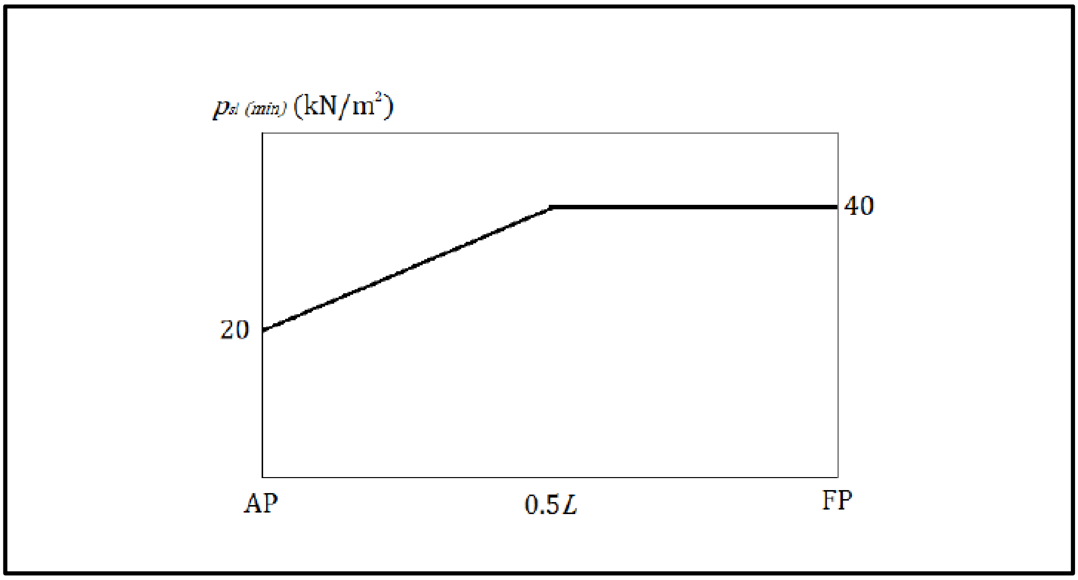


Figure 4.2. 28 Minimum slamming pressure on flat cross structures (DNV-GL)

4.2.5.5 Registro Italiano Navale (HSC/PD)

As it was mentioned in *4.2.2.3 Bureau Veritas (HSC/PSS),* rules and regulations on HSC was established along by BV, RINA and Germanischer Lloyd. Furthermore, RINA single published *Rules for the Classification of High-Speed Craft (January 2009),* this edition contains a revision of the rules mainly including two set of amendments, effective from 1 July 2006 and 1 July 2008, already published with RINA Circulars 3493/A on 29 June 2006 and 3559/A on 27 June 2008.

However, no changes were made that affect design vertical acceleration, thus, no further comments are referred, as the rules are the same as in 4.2.5.3 Bureau Veritas (HSC/PD).

4.2.5.6 Conclusion (HSC/PD)

Generally for deck design pressures the classification societies arrange their requirements in two different ways. In one hand there is ABS, BV and RINA which inspect the deck location separately by suggesting various formulas and on the other hand LR and DNV-GL suggest a general equation to be used as appropriate depending on the location of the deck.

Interesting is the fact that whereas in all equations on calculating pressure on weather deck, given by the societies, the vertical acceleration is part of, ABS estimations depend only to the length of the ship and DNV-GL equation depends mainly to a wave factor, ignoring of course the vertical acceleration. LR and BV/RINA deck pressures are proportional to the sum $(1+0{,}5a_{cg})$ and proportional to Δ, respectively. There is no other similarity amongst the societies.

Concerning components included, there are not major differentiations, except that DNV-GL misses to refer to interior (enclosed) decks.

Lastly, it is noted that on calculating cargo deck's design pressure LR, ABS and DNV-GL give the same formula, which is also similar to BV. As mentioned in previous paragraphs of this section equations referring to wet deck structures similarities are also exist among LR, ABS and BV.

4.2.5.7 Example Calculations at 0,25L, 0,50L and 0,75L (HSC/PD)

LR deck design pressure calculations:

According to *4.2.8 Local Design Criteria by Lloyd's Register*, to determine scantlings the pressure for deck plating, P_{WDP}, is to be the greater of:

$H_f S_f G_f C_f P_{wl}$

P_{cd}

Where,

P_{cd} = cargo tank pressure, *4.2.5.1 Lloyd's Register (HSC/PD)*
P_{wl} = pressure on weather deck, see *4.2.5.1 Lloyd's Register (HSC/PD)*

Since the class notation that has been chosen is that of Passenger type, there is no cargo pressure acting on the weather deck. In addition pressure on weather deck is not dependent to the longitudinal position of the load point considered, thus the following calculations refer to 0,25L, 0,50L and 0,75L.

The pressure has been calculated according to the following:

- P_{wl} is be taken as in equation *4.2.37,* where $a_v = 1{,}025\ m/s^2$ as in equation *4.2.1*
- H_f equal to 1, as HSC, *see 4.2.8.1 Character of classification and class notations*
- S_f equal to 1, as Passenger Type, *see 4.2.8.1 Character of classification and class notations*
- C_f equal to 1, as Mono-hull, *see 4.2.8.1 Character of classification and class notations*
- G_f equal to 0,8, as Service area G2A, *see 4.2.8.1 Character of classification and class notations*

ABS deck design pressure calculations:

Neither ABS requirement on deck design pressure are depended on the longitudinal position of the load point considered. Its calculations also refer to 0,25L, 0,50L and 0,75L, and have been conducted as follows:

- p_d is calculated according to *Table 4.2.13 Deck Design Pressures, Pd (ABS)*, see *4.2.5.2 American Bureau of Shipping (PD)*

BV and RINA deck design pressure calculations:

In contrast to LR and ABS regulations, BV suggested sea pressure is depended on the longitudinal position of the load point considered due to the fact that deck design pressure equation *4.2.41* includes the factor of vertical acceleration of any section clear of the LCG. The deck design pressure value for each point has been calculated as follows:

- For $x/L = 0{,}25\ and\ 0{,}50$
  p_d is calculated as in equation *4.2.41*, as per weather deck and exposed areas without deck cargo, where $z_d = 0{,}92$, Thus $p = 6\ kN/m^2$. Vertical acceleration as in equation 4.2.9, where $k_v = 1$
- For $x/L = 0{,}75$
  p_d is calculated according to above indication. Although vertical acceleration as in equation 4.2.9, where $k_v = 1{,}5$

DNV-GL deck design pressure calculation:

Alike BV and RINA, DNV-GL suggested deck design pressure is depended to the longitudinal position of considered load point, as the factor k_s of equation *4.2.29* varies along the hull. Nevertheless the pressure that is calculated via equation *4.2.29*, where $h_0 = 0{,}92$, for any of the 0,25L, 0,50L and 0,75L points does not surpass the minimum value as indicated by *Table 4.2.12 Minimum sea pressures* (kN/m^2) *(DNV-GL)*, for service restriction notation **R0**. Hence $p = 5\ kN/m^2$.

The results of the above calculations are presented in *Figure 4.2.29 Deck Design Pressures.*

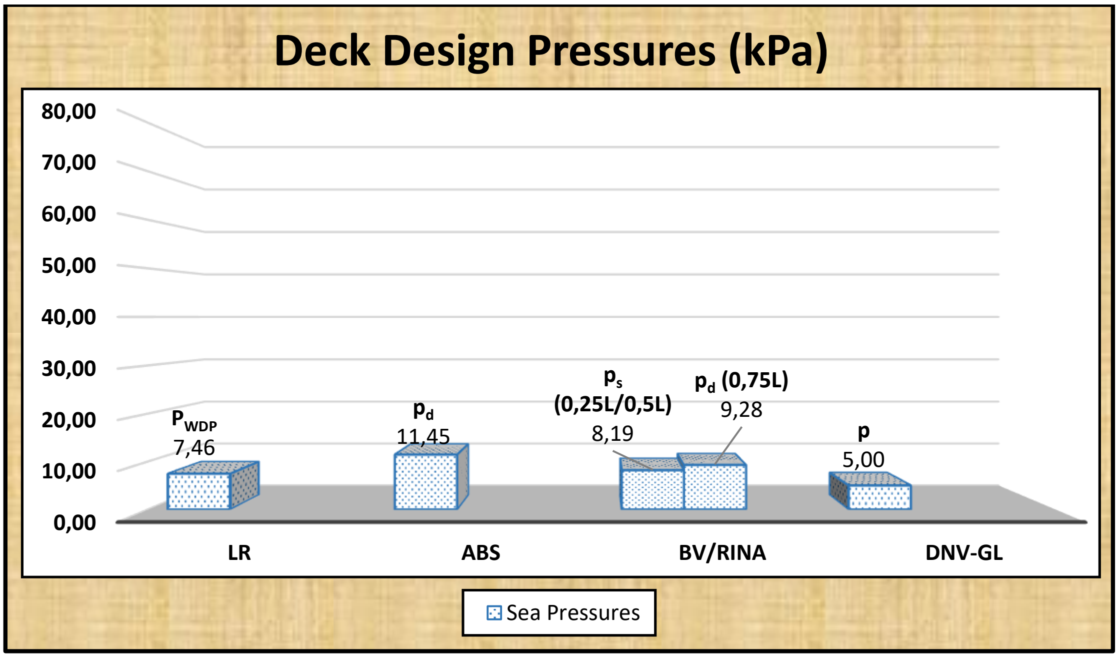


Figure 4.2. 29 Deck Design Pressures

Although ABS equation on deck design pressure is a bit odd, as its value depends only to the ship length, it results to the greater design pressure value. Safety factor must have been taken into consideration for its structure as its value is significantly higher than most of the calculating pressures, except BV and RINA estimations on 0,75L.

LR and BV/RINA equations may not present similarities, but their results on 0,25L and 0,50L do, as their difference in considered small. Lastly, DNV-GL, as in application example of side shell design pressure, suggests the lowest design pressure to act on the deck of the vessel.

4.2.6 Pressures on Forebody (HSC/PF: Pressure on Forebody)

4.2.6.1 Lloyd's Register (HSC/PF)

As in previous cases, LR gives guidelines for two kind of crafts, those operating in displacement mode and those operating in the non-displacement mode, in *Rules and Regulations for the Classification of Special Service Craft's (July 2018)* Pt. 5, Ch. 2, Sec. 5.

For displacement mode the slamming pressure on forebody and bow at load waterline due to relative motion should be taken as:

$P_f = f_f \cdot L_{WL} \cdot (0{,}8 + 0{,}15 \cdot \Gamma)^2 \; kN/m^2$ at FP (4.2.45)

$= P_{dh}$ at 0,9L_{WL} from aft end of L_{WL}

$= P_m$ at 0,75L_{WL} from aft end of L_{WL}

$=$ 0,0 between aft end of L_{WL} and 0,75L_{WL} from aft end of L_{WL}

Intermediate values to be determined by linear interpolation.

Where,

f_f = forebody impact pressure factor as defined in *Table 4.2.14 Forebody impact pressure factor (LR)*

L_{WL} = Waterline length, in metres, as defined in *4.1.2.1 Lloyd's Register (D)*

Γ = Taylor quotient, as defined in *4.1.2.1 Lloyd's Register (D)*

P_{dh} = Impact pressure on bottom shell for displacement mode, as defined in *4.2.3.1 Lloyd's Register (HSC/PBS) and equation 4.2.19*

P_m = Hydrodynamic wave pressure, as given in *equation 4.2.16*

Table 4.2. 14 Forebody impact pressure factor (LR)

Craft type	f_f
Mono-hull craft in non-displacement mode	0,94
Mono-hull craft in displacement mode	0,89
Catamarans and multi-hull craft with partially submerged hulls	1,0
Swaths and multi-hull craft with fully submerged hulls	0,91
Craft supported by hydrodynamic lift provided by foils or other lifting devices	0,81
Note Where multiple craft types apply, the higher value of f_f is to be used.	

Respectively, for non-displacement mode, the forebody and bow slamming pressure at the load waterline is to be taken as follows:

P_f = the greater of P_{dls} or $f_f \cdot L_{WL} \cdot (0{,}8 + 0{,}15 \cdot \Gamma)^2\ kN/m^2$ at FP (4.2.46)
$= P_{dls}$ at $0{,}75L_{WL}$ from aft end of L_{WL}
$= P_m$ at $0{,}5L_{WL}$ from aft end of L_{WL}
$= 0{,}0$ between aft end of L_{WL} and $0{,}5L_{WL}$ from aft end of L_{WL}
Intermediate values to be determined by linear interpolation.

Where,

f_f = forebody impact pressure factor as defined in *Table 4.2.14 Forebody impact pressure factor (LR)*
L_{WL} = Waterline length, in metres, as defined in *4.1.2.1 Lloyd's Register (D)*
Γ = Taylor quotient, as defined in *4.1.2.1 Lloyd's Register (D)*
P_{dls} = Impact pressure on side shell for non-displacement mode, as defined in *4.2.3.1 Lloyd's Register (HSC/PsS) and equation 4.2.32*
P_m = Hydrodynamic wave pressure, as given in *equation 4.2.16*

Regulation presented on this segment are to be used in conjunction with requirements of *4.2.8 Local Design Criteria by Lloyd's Register,* as appropriate.

4.2.6.2 American Bureau of Shipping (HSC/PF)

In a more simplistic manner as described in *Rules for Building and Classing High-Speed Craft (October 2018),* Pt. 3, Ch. 2, sec 2, ABS states that at the fore end of the craft, for forward of 0,125L from the stem, side design pressure is to be not less than given by the following equation:

$$p_{sf} = 0{,}28 \cdot F_a \cdot C_F \cdot N_3 \cdot (0{,}22 + 0{,}15 \tan\alpha)\left(0{,}4V \sin\beta + 0{,}6\sqrt{L}\right)^2 \ kN/m^2 \qquad (4.2.47)$$

Where,

F_a = 3,25 for plating and 1.0 for longitudinals, transverses and girders
C_F = 0,0125L for L < 80 m
= 1,0 for L ≥ 80 m
N_3 = 9,8
α = flare angle, the angle between a vertical line and the tangent to the side shell plating, measured in a vertical plane at 90° to the horizontal tangent to the side shell, see *Figure 4.2.5 Deadrise, Flare, and Entry Angles (ABS)*
β = entry angle, the angle between a longitudinal line, parallel to the centerline and the horizontal tangent to the side shell, see *Figure 4.2.5 Deadrise, Flare, and Entry Angles (ABS)*
V = craft design speed in knots, as defined in *4.1.2.2 American Bureau of Shipping (D)*
L = Scantling Length as defined in *4.1.2.2 American Bureau of Shipping (D)*

Since there no further instructions given by ABS, *equation 4.2.25* may be used in order to determine impact pressure on the fore region of the craft.

4.2.6.3 Bureau Veritas (HSC/PF)

Similarly to ABS, concerning impact pressure due to bottom slamming at the fore of the hull, BV *equation 4.2.28* may be used as appropriate for determination of which, as there are no further indication on the matter in *Rules for the Classification of High Speed Craft (February 2002).*

Likewise, in terms of sea pressure, BV‘s *equations 4.2.27.a* and *4.2.27.b,* presented in *4.2.4.3 Bureau Veritas (HSC/PSS),* covers the whole length of the craft and it should be used accordingly in order to determine the hydrostatic sea pressure at the forebody.

4.2.6.4 Det Norske Veritas - Germanischer Lloyd (HSC/PF)

In the same manner are structured the regulations of DNV-GL, in *Rules for classification: High speed and light craft (January 2018),* sea pressure and impact pressure. As presented in segment *4.2.3.4 Det Norske Veritas - Germanischer Lloyd (HSC/PBS)* and *4.2.4.4 Det Norske Veritas - Germanischer Lloyd (HSC/PSS),* sea pressure and forebody to bow impact pressure shall be taken as in *equation 4.2.29* and *4.2.35* respectively.

No further instruction are made by DNV-GL on this matter.

4.2.6.5 Registro Italiano Navale (HSC/PF)

As it was mentioned in *4.2.2.3 Bureau Veritas (HSC/PSS),* rules and regulations on HSC was established along by BV, RINA and Germanischer Lloyd. Furthermore, RINA single published *Rules for the Classification of High-Speed Craft (January 2009),* this edition contains a revision of the rules mainly including two set of amendments, effective from 1 July 2006 and 1 July 2008, already published with RINA Circulars 3493/A on 29 June 2006 and 3559/A on 27 June 2008.

However, no changes were made that affect design vertical acceleration, thus, no further comments are referred, as the rules are the same as in 4.2.6.3 Bureau Veritas (HSC/PF).

4.2.6.6 Conclusion (HSC/PF)

LR and ABS are the only classification societies to suggest specific calculation for the fore part of the crafts. Since there is no significant similarities in their respective methods, it should be mentioned that ABS requirements refer to 0,125L from the stem and LR's reach to 0,75L and 0,5L from aft end of waterline length, for crafts operating in displacement and non-displacement mode respectively. Also by DNV-GL indications the foredbody side design pressure reaches to 0,4L from aft end of waterline length.

4.2.7 Pressures on Other Components (HSC/POC: Pressure on Other Components)

4.2.7.1 Lloyd's Register (HSC/POC)

Pressures on various components are given by LR in *Rules and Regulations for the Classification of Special Service Craft (July 2018),* Pt. 5, Ch. 2, Sec. 7, in which are covered parts like deckhouses, bulwarks, superstructures, bulkheads and pillars.

By the following is calculated the plating design pressure of deckhouse, bulwarks, first tier and above superstructures as presented in *eq. 4.2.47.* LR also indicates that component design pressure of windows of toughened safety glass is to be calculated by the same equation, but C_1 is to be taken as indicated by *equation 4.2.48.*

$$P_{dhp} = C_1 \cdot P_d \quad kN/m^2 \qquad (4.2.48)$$

Where,

P_d = Pressure on weather and interior decks as defined in *4.2.5.1 Lloyd's Register (HSC/PD)*
C_1 = 1,25 for deckhouse and superstructure fronts on upper deck within the forward third of L_R
= 1,15 for deckhouse and superstructure fronts on upper deck outside the forward third of L_R and exposed machinery casings on the upper deck
= 1,0 for deckhouse and superstructure fronts above the lowest tier
= 0,8 for superstructure sides. A value of 0,64 may be used where the sides of the superstructure are stepped in from the sides of the craft by 1,0 m or more
= 0,5 elsewhere
L_R = Rule length in metres

For windows of toughened safety glass the component design pressure, P_{dhp}, is to be calculated taking C_1 as follows:

$$C_1 = W_1 \cdot W_2 \cdot W_3 \quad kN/m^2 \qquad (4.2.49)$$

Where

W_1 = 2,0 for the lowest tier of unprotected front
= 1,5 for superstructure fronts above the lowest tier
= 1,0 for superstructure sides. A value of 0,8 may be used where the sides of the superstructure are stepped in from the sides of the craft by 1,0 metre or more
= 0,67 elsewhere
W_2= 0,67 + 0,33 (x_b/L_{WL}) where x_b > 0,5L_{WL} from AP
= 0,67 elsewhere
W_3 = 1 – *(y – F)/y*
x_b = distance, in metres, from AP
y = vertical distance, in metres, from the static load waterline at the deepest design draught to the structural element considered
F = *(D – T)* in metres
L_{WL} = Length waterline, as defined in *4.1.2.1 Lloyd's Register (D)*
T = Draught as defined in *4.1.2.1 Lloyd's Register (D)*
D = Depth as defined in *4.1.2.1 Lloyd's Register (D)*

According to LR, for windows positioned on the first tier, C_1 is not to be taken less than that used for the deckhouse plating and P_d for windows may be tapered to 0,5P_d in accordance with *Table 4.2.7 Combined pressure distribution* (LR).

The design pressure on watertight and deep tank bulkheads is presented in a more peculiar way. The *equation 4.2.49* covers the components given in bullets below of. Furthermore while defining h_b, LR gives an alternate definition that guides to the calculation of watertight bulkhead plating and stiffening clear of watertight doors.

$$P_{bh} = 11{,}2 \cdot h_b \quad kN/m^2 \tag{4.2.50}$$

- deep tank bulkheads,
- watertight bulkhead doors and
- stiffening supporting watertight bulkheads in way of watertight doors

Where,

h_b = load head in metres, measured as described in (b)
= 7,2 h_b kN/m^2 for:
  - watertight bulkhead plating and
  - stiffening clear of watertight doors

Where,
h_b = load head in metres, measured as described below in (a) for deep tank bulkheads and (c) for doors

(a) = Watertight bulkheads:
(i) Plating: the distance from a point one-third of the height of the plate above its lower edge to the bulkhead deck at side.
(ii) Stiffeners: the distance from the mid-point of the stiffener span to the bulkhead deck at side.

(b) = Deep tank bulkheads:
For determination of head, the overflow is to be taken as not less than 1,8 m above the crown of the tank.
(i) Plating: the greater of:

- the distance from the point one-third of the height of the plate above its lower edge to the top of the tank

- half the distance from a point one third of the height of the plate above its lower edge to the top of the overflow.

    (ii) Stiffeners: the greater of:

- the distance from the mid-point of the span to the top of the tank
- half the distance from mid-point of span to the top of the overflow.

(c) Watertight door and supporting construction

    (i) Plating: the distance from the point one-third of the height of the plate above its lower edge to the main deck

    (ii) Stiffeners: the distance from the mid-point of the span the main deck

Lastly, LR regulations on design loads are completed by proposing a formula on computing the design load supported by a pillar, which is not to be taken less than 5 kN and is to be calculated as follows:

$$P_{PI} = S_{gt} \cdot b_{gt} \cdot P_c + P_a \ \ kN \tag{4.2.51}$$

Where,

P_c = basic deck girder design pressure, as appropriate, plus any other loadings directly above the pillar, in C

P_a = load, in kN, from pillar or pillars above, assumed zero if there are no pillars over

S_{gt} = spacing, or mean spacing, of girders or transverses, in metres

b_{gt} = distance between centres of two adjacent spans of girders or transverses supported by the pillar, in metres

Regulation presented on this segment are to be used in conjunction with requirements of *4.2.8 Local Design Criteria by Lloyd's Register,* as appropriate.

4.2.7.2 American Bureau of Shipping (HSC/POC)

Alike LR, ABS *Rule for Building and Classing High-Speed Craft (October 2018),* Pt. 3, Ch. 2, Sec. 2 contains regulation on design pressure of superstructures and deckhouses. However ABS does not provide formulas, but points out specific value for each location that varies depending on *L,* craft length as defined in *4.1.2.2 American Bureau of Shipping (D),* and to be as given in *Table 4.2.15 Superstructures and Deckhouses Design Pressures (ABS).* For craft between 12,2 and 30,5 m, design pressure is to be obtained by interpolation.

Table 4.2. 15 Superstructures and Deckhouses Design Pressures (ABS)

Location	L ≤ 12.2m kN/m^2	L > 30,5m kN/m^2
Superstructure and Deckhouse Front Plating	24,1	37,9
Superstructure and Deckhouse Front Stiffeners	24,1	24,1
Superstructure and Deckhouse Aft End and House Side Plating	10,3	13,8
Superstructure and Deckhouse Aft End and House Side Stiffeners	10,3	10,3
House Tops, Forward of Midships, Plating and Stiffeners	6,9	8,6
House Tops, Aft of Midships, Plating and Stiffeners	3,4	6,9

In the same section, ABS includes also regulations on bulkhead structures. Similarly to LR, ABS equations *4.2.51,* concerning both integral and non-integral tank boundaries, and *4.2.52,* concerning watertight boundaries are referring to the design pressure of both plates' and stiffeners'. Tank boundaries and watertight boundaries design pressure are defined as p_t and p_w, respectively by ABS, and are to be taken not less than the following equations.

$$p_t = N_3 \cdot h \;\; kN/m^2$$
$$p_t = \rho \cdot g \cdot (1 + 0{,}5 \cdot n_{xx}) \cdot h_2 \;\; kN/m^2 \qquad (4.2.52)$$

Where,

N_3 = 9,8

h = greatest of the following distances, in m, 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:
    (i) 0,01*L* + 0,15 m
    (ii) 0,46 m

Where *L* is the craft length as defined

$\rho \cdot g$ = Specific weight of the liquid, not to be taken less than 10,05 kN/m^3

n_{xx} = vertical acceleration at midspan of the tank, as defined in *4.2.2.2 American Bureau of Shipping (HSC/VA)*

h_2 = distance from lower edge of plate panel or center of area supported by stiffener to the top of the tank, in m

As per tank boundaries the pressure to be used is the greater of the two given in *eq. 4.2.51.*

$$p_w = N_3 \cdot h \;\; kN/m^2 \qquad (4.2.53)$$

Where,

N_3 = 9,8

h = distance, in m, from the lower edge of plate panel or the center of area supported by the stiffener to the bulkhead deck at centerline

An insertion to the matter, made only by ABS, is dedicated to operational loads. The loads that are falling to this category are human loads and helicopter loads, the latter was not mentioned in relevant deck segment due to its peculiarity and rarity.

Concerning human load ABS states, the same previously referenced section, "*that a composite deck structures are to withstand a point load equivalent to the weight of a man in the middle of the plate or the midspan stiffener".*

While *Rule for Building and Classing High-Speed Craft (October 2018)* contains even general requirements for plans, scantlings and specified loadings, only the most basic regulations would be presented on this thesis.

ABS suggests that for a platform type helicopter decks, a minimum distributed loading of 2010 N/m^2 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 *Table 4.2.13 Deck Design Pressures, Pd (ABS), in 4.2.5.2 American Bureau of Shipping (HSC/PD).* Lastly, if a craft is built to accommodate helicopter safely to the deck in a predetermined position, the structure is to be able to withstand a local load than is at least:

$$P_{HC} = W_{to} \cdot (1 + 0{,}5 \cdot n_{xx}) + C_e \quad kN/m^2 \qquad (4.2.54)$$

Where,

W_{to} = maximum take-off weight
n_{xx} = average vertical acceleration at the location under consideration as defined in *4.2.2.2 American Bureau of Shipping (HSC/VA)*
C_e = 0,49

4.2.7.3 Bureau Veritas (HSC/POC)

BV not only include requirement on design sea pressures on deckhouses, design pressures on tanks and bulkheads, as ABS, but also provides regulation specifically about sea pressures on front walls of the hull, as LR.

In segment C3.5 of *Rules for the Classification of High Speed Craft (February 2002)* are contained all the following regulation made by BV. The first one concerns sea pressure on front walls of the hull (in case of stepped main deck), not located at the fore end, which is not to be less than:

$$p_{sf} = 6 \cdot \left(1 + \frac{x_1}{2 \cdot L(C_B + 0{,}1)}\right) \cdot (1 + 0{,}045 \cdot L - 0{,}38 \cdot z_1) \; kN/m^2 \qquad (4.2.55)$$

Where,

x_1 = distance, in m, from front walls to the midship perpendicular (for front walls aft of the midship perpendicular, x_1 is equal to 0)
z_1 = distance, in m, from load point to waterline at draught T.
L = Scantling Length as defined in *4.1.2.3 Bureau Veritas (D)*
C_B = Block coefficient as defined in *4.1.2.3 Bureau Veritas (D)*

Supplementary, BV distinct cases of incline wall by stating *"Where front walls are inclined backwards, the pressure calculated above can be reduced to (p_{sf} $sin\,a$), where α is the angle in degree between front wall and deck. p_{sf} is not less than the greater of:*

$3 + (6{,}5 + 0{,}6 \cdot L) \cdot sin\, a$

$3 + 2{,}4 \cdot a_{cg}$"

Not alike LR on this, BV provides distinct formula on calculating sea pressure considered acting on walls of deckhouses, which is not be taken less than as given in equation *4.2.55.* Moreover BV points out minimum values of pressure on walls of deckhouses, p_{su}, that depends to the location considered.

The minimum values of p_{su}, in kN/m2, to be considered are:

- for the front wall of the lower tier: p_{su} = 6,5 + 0,06 . L
- for the sides and aft walls of the lower tier: p_{su} = 4,0
- for the other walls or sides: p_{su} = 3,0

$$p_{su} = K_{su} \cdot \left(1 + \frac{x_1}{2 \cdot L(C_B + 0{,}1)}\right) \cdot (1 + 0{,}045 \cdot L - 0{,}38 \cdot z_1) \;\; kN/m^2 \qquad (4.2.56)$$

Where,

K_{su} = coefficient equal to:
- for front walls of a deckhouse located directly on the main deck not at the fore end: K_{su} = 6,0
- for unprotected front walls of the second tier, not located at the fore end: K_{su} = 5,0
- for sides of deckhouses, b being the breadth, in m, of the considered deckhouses*:* $K_{su} = 1{,}5 + 3{,}5b/B$ with 3 ≤ K ≤ 5
- for the other walls: K_{su} = 3,0

$x_1,\ L,\ C_B\ and\ z_1$ are as defined in the previous equation

Quite similar to ABS indications about pressure acting on tank structure, BV provides two formulas, from which the greater is to be used. The two equation given in *eq. 4.2.56* by BV are pretty close to the corresponding ABS' ones, given in *eq. 4.2.51*. Major difference is the fact that ABS misses the factor that refers to the setting pressure of pressure relief valve.

$$\begin{gathered} p_{t1} = 9{,}81 \cdot h_1 \cdot \rho \cdot (1 + 0{,}4 \cdot a_v) + 100 \cdot p_v \quad kN/m^2 \\ p_{t2} = 9{,}81 \cdot h_2 \quad kN/m^2 \end{gathered} \qquad (4.2.57)$$

Where,

h_1 = distance, in m, from load point to tank top

h_2 = distance, in m, from load point to top of overflow or to a point located 1,5 m above the tank top, whichever is greater

ρ = liquid density, in t/m^3 (1,0 t/m^3 for water)

p_v = setting pressure, in bars, of pressure relief valve, when fitted

a $_v$ = vertical acceleration along the hull, as defined in *4.2.2.3 Bureau Veritas (HSC/VA)*

Pressures on subdivision bulkheads provisions made by BV are not to be less that given in *equation 4.2.57,* which is almost identical to ABS' *equation 4.2.52.*

$$p_{sb} = 9{,}81 \cdot h_3 \quad kN/m^2 \qquad (4.2.58)$$

Where,

h_3 = distance, in m, from load point to bulkhead top

4.2.7.4 Det Norske Veritas - Germanischer Lloyd (HSC/POC)

As referenced in previous segments, sea pressure acting in deckhouses is presented in *4.2.3.4 Det Norske Veritas - Germanischer Lloyd (HSC/PBS)* by *equation 4.2.29*, which is used for several components of the craft. Along with *Table 4.2.11 Load intensity factors (a) for weather exposed areas (DNV-GL), equation 4.2.29* should be used not only for deckhouses, but also for front and end bulkheads.

In terms of watertight bulkheads (compartment flooded), however, the design pressure shall be taken as follows:

$$p = 10 \cdot h_b \quad kN/m^2 \tag{4.2.59}$$

Where,

h_b = Vertical distance, in m, from load point to the top of bulkhead top or to flooded waterline if deeper

DNV-GL, in *Rules for classification: High speed and light craft (January 2018)*, Pt. 3, Ch. 1, Sec. 3, includes regulations on pressure in tanks, which is to be taken as the greater of those presented in *equation 4.2.59* and exclusively suggests that tanks for bunkers and tank bulkheads shall normally be designed for liquids of density equal to that of sea water, taken as $\rho = 1{,}025\ t/m^3$. (i.e. $\rho g_0 \cong 10$).

$$\begin{gathered} p = \rho \cdot (g_0 + 0{,}5 \cdot a_v) \cdot h_s \quad kN/m^2 \\ p = 0{,}67 \cdot \rho \cdot g_0 \cdot h_p \quad kN/m^2 \\ p = \rho \cdot g_0 \cdot h_s + 10 \quad kN/m^2 \text{ for L} \le 50\text{m} \\ p = \rho \cdot g_0 \cdot h_s + 0{,}3 \cdot L - 5 \quad kN/m^2 \text{ for L} > 50\text{m} \end{gathered} \tag{4.2.60}$$

Where,

h_s = vertical distance in m from the load point to the top of tank

h_p = vertical distance in m from the load point to the top of air pipe or filling station.

g_0 = Gravity acceleration

a_v = vertical acceleration along the hull, as defined in *4.2.2.4 Det Norske Veritas - Germanischer Lloyd (HSC/VA)*

In addition to the previous, DNV-GL contains, exclusively, information on design pressure of wash bulkheads, which is given in *equation 4.2.60.*

$$p = 3{,}5 \cdot l_t \quad kN/m^2 \tag{4.2.61}$$

Where,

l_t = the greater distance in m to the next bulkhead forward or aft

Finally, in the same section DNV-GL completes its regulations on design pressures by defining the pressure on inner bottom, decks and hatch cover due to dry cargo, store or equipment and the vertical force acting on supporting structures from rigid units of cargo, equipment or other structural components. These are to be taken as given by *equation 4.2.61* and *4.2.62*, respectively.

$$p = \rho \cdot H \cdot (g_0 + 0{,}5 \cdot a_v)\ kN/m^2 \tag{4.2.62}$$

Where,

ρ = Density of stowage
H = stowage height in m.
a_v = Vertical acceleration along the hull, as defined in *4.2.2.4 Det Norske Veritas - Germanischer Lloyd (HSC/VA)*

Standard value of ρ, are provided by DNV-GL in Table 4.2.16 Minimum deck cargo load (DNV-GL).

Table 4.2. 16 Minimum deck cargo load (DNV-GL)

Decks	*Minimum load*
Decks intended for cargo	q = 1.0 t/m^3
Accommodation decks	q = 0.25 t/m^3

$$p_v = (g_0 + 0{,}5 \cdot a_v) \cdot M\ \ kN \tag{4.2.63}$$

Where,

M = mass of unit in tonnes
g_0 = Gravity acceleration
a_v = vertical acceleration along the hull, as defined in *4.2.2.4 Det Norske Veritas - Germanischer Lloyd (HSC/VA)*

4.2.7.5 Registro Italiano Navale (HSC/POC)

As it was mentioned in *4.2.2.3 Bureau Veritas (HSC/PSS),* rules and regulations on HSC was established along by BV, RINA and Germanischer Lloyd. Furthermore, RINA single published *Rules for the Classification of High-Speed Craft (January 2009),* this edition contains a revision of the rules mainly including two set of amendments, effective from 1 July 2006 and 1 July 2008, already published with RINA Circulars 3493/A on 29 June 2006 and 3559/A on 27 June 2008.

However, no changes were made that affect design vertical acceleration, thus no further comments are referred, as the rules are the same as in 4.2.7.3 Bureau Veritas (HSC/POC).

4.2.7.6 Conclusion (HSC/POC)

While a variety of components are contained in the rules of the five classification societies, certain parts are included by all, such as deckhouses, bulkheads, supersrtusctures and tanks. Thus it may be assumed that those components are of major importance.

As regards singular requirements set by each society, LR includes pillars, ABS calculates human and helicopter loads, BV and RINA have particular equation for front walls and DNV-GL provide an equation specifically for the wash bulkhead.

4.2.8 Local Design Criteria by Lloyd's Register

4.2.8.1 Character of classification and class notations

The requirement given on this segment are to be used in conjunction to the rest of LR rules and regulation that have presented so far, as the criteria given below supplement the requirements that LR has set.

As in most of the cases, LR indicates different requirements for crafts operating in non-displacement and displacement mode. However the notations and factors included in the present sub-segment are common for both.

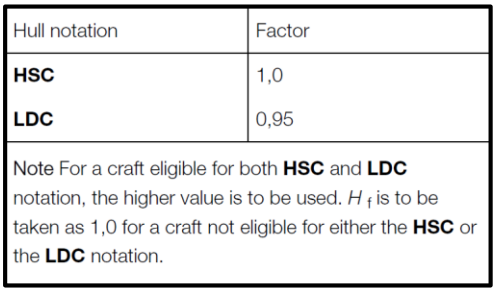
Generally, according to LR, the design pressure, in kN/m^2, for a particular component is to be determined as:

Design pressure= $\delta_f \cdot H_f \cdot G_f \cdot S_f \cdot C_f \cdot load\ criterion$

Where,

H_f = hull notation factor given in *Table 4.2.17 Hull notation factor, H_f (LR)*
G_f = service area restriction notation factor given in *Table 4.2.18 Service area notation factor,* G_f (LR)
S_f = service type factor notation given in *Table 4.2.19 Service type notation factor, S_f*(LR)
C_f = craft type notation factor given in *Table 4.2.20 Craft type notation factor, C_f* (LR)
δ_f = stiffening type factor as given in *Table 4.2.21 Stiffening type factor, δ_f* (LR)

Table 4.2. 17 *Hull notation factor, H_f (LR)*



Hull notation	Factor
HSC	1,0
LDC	0,95

Note For a craft eligible for both **HSC** and **LDC** notation, the higher value is to be used. H_f is to be taken as 1,0 for a craft not eligible for either the **HSC** or the **LDC** notation.

Where,

HSC = A high speed craft is a craft capable of maximum speed, V, not less than

$$V = 7{,}19\ \nabla^{1/6}\ knots$$

Where,
∇ = moulded displacement, in m^3, of the craft corresponding to the design waterline

LDC = A light displacement craft is a craft with a displacement not exceeding:

$$\Delta = 0{,}04 \cdot (L_R \cdot B)^{1{,}5} \;\; tonnes$$

Where,
L_R = Rule length, in m, as defined in *4.1.2.1 Lloyd's Register (D)*
B = Breadth, in m, as defined.in *4.1.2.1 Lloyd's Register (D)*

Table 4.2. 18 Service area notation factor, G_f (LR)

Service area restriction notation	Factor
G1, Zone 3	0,6
G2, Zone 2	0,75
G2A, Zone 1	0,8
G3	0,85
G4	1,0
G5	1,2
G6	1,25

Where,

(a) **Zone 3** covers craft intended for operation in inland waters where the maximum recorded significant wave height based on long-term significant wave height statistics excluding the highest five per cent of the recorded significant wave heights does not exceed 0,5 m. The geographical limits of the intended service are to be identified by the Builder and agreed with LR.

(b) **Zone 2** covers craft intended for operation in inland waters and estuaries where the maximum recorded significant wave height based on long-term significant wave height statistics excluding the highest five per cent of the recorded significant wave heights does not exceed 1,0 m. The geographical limits of the intended service are to be identified by the Builder and agreed with LR.

(c) **Zone 1** covers craft intended for operation in inland waters and estuaries where the maximum recorded significant wave height based on long-term significant wave height statistics excluding the highest five per cent of the recorded significant wave heights does not exceed 1,6 m. The geographical limits of the intended service are to be identified by the Builder and agreed with LR.

(d) **G1 Service Group 1** covers craft intended for service in sheltered waters adjacent to sandbanks, estuaries, reefs, breakwaters or other coastal features and in similarly sheltered waters between islands in reasonable weather where the range to refuge is, in general, five nautical miles or less. The geographical limits of the intended service are to be identified by the Builder and agreed with LR.

(e) **G2 Service Group 2** covers craft intended for service in reasonable weather, in waters where the range to refuge is 20 nautical miles or less. This group will usually cover craft intended for service in coastal waters, for which geographical limits are to be identified by the Builder and agreed with LR.

(f) **G2A Service Group 2A** covers craft intended for service in reasonable weather in waters where the range to refuge is 60 nautical miles or less. The geographical limits of the intended service are to be reported to LR.

(g) **G3 Service Group 3** covers craft intended for service in waters where the range to refuge is 150 nautical miles or less. The geographical limits of the intended service are to be reported to LR.

(h) **G4 Service Group 4** covers craft intended for service in waters where the range to refuge is 250 nautical miles or less. The geographical limits of the intended service are to be reported to LR.

(i) **G5 Service Group 5** covers craft intended for service in waters where the range to refuge is 350 nautical miles or less. The geographical limits of the intended service are to be reported to LR.

(j) **G6 Service Group 6** covers yachts and steel patrol craft having unrestricted service.

Table 4.2. 19 Service type notation factor, S_f (LR)

Service type notation	Factor
Cargo (A)	1,0
Cargo (B)	1,1
Passenger	1,0
Passenger (A)	1,0
Passenger (B)	1,1
Patrol	1,2
Pilot	1,25
Yacht	1,1
Workboat	1,25

Where,

Cargo (A)	This notation will be assigned to cargo craft other than Cargo (B) craft.
Cargo (B)	This notation will be assigned to unassisted high speed cargo craft of 500 gross tons and over which do not proceed in the course of their voyage more than eight hours at operational speed from a place of refuge when fully laden. These craft correspond to `Cargo Craft' as defined in the HSC Code.
Passenger	This notation will be assigned to passenger craft other than Passenger (A) or Passenger (B) craft.
Passenger (A)	This notation will be assigned to assisted high speed craft carrying not more than 450 passengers on board and which do not proceed in the course of their voyage more than four hours at operational speed from a place of refuge when fully laden. These craft correspond to `Category A Craft' as defined in the HSC Code.
Passenger (B)	This notation will be assigned to unassisted high speed craft which may carry more than 450 passengers on board and which do not proceed in the course of their voyage more than four hours at operational speed from a place of refuge when fully laden. These craft correspond to `Category B Craft' as defined in the HSC Code.
Passenger Yacht	This notation will be assigned on request to yachts which are built in accordance with the applicable requirements
Patrol	This notation will be assigned to pilot launches complying with the relevant requirements of LR’s Rules.
Pilot	This notation will be assigned to pilot launches complying with the relevant requirements of LR’s Rules.
Yacht or Support Yacht Craft	This notation will be assigned to all yachts
Wind Farm Service Vessel	This notation will be assigned to Wind Farm Service Vessels that comply with the relevant requirements for workboats and which take into account specific Wind Farm Service applications that they may be required to undertake, see LR’s Guidance Notes for the Classification of Wind Farm Service Vessels.
Workboat	This notation will be assigned to pilot launches complying with the relevant requirements of LR’s Rules.

Table 4.2. 20 Craft type notation factor, C_f (LR)

Craft type notation	Factor
Catamaran	1,0
Hydrofoil	1,1
Mono	1,0
Multi	1,1
RIB	1,15
SES	1,0
SWATH	1,0

Where,

Catamaran	This notation will be assigned to all catamarans including low wash and wave piercing catamarans.
Hydrofoil	This notation will be assigned to hydrofoil craft.
Mono	This notation will be assigned to mono-hull craft other than amphibious air cushion vehicles, hydrofoils and rigid inflatable boats.
Multi	This notation will be assigned to multi-hull craft other than catamarans, swaths and surface effect ships.
RIB	This notation will be assigned to rigid inflatable boats.
SES	This notation will be assigned to surface effect ships.
SWATH	This notation will be assigned to small waterplane area twin hull ships.

Table 4.2. 21 Stiffening type factor, δ_f (LR)

Type	δ_f
Primary stiffening members and transverse frames	0,5
Secondary and local stiffening members Transverse beams	0,8

4.2.8.2 Craft operating in non-displacement mode

The design pressures, in kN/m^2, to be used to determine the scantlings of structural elements are to be taken as specified in *Table 4.2.22 Design pressures for non-displacement craft (LR).*

Table 4.2. 22 Design pressures for non-displacement craft (LR)

Category/location	Craft type	Symbol	Plating pressure	Min.	Symbol	Stiffener pressure	Min.
Mono-hull craft							
Bottom shell	Basic craft	P_{BP}	Greater of $H_f S_f P_s$ $H_f S_f C_f P_{dl}$ $H_f S_f G_f C_f P_f$		P_{BF}	Greater of $\delta_f H_f S_f P_s$ $\delta_f H_f S_f C_f P_{dl}$ $\delta_f H_f S_f G_f C_f P_f$	
	Craft with foils or other lifting devices	P_{BP}	Greater of $H_f S_f P_s$ $H_f S_f C f P_{fb}$		P_{BF}	Greater of $\delta_f H_f S_f P_s$ $\delta_f H_f S_f C_f P_{fb}$	
Side Shell		P_{SP}	P_{BP}		P_{SF}	$\delta_f P_{BP}$	
Multi-hull craft							
Bottom shell	Basic craft	P_{BP}	Greater of $H_f S_f P_s$ $H_f S_f C_f P_{dl}$ $H_f S_f G_f C_f P_f$		P_{BF}	Greater of $\delta_f H_f S_f P_s$ $\delta_f H_f S_f C_f P_{dl}$ $\delta_i H_f S_f G_f C_f P_f$	
	Craft with foils or other lifting devices	P_{BP}	Greater of $H_f S_f P_s$ $H_f S_f C f P_{fb}$		P_{BF}	Greater of $\delta_f H_f S_f P_s$ $\delta_f H_f S_f C_f P_{fb}$	
	Fully submerged hulls	P_{BP}	Greater of $H_f S_f P_s$ $H_f S_f G_f P_f$		P_{BF}	Greater of $\delta_f H_f S_f P_s$ $\delta_f H_f S_f G_f P_f$	
Outboard side shell		P_{SP}	P_{BP}		P_{SF}	$\delta_f P_{BP}$	
Inboard side shell		P_{SP}	Greater of P_{BP} 1,6 P_{WDP} at wet deck		P_{SF}	Greater of $\delta_f P_{BP}$ 1,9 P_{WDP} at wet deck	
Wet deck		P_{CP}	Greater of $H_f S_f P_s$ $H_f S_f P_{pc}$		P_{CF}	Greater of $\delta_f H_f S_f P_s$ $\delta_f H_f S_f P_{pc}$	

Weather deck *see* Note 1		P_{WDP}	Greater of $H_f S_f G_f C_f P_{wl}$ P_{cd}	7	P_{WDF}	Greater of $\delta_f H_f S_f G_f C_f P_{wl}$ P_{cd}	7
Coachroof deck, *see* Note 1		P_{CRP}	$H_f S_f G_f C_f P_{wl}$	7	P_{CRF}	$\delta_f H_f S_f G_f C_f P_{wl}$	7
Interior deck		P_{IDP}	Greater of $H_f S_f C_f P_{wl}$ P_{cd}	3,5	P_{IDF}	Greater of $\delta_f H_f S_f C_f P_{wl}$ P_{cd}	3,5
Deckhouses, bulwarks and superstructure		P_{DHP}	$H_f S_f G_f C_f P_{dhp}$		P_{DHF}	$\delta_f H_f S_f G_f C_f P_{dhp}$	
Deckhouse windows of toughened safety glass		P_{DHP}	$H_f S_f G_f C_f P_{dhp}$ For windows on first tier and deckhouse fronts All other windows	7 5			
Inner bottom		P_{IBP}	$H_f S_f P_m + P_h$	$10T$	P_{IBF}	$\delta_f (H_f S_f P_m + P_h)$	$10T$
Watertight and deep tank bulkheads		P_{BHP}	P_{bh}		P_{BHF}	P_{bh}	

Note 1. G_f is not to be taken less than 1,0.

Note 2. The result of each row in each cell is found as the product of all items on that row in that cell.

Where,

P_m = Hydrodynamic pressure as defined, see *4.2.3.1 Lloyd's Register (HSC/PBS)*
P_{dl} = impact pressure *see 4.2.3.1 Lloyd's Register (HSC/PBS)* and *4.2.4.1 Lloyd's Register (HSC/PSS)*
P_{fb} = impact pressure for craft supported by hydrodynamic lift provided by foils or other lifting devices, see *4.2.3.1 Lloyd's Register (HSC/PBS)* and *4.2.4.1 Lloyd's Register (HSC/PSS)*
P_s = shell envelope pressure, see *4.2.3.1 Lloyd's Register (HSC/PBS)* and *4.2.4.1 Lloyd's Register (HSC/PSS)*
P_f = forebody impact pressure, see *4.2.6.1 Lloyd's Register (HSC/PF)*
P_{cd} = cargo tank pressure, *4.2.5.1 Lloyd's Register (HSC/PD)*
P_{dhp} = deckhouse, bulwalks and superstructure pressure, see *4.2.7.1 Lloyd's Register (HSC/POC)*
P_{bh} = watertight and deep tank bulkhead pressure, see *4.2.7.1 Lloyd's Register (HSC/POC)*
P_{pc} = impact pressure acting on the cross-deck structure, see *4.2.5.1 Lloyd's Register (HSC/PD)*
P_{wl} = pressure on weather deck, see *4.2.5.1 Lloyd's Register (HSC/PD)*
P_{BP} = design pressure for bottom plating
P_{BF} = design pressure for bottom stiffening
P_{SP} = design pressure for side shell plating
P_{SF} = design pressure for side shell stiffening
P_{CP} = design pressure for cross-deck plating
P_{CF} = design pressure for cross-deck stiffening
P_h = hydrostatic pressure, see *4.2.3.1 Lloyd's Register (HSC/PBS)*
P_{WDP} = design pressure for weather deck plating
P_{WDF} = design pressure for weather deck stiffening
P_{CRP} = design pressure for coachroof plating
P_{CRF} = design pressure for coachroof stiffening
P_{IDP} = design pressure for interior deck plating

P_{IDF} = design pressure for interior deck stiffening

P_{IBP} = design pressure for inner bottom plating

P_{IBF} = design pressure for inner bottom stiffening

P_{DHP} = design pressure for deckhouse, bulwarks and superstructures plating and windows

P_{DHF} = design pressure for deckhouse, bulwarks and superstructure stiffening

P_{BHP} = design pressure for bulkheads

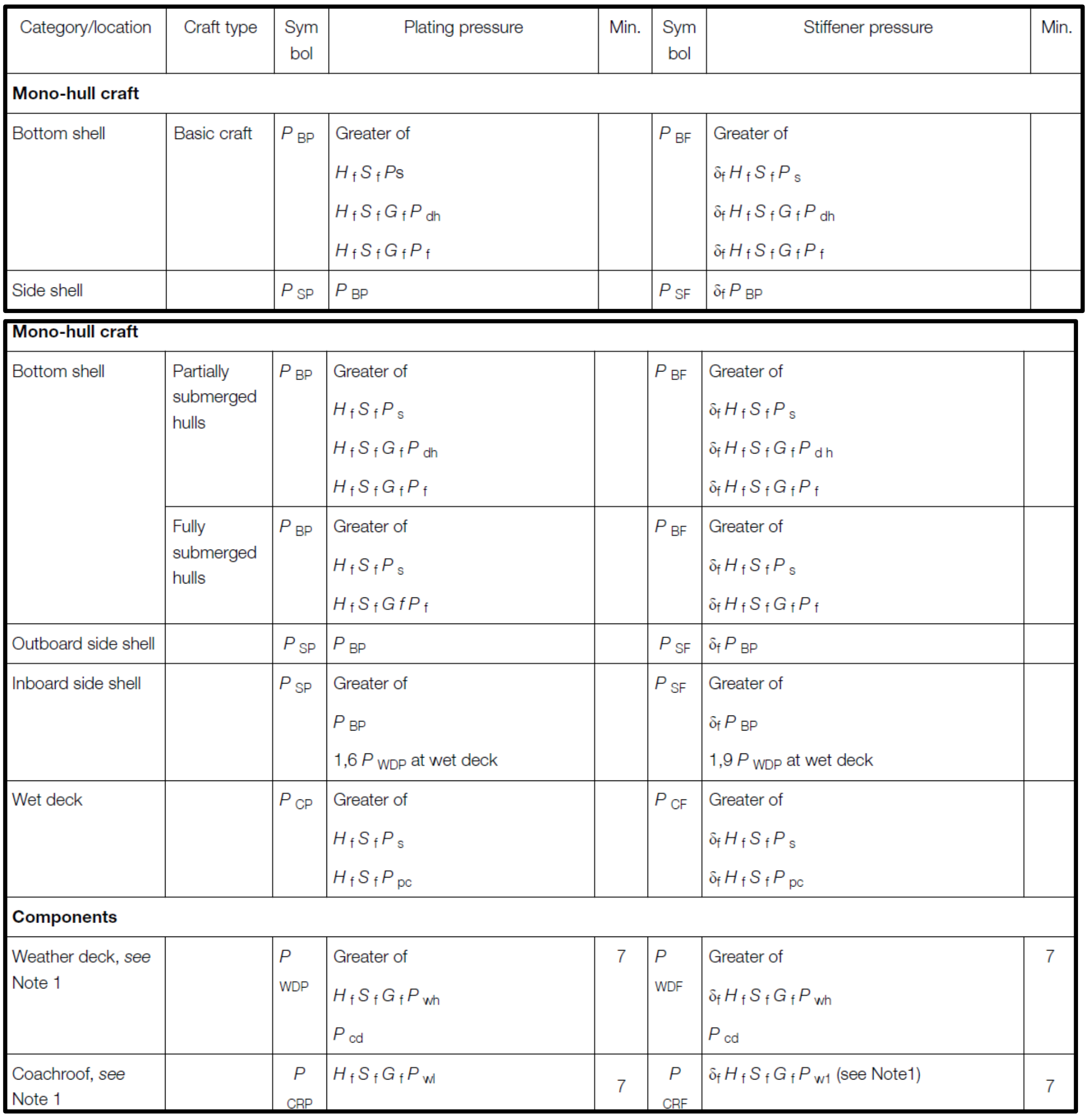
P_{CDP} = design pressure for cargo deck plating

T, LR, B, Δ and Γ are as defined in *4.1.2.1 Lloyd's Register (D)*

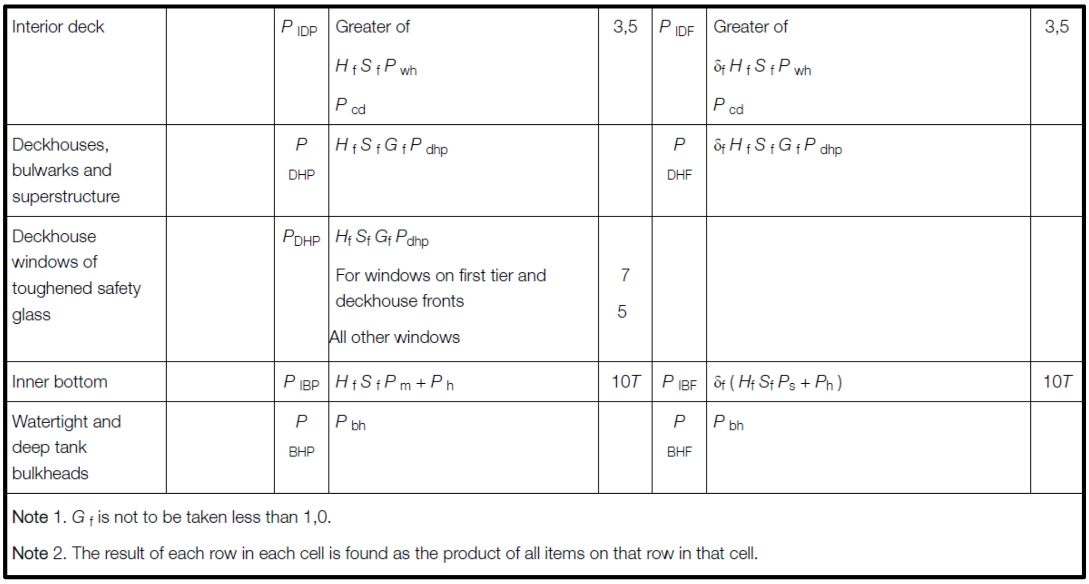
4.2.8.3 Craft operating in displacement mode

The design pressures, in kN/m^2, to be used to determine the scantlings of structural elements are to be taken as specified in *Table 4.2.23 Design pressures for displacement craft (LR).*

Table 4.2. 23 Design pressures for displacement craft (LR)



Category/location	Craft type	Symbol	Plating pressure	Min.	Symbol	Stiffener pressure	Min.
Mono-hull craft							
Bottom shell	Basic craft	P_{BP}	Greater of $H_f S_f Ps$ $H_f S_f G_f P_{dh}$ $H_f S_f G_f P_f$		P_{BF}	Greater of $\delta_f H_f S_f P_s$ $\delta_f H_f S_f G_f P_{dh}$ $\delta_f H_f S_f G_f P_f$	
Side shell		P_{SP}	P_{BP}		P_{SF}	$\delta_f P_{BP}$	
Mono-hull craft							
Bottom shell	Partially submerged hulls	P_{BP}	Greater of $H_f S_f P_s$ $H_f S_f G_f P_{dh}$ $H_f S_f G_f P_f$		P_{BF}	Greater of $\delta_f H_f S_f P_s$ $\delta_f H_f S_f G_f P_{d h}$ $\delta_f H_f S_f G_f P_f$	
	Fully submerged hulls	P_{BP}	Greater of $H_f S_f P_s$ $H_f S_f G f P_f$		P_{BF}	Greater of $\delta_f H_f S_f P_s$ $\delta_f H_f S_f G_f P_f$	
Outboard side shell		P_{SP}	P_{BP}		P_{SF}	$\delta_f P_{BP}$	
Inboard side shell		P_{SP}	Greater of P_{BP} 1,6 P_{WDP} at wet deck		P_{SF}	Greater of $\delta_f P_{BP}$ 1,9 P_{WDP} at wet deck	
Wet deck		P_{CP}	Greater of $H_f S_f P_s$ $H_f S_f P_{pc}$		P_{CF}	Greater of $\delta_f H_f S_f P_s$ $\delta_f H_f S_f P_{pc}$	
Components							
Weather deck, *see* Note 1		P_{WDP}	Greater of $H_f S_f G_f P_{wh}$ P_{cd}	7	P_{WDF}	Greater of $\delta_f H_f S_f G_f P_{wh}$ P_{cd}	7
Coachroof, *see* Note 1		P_{CRP}	$H_f S_f G_f P_{wl}$	7	P_{CRF}	$\delta_f H_f S_f G_f P_{w1}$ (see Note1)	7



Interior deck		P_{IDP}	Greater of $H_f S_f P_{wh}$ P_{cd}	3,5	P_{IDF}	Greater of $\delta_f H_f S_f P_{wh}$ P_{cd}	3,5
Deckhouses, bulwarks and superstructure		P_{DHP}	$H_f S_f G_f P_{dhp}$		P_{DHF}	$\delta_f H_f S_f G_f P_{dhp}$	
Deckhouse windows of toughened safety glass		P_{DHP}	$H_f S_f G_f P_{dhp}$ For windows on first tier and deckhouse fronts All other windows	7 5			
Inner bottom		P_{IBP}	$H_f S_f P_m + P_h$	$10T$	P_{IBF}	$\delta_f (H_f S_f P_s + P_h)$	$10T$
Watertight and deep tank bulkheads		P_{BHP}	P_{bh}		P_{BHF}	P_{bh}	

Note 1. G_f is not to be taken less than 1,0.

Note 2. The result of each row in each cell is found as the product of all items on that row in that cell.

Where,

Symbols are as defined in 4*.2.8.2 Craft operating in non-displacement mode*

Section

4.3 Planing and Semi-Planing Motor Yacht

4.3.1 General (Planing and Semi-Planing Yacht: PSPY)

While there is not a standard definition, yacht may considered a pleasure, commercial or sport vessel which is propelled by sail or by engine or by combination of both. Obviously the requirements of this section relate only to crafts operating with mechanical propulsion.

The rules and regulations given by all five classification societies are normally applied for crafts with overall length greater or equal to 24 metres. In spite of that, special consideration may be given for smaller crafts, especially if they fill requirements of other International Standards, a feature that finds the societies in agreement. Furthermore, not all societies are referring to sport yacht and are limited to passenger yachts.

4.3.2 Vertical Acceleration (PSPY/VA: Vertical Acceleration)

4.3.2.1 Lloyd's Register (PSPY/VA)

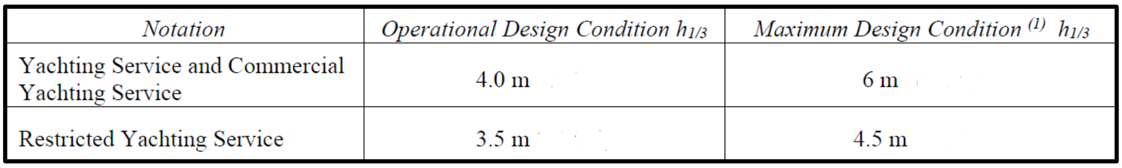
LR *Rules and Regulations for the Classification of Special Service Craft (July 2018)* finds application in several type of crafts, including yachts. Also, LR does not give distinct equation on vertical acceleration depending on the type of craft, but rather distinguish them per operating mode and number of hulls. Therefore, formulas on calculating vertical acceleration of planing or semi planing yachts shall be obtained from *4.2.2.1 Lloyd's Register (HSC/VA),* as applicable.

Furthermore, it should be reminded that LR regulations, referring to non-displacement mode, apply to craft operating in full planing or semi planing modes.

4.3.2.2 American Bureau of Shipping (PSPY/VA)

ABS respective rulebook is *Guide for Building and Classing Yachts (October 2018).* As presented in Pt. 3, Ch. 2, Sec. 2 of the referenced article, ABS regulations on design vertical acceleration are identical to the corresponding of High-Speed Craft's. Thus, in order to calculate design vertical acceleration of planing or semi planing yacht, equations presented in *4.2.2.2 American Bureau of Shipping (HSC/VA)* are to be used, as applicable. However maximum values for design significant wave, $h_{1/3}$, are defined by *Table 4.3.1 Motor Yacht Design Significant Wave Heights (ABS),* below.

Table 4.3. 1 Motor Yacht Design Significant Wave Heights (ABS)



Notation	*Operational Design Condition* $h_{1/3}$	*Maximum Design Condition* (1) $h_{1/3}$
Yachting Service and Commercial Yachting Service	4.0 m	6 m
Restricted Yachting Service	3.5 m	4.5 m

Note: Speed, V, for Maximum Design Condition to be taken as 10 knots

A minor differentiation is that instead of providing a formula to calculate maximum value, ABS notes that vertical acceleration need not to be taken greater than 7,0 g's. Also this feature is attached only to mono-hulls.

4.3.2.3 Bureau Veritas (PSPY/VA)

BV divides motor yachts in two categories, high and slow speed motor yachts, both of them contained in *Rules for the Classification and the Certification of Yachts (March 2012),* Pt. B, Ch. 4, Sec. 3.

Considering high speed motor yacht, the design vertical acceleration is defined as in *4.2.2.3 Bureau Veritas (HSC/VA),* but *foc* and *Soc*, used in *equation 4.2.8,* are to be taken as defined in *Table 4.3.2 foc for motor yacht (BV)* and *Table 4.3.3 Soc for motor yacht (BV),* respectively. Equation *4.2.10* given in the same segment also applies.

In addition, BV provides a table with maximum values of vertical acceleration depending on the type of the craft, data of which are given in *Table 4.3.4 Maximum values of acg for motor yacht (BV)*. Nevertheless not an equation for calculating design acceleration at any section clear of the LCG is given.

Table 4.3. 2 foc for motor yacht (BV)

Type of design **(1)**	Cruise motor yacht	Sport motor yacht	Offshore racing motor yacht **(2)**	Motor yacht with specific equipment
foc	0,666	1,000	1,333	1,666

(1) The type of design is to be defined by the yacht designer, based on the following type classification:

- Cruise Motor yacht:
  At maximum speed in service, the hull is mainly intended to be sustained by a combination of buoyancy and planning effect
- Sport Motor yacht:
  At maximum speed in service, the hull may be submitted during short moments to only planning effect
- Offshore racing Motor yacht:
  At maximum speed in service, the hull is consistently submitted to planning effect
- Motor yacht with specific equipment:
  The yacht is submitted to the same effect as Offshore racing Motor yacht and is fitted with safety arrangement (for example safety belts).

(2) This value is given for information only, racing yachts not being covered by the present Rules

Table 4.3. 3 Soc for motor yacht (BV)

Sea conditions **(1)**	Open sea **(2)**	Restricted open sea **(3)**	Moderate environment **(4)**	Smooth sea **(5)**
Soc	C_F **(6)**	0,3	0,23	0,14

(1) The sea conditions are defined with reference to significant wave heights H_s which are exceeded for an average of not more than 10 percent of the year:

- Open-sea service: $H_s \geq 4,0$ m
- Restricted open-sea service: $2,5 \text{ m} \leq H_s < 4,0$ m
- Moderate environment service: $0,5 \text{ m} < H_s < 2,5$ m
- Smooth sea service: $H_s \leq 0,5$ m.

(2) Category A in case of EC Directive, **unrestricted navigation** or **navigation limited to 60 nautical miles** for Classification.

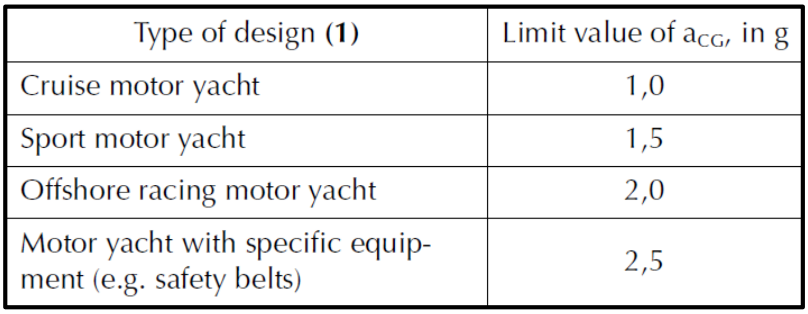
(3) Category B in case of EC Directive.

(4) Category C in case of EC Directive, **coastal area** for Classification.

(5) Category D in case of EC Directive, **sheltered area** for Classification.

(6) $C_F = 0,2 + \dfrac{0,6}{V/\sqrt{L_W}} \geq 0,32$

Table 4.3. 4 Maximum values of acg for motor yacht (BV



Type of design **(1)**	Limit value of a_{CG}, in g
Cruise motor yacht	1,0
Sport motor yacht	1,5
Offshore racing motor yacht	2,0
Motor yacht with specific equipment (e.g. safety belts)	2,5

As per slow speed yachts, BV clarifies that no specific acceleration are to be calculated. The effect of yacht motions are directly taken into consideration in the Rules formulae for the determination of wave loads.

4.3.2.4 Det Norske Veritas - Germanischer Lloyd (PSPY/VA)

In respect of *Rules for Classification: Yachts (October 2016),* Pt. 3, Ch. 3, by DNV-GL, crafts' accelerations for dynamic load cases, design operational conditions and design loads shall be regulated as applicable, whether referring to a mono-hull motor or high speed motor or a multi hull motor yacht.

In cases of mono-hull high speed and multi-hull motor yachts design vertical acceleration, as defined for the ship type crew boat, according to *4.2.2.4 Det Norske Veritas - Germanischer Lloyd (HSC/VA)* is applicable, as it is mentioned in sections 4 and 5 of the referenced chapter.

As regards mono-hull motor yachts that are not high-speed, indications made in *4.4.2.4 Det Norske Veritas - Germanischer Lloyd (DSY/VA)* are to be applied.

4.3.2.5 Registro Italiano Navale (PSPY/VA)

RINA provides two rulebooks, one concerning pleasure yachts and one concerning yacht for commercial use, whose rules on vertical acceleration and design loads are same. Therefore references would be addressed only to one of them as there not any discrepancies on the content concerning the concerning the subject that is discussed.

As in *Rules for Yachts Designed for Commercial Use (January 2019),* RINA specifications on planing and semi-planing yacht's vertical acceleration are conclude to those given in *4.3.2.3 Bureau Veritas (PSPY/VA),* as the design vertical acceleration is not to be taken less than the one defined by BV for the ship type Cruise motor yacht in open-sea condition. A discrepancy between the two that instead of 0,666, the value that corresponds to the cruise motor yacht *foc* factor is equal to 0,65.

In RINA regulations, equation *4.2.10*, referenced in *4.3.2.3 Bureau Veritas (PSPY/VA),* is not included.

Also RINA provides equation on calculating vertical acceleration at any clear section of the LCG and is equal to:

$$a_v = k_v \cdot a_{cg} \qquad (4.3.1)$$

Where

K_v = Longitudinal distribution factor, defined in *Figure 4.3.1 Longitudinal distribution factor (RINA)*, equal to 2.x/L or 0,8, whichever is the greater, where x is the distance, in m, from the calculation point to the aft perpendicular

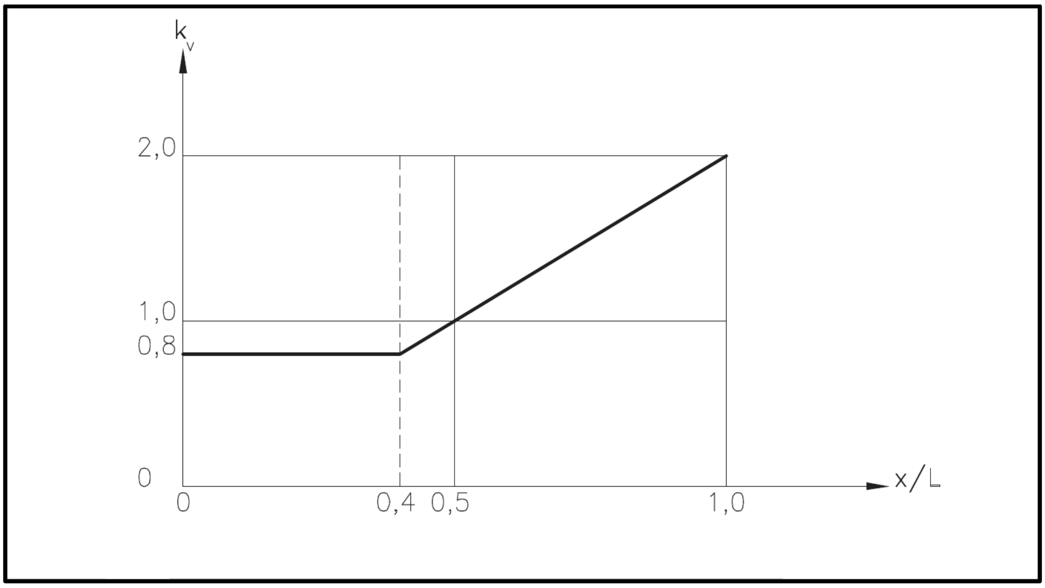


Figure 4.3. 1 Longitudinal distribution factor (RINA)

4.3.2.6 Conclusion (PSPY/VA)

The classifications societies set mostly similar requirements, for the vertical acceleration of planing and semi-planing motor yachts, with the respective of HCS', as it was expected since those yacht operate in high speeds. Hence the conclusion that was drawn in *4.2.2.6 Conclusion (HSC/VA)* apply here as well.

However it should be reminded that in BV's rule document there is not an equation for calculating design acceleration at any section clear of the LCG.

4.3.3 Pressures on Bottom Shell (PSPY/PBS: Pressure on Bottom Shell)

4.3.3.1 Lloyd's Register (PSPY/PBS)

LR and *Rules and Regulations for the Classification of Special Service Craft (July 2018)* find application in several type of crafts, including yachts. Also, LR does not give distinct equation on pressures on bottom shell depending on the type of craft, but rather distinguish them per operating mode and number of hulls. Therefore, formulas on calculating design pressures of planing or semi planing yachts shall be obtained from *4.2.3.1 Lloyd's Register (HSC/PBS),* as applicable.

Furthermore, it should be reminded that LR's regulations, referring to non-displacement mode, apply to craft operating in full planing or semi planing modes.

4.3.3.2 American Bureau of Shipping (PSPY/PBS)

Regulations on calculating design hydrostatic and bottom slamming pressure are included in *Guide for Building and Classing Yachts (October 2018)* Pt. 3, Ch. 2, Sec. 3. The formulas provided are similar to those presented in *4.2.3.2 American Bureau of Shipping (HSC/PBS).*

Specifically, in order to calculate hydrostatic pressure and bottom slamming pressure equation *4.2.23* and *4.2.26* shall be used respectively.

Note that, concerning yachts, ABS does not provide formula referring to bottom slamming along the hull, only at LCG. In addition, equation *4.2.26* is used for crafts with length less than 61 metres, it terms of high-speed crafts, while is generally used for yachts.

4.3.3.3 Bureau Veritas (PSPY/PBS)

BV also suggests formulas to compute design bottom slamming pressure, but, instead of supplementary providing requirements on hydrostatic forces, as ABS, it considers that local sea loads are constituted by the wave loads.

The formula that is indicated by BV in *Rules for Yachts (March 2012),* concerns both bottom and side shell and is to be used for all type of crafts. The wave loads are to be taken into account for the platings, secondary stiffeners and primary stiffeners in the different areas of the hull defined in *Figure 4.3.2 Load areas and coefficient Xi for the external side shell and bottom sea pressure (BV).*

According to BV wave loads are to be calculated as follows:

$$P_s = 9{,}807 \cdot n \cdot [T + \left(\frac{C_W}{X_i} + h_2\right) - z] \geq P_{dmin} \; kN/m^2 \tag{4.3.2}$$

Where,

P_{dmin} = Minimum sea pressure on exposed deck, in kN/m^2, on the considered area, as defined in *4.3.5.3 Bureau Veritas (PSPY/PD)*

C_W = Wave height, in m, to be taken equal to

= $10 \cdot \log(L_W) - 10$ for $L_W \geq 18$ m

= $0{,}065 \cdot L_W + 1{,}5$ for $L_W < 18$ m

L_W = Wave length in m, as defined in *4.1.2.3 Bureau Veritas (D)*

T = Full load draught, in m

n = Coefficient depending on the navigation notation, as given in *4.1.2.3 Bureau Veritas (D)*

X_i = Wave load coefficient, defined in *Table 4.3.5 Wave load coefficients (BV)*, in relation to the area considered

z = Height, in m, of the calculation point, measured as defined in *Figure 4.3.3 Vertical distance z (BV)* in relation to the type of yacht

h_2 = Distance in m, equal to:

- for bottom and external side shell of hull:
  $h_2 = 0$
- for internal side shell of catamaran and bottom of cross deck of catamaran:

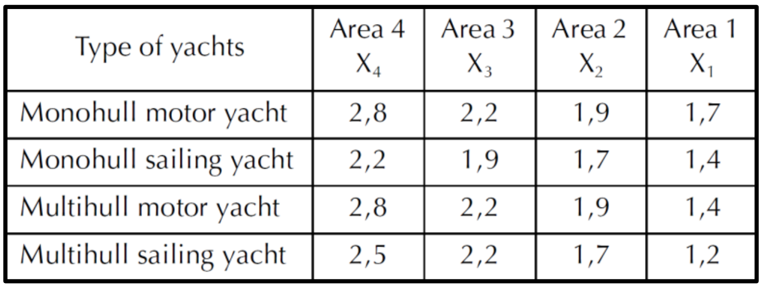
$$h_2 = \frac{B_W \cdot (T + \frac{c_W}{X_i}) \cdot c_B}{B_i}$$

B_W = Breadth at full load waterline at considered transverse section see *Figure 4.3.4 Vertical distance z for catamarans (BV)*

B_i = Distance between internal side shells at waterline at considered transverse section, in m, see *Figure 4.3.4 Vertical distance z for catamarans (BV)*

c_B = block coefficient as defined in *4.1.2.3 Bureau Veritas (D)*

Table 4.3. 5 Wave load coefficients (BV)



Type of yachts	Area 4 X_4	Area 3 X_3	Area 2 X_2	Area 1 X_1
Monohull motor yacht	2,8	2,2	1,9	1,7
Monohull sailing yacht	2,2	1,9	1,7	1,4
Multihull motor yacht	2,8	2,2	1,9	1,4
Multihull sailing yacht	2,5	2,2	1,7	1,2

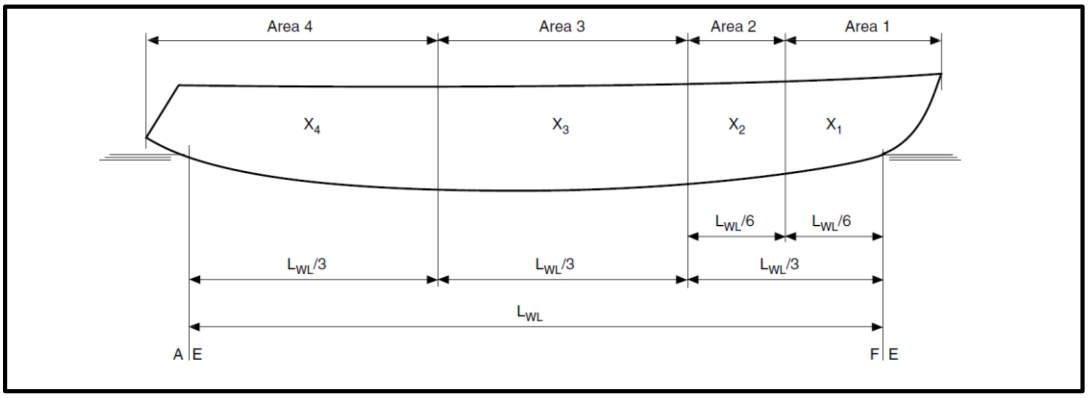


Figure 4.3. 2 Load areas and coefficient Xi for the external side shell and bottom sea pressure (BV)

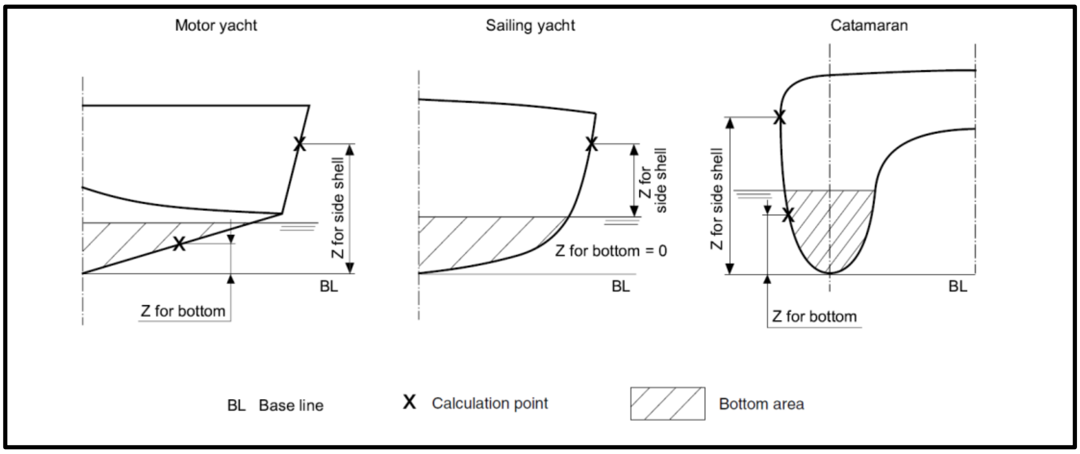


Figure 4.3. 3 Vertical distance z (BV)

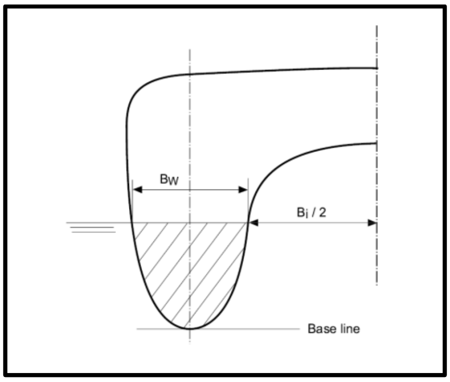


Figure 4.3. 4 Vertical distance z for catamarans (BV)

As per bottom slamming, the pressure acting while craft is in planing or semi-planing mode is not to be less than it is indicated by equation *4.2.28,* given in *4.2.3.3 Bureau Veritas (HSC/PBS)* and refers to high-speed crafts. Technicalities concerning factors K_2 and K_3 occur, hence both of them are rewritten below.

K_2 = factor accounting for impact area, equal to:

$K_2 = 0{,}455 - 0{,}35 \cdot \frac{u^{0{,}75} - 1{,}7}{u^{0{,}75} + 1{,}7}$, with:

For steel and aluminium structure, and for glass sidescuttle:

$K_2 \geq 0{,}50$ for plating and side scuttle

$K_2 \geq 0{,}45$ for ordinary stiffeners

$K_2 \geq 0{,}35$ for primary stiffeners

For composite and plywood structure, and for plastic sidescuttle:

$K_2 \geq 0{,}35$ for plating and sidescuttle, and for ordinary and primary stiffeners

$u = 100 \cdot \frac{s}{S_r}$

where s is the area, in m^2, supported by the element (plating, stiffener, floor or girder). For plating, the supported area is the spacing between the stiffeners multiplied by their span, without taking for the latter more than three times the spacing between the stiffeners

S_r = Reference area, in m^2, equal to $S_r = 0{,}7 \cdot \frac{\Delta}{T}$

For catamaran, Δ in the above formula is to be taken as half the craft displacement

K_3 = factor accounting for shape and deadrise of the hull, equal to:

$K_3 = (70 - a_d)/(70 - a_{dCG})$

where a_{dCG} is the deadrise angle, in degrees, measured at LCG and α_d is the deadrise angle, in degrees, between horizontal line and straight line joining the edges of respective area measured at the longitudinal position of the load point, see *Figure 4.3.5 Deadrise angle (BV)*

values taken for a_d and a_{dCG} are to be the following boundary:

- For sailing yacht: 10° and 30°
- For motor yacht: 10° and 50°

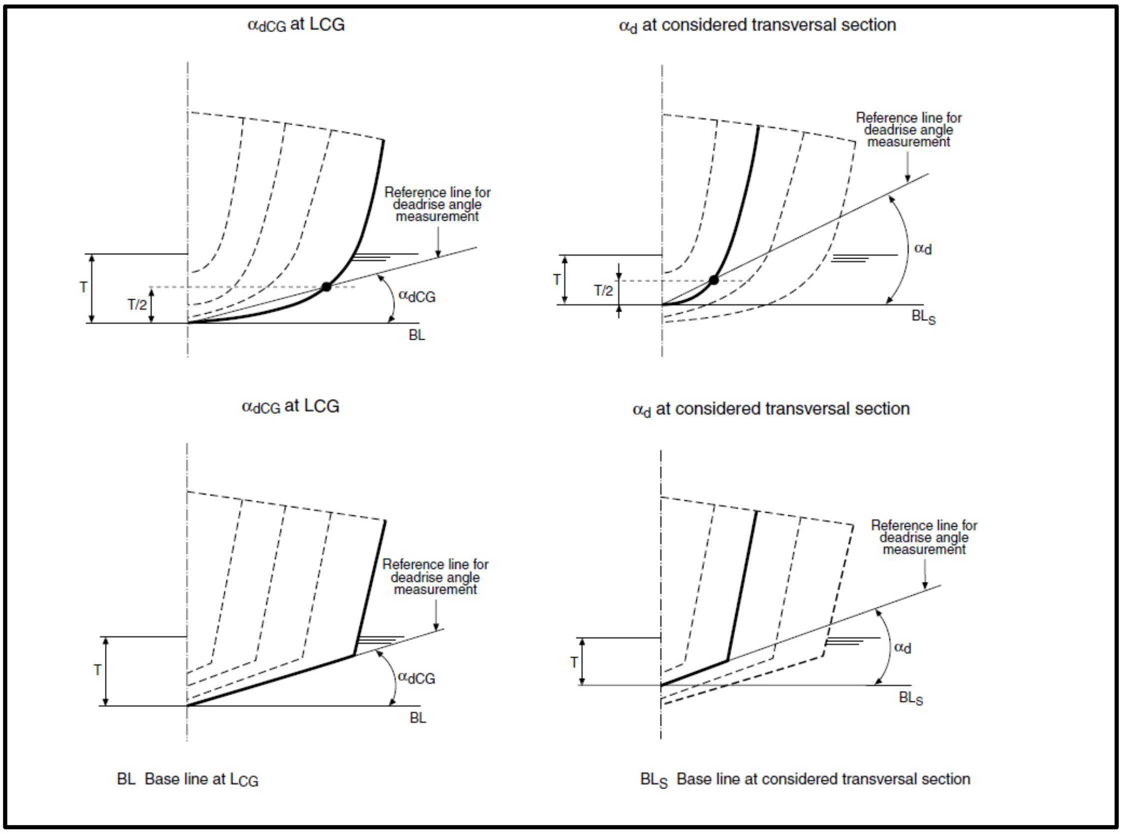


Figure 4.3. 5 Deadrise angle (BV)

Note also that for high speed motor multi-hull yachts, bottom slamming load, which specified by equation *4.2.28*, is to be calculated for each float.

4.3.3.4 Det Norske Veritas – Germanishcer Lloyd (PSPY/PBS)

In respect of *Rules for Classification: Yachts (October 2016),* Pt. 3, Ch. 3, by DNV-GL, crafts' accelerations for dynamic load cases, design operational conditions and design loads shall be regulated as applicable, whether referring to a mono-hull motor or high speed motor or a multi hull motor yacht.

In cases of mono-hull high speed and multi-hull motor yachts design bottom pressures according to *4.2.3.4 Det Norske Veritas - Germanischer Lloyd (HSC/PBS)* is applicable, as it is mentioned in sections 4 and 5 of the referenced chapter.

As regards mono-hull motor yachts that are not high-speed, indications made in *4.4.3.4 Det Norske Veritas - Germanischer Lloyd (DSY/PBS)* are to be applied.

4.3.3.5 Registro Italiano Navale (PSPY/PBS)

RINA's requirements, included in *Rules for Yachts Designed for Commercial Use (January 2019)* Pt. B, Ch. 1, Sec. 5, while take into consideration impact pressure due to bottom slamming, hydrostatic heads and wave load, which mainly determine the scantlings of bottom and sides shell, indicate one equation to express their combined effect.

Specifically, the design pressure for planing and semi-planing yachts is to be assumed equal to the greater of the values given in equation *4.3.3* and *4.3.4* that are given below.

$$p_1 = 0{,}24 \cdot L^{0{,}5} \cdot \left(1 - \frac{h_0}{2 \cdot T}\right) + 10 \cdot (h_0 + a \cdot L)\ \ kN/m^2 \qquad (4.3.3)$$

Where,

T = draught, in m, as defined in *4.1.2.5 Registro Italiano Navale (D)*

L = Scantling length, in m, as defined in *4.1.2.5 Registro Italiano Navale (D)*

h_0 = vertical distance, in m, from the pdr (pdr as defined in *4.1.2.5 Registro Italiano Navale (D)*) to the full load waterline

a = coefficient function of the longitudinal pdr, equal to:

- 0,036 aft of 0,5 L
- 0,04/(C_B - 0,024) in way of $P_{P_{AV}}$(as defined in *4.1.2.5 Registro Italiano Navale (D)*)
- values for intermediate positions obtained by linear interpolation

C_B = Block coefficient as defined in *4.1.2.5 Registro Italiano Navale (D)*

RINA supplements *“The pressure p_1 is, in any case, not to be assumed as < 10 D.”*

$$p_2 = 15 \cdot (1 + a_v) \cdot \frac{\Delta}{L \cdot C_s} \cdot g \cdot F_L \cdot F_1 \cdot F_a\ \ kN/m^2 \qquad (4.3.4)$$

Where,

a_v = maximum design value of vertical acceleration, in g, at the transverse section considered, as defined in *4.3.2.5 Registro Italiano Navale (PSPY/VA)*

Δ = Displacement, in t, as defined in *4.1.2.5 Registro Italiano Navale (D)*

L = Scantling length, in m, as defined in *4.1.2.5 Registro Italiano Navale (D)*

C_s = Support contour of the yacht, in m, defined as the transverse distance, measured along the hull, from the chines to 0,5 L. For twin hull yachts, Cs is twice the distance measured along the single hull.

F_L = coefficient given in *Figure 4.3.6 FL coefficient (RINA)* as a function of the longitudinal position of the pdr (as defined in *4.1.2.5 Registro Italiano Navale (D)*)

F_1 = coefficient function of the shape and inclination of the hull to be taken > 0,4 given by: $\left(F_1 = \frac{50-\beta_X}{50-\beta_{CG}}\right) \geq 0{,}4$

β_x = Deadrise of the transverse section under consideration.
In hulls without a clearly visible deadrise, this is the angle formed by the horizontal axis and the straight line joining keel and chine.

β_{CG} = deadrise angle, in degrees, of the section in way of the LCG

F_a = coefficient equal to:
= $0{,}30 - 0{,}15 \cdot \log(\frac{1{,}43 \cdot A_1 \cdot T}{\Delta})$

A_1 = is the surface, in m^2, of the plating panel considered or the surface of the area supported by the stiffener

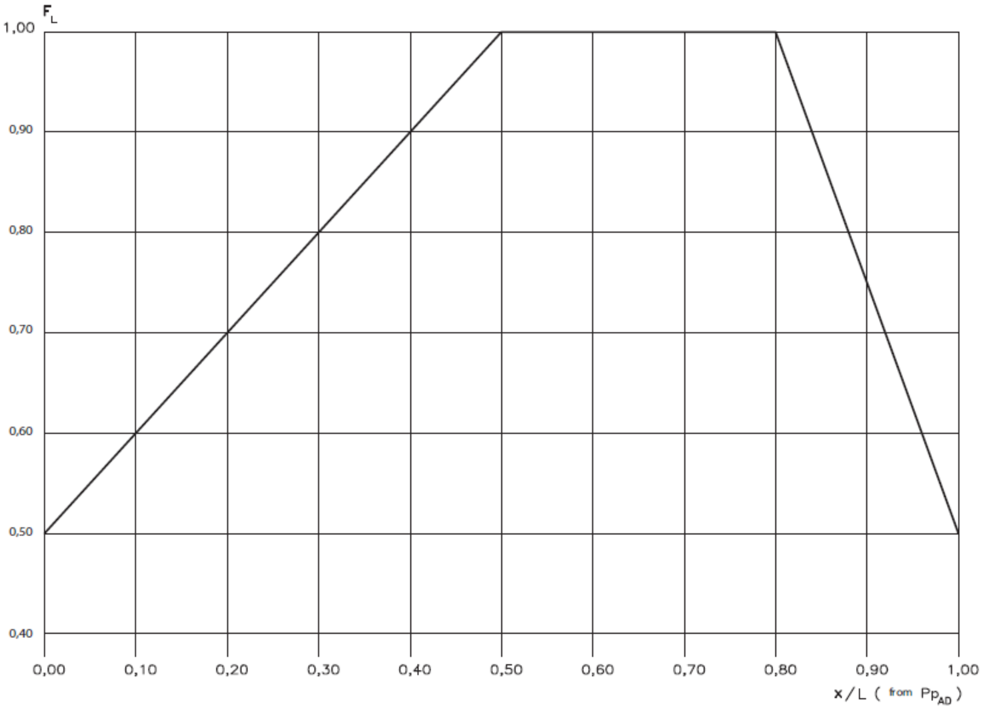


Figure 4.3. 6 F_L coefficient (RINA)

Where,

$P_{P_{AD}}$ = Aft perpendicular as defined in *4.1.2.5 Registro Italiano Navale (D)*

4.3.3.6 Conclusion (PSPY/PBS)

Supplementary to comments made in *4.2.3.6 Conclusion (HSC/PBS)*, which also apply here, it is notable that RINA regulations consider only one pressure acting on the bottom of the craft, which is to be the greater of two, depending on the morphology of the hull and express the sea loads (hydrostatic and wave loads) and another, which depends on vertical acceleration and its equation is similar to DNV-GL and ABS bottom slamming pressure.

Noteworthy is also BV equation on calculating wave loads which not only includes parameters to be modified depending on the load area of the yacht, but can be adjusted for the type of yacht as well.

4.3.4 Pressures on Side Shell (PSPY/PSS: Pressure on Side Shell)

4.3.4.1 Lloyd's Register (PSPY/PSS)

LR and *Rules and Regulations for the Classification of Special Service Craft (July 2018)* finds application in several type of crafts, including yachts. Also, LR does not give distinct equation on pressures on side shell depending on the type of craft, but rather distinguish them per operating mode and number of hulls. Therefore, formulas on calculating design pressures of planing or semi planing yachts shall be obtained from *4.2.4.1 Lloyd's Register (HSC/PSS),* as applicable.

Furthermore, it should be reminded that LR's regulations, referring to non-displacement mode, apply to craft operating in full planing or semi planing modes.

4.3.4.2 American Bureau of Shipping (PSPY/PSS)

Regulations on calculating design hydrostatic and side slamming pressure are included in *Guide for Building and Classing Yachts (October 2018)* Pt. 3, Ch. 2, Sec. 3. The formulas provided are similar to those presented in *4.2.4.2 American Bureau of Shipping (HSC/PSS).*

Specifically, in order to calculate hydrostatic pressure and side slamming pressure equation *4.2.33* and *4.2.34* shall be used respectively.

4.3.4.3 Bureau Veritas (PSPY/PSS)

In *Rules for the Classification and the Certification of Yachts (March 2012)* Pt. B, Ch. 4, Sec. 3, by BV, the rules and regulation on local design loads acted on the side shell are contained.

For platings and secondary stiffeners the loads that are to be taken into account are, according to BV, wave loads and dynamic loads. The wave loads may be taken as described in *4.3.3.3 Bureau Veritas (PSPY/PBS),* since the formula to be used is common for both bottom and side shell.

As per impact loads, BV, in contrast to the fact that for bottom impact pressure provided distinct equations for planing and semi-planing yachts, gives formulas to be considered for all type of yachts. However BV divides yachts, in terms of side shell impact pressure, to mono-hull and catamaran.

The impact pressure that acts on the side shell of mono-hulls is not to be taken less than given by the following:

$$p_{smin} = 80 \cdot n \cdot K_2 \quad kN/m^2$$

- in areas 1 and 2 (as defined in *Figure 4.3.3 Load areas and coefficient Xi for the external side shell and bottom sea pressure (BV)*), between the full load waterline and 1 m above

$$p_{smin} = 50 \cdot n \cdot K_2 \quad kN/m^2 \qquad (4.3.5)$$

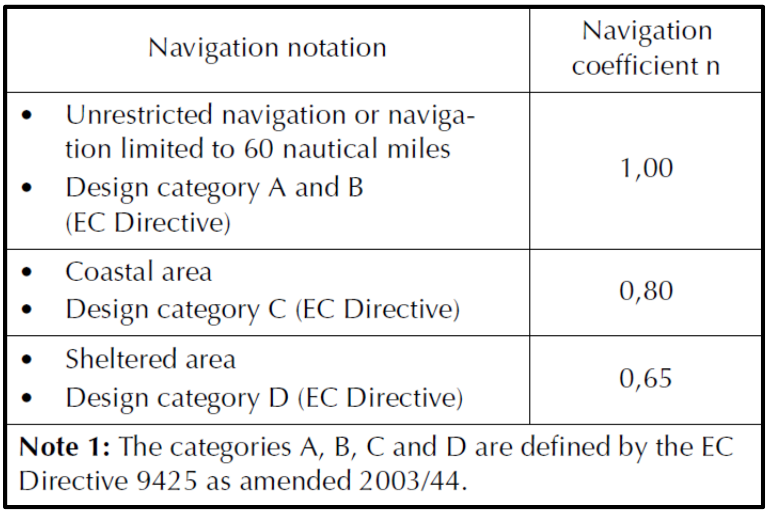
- elsewhere

Where,

K_2 = factor accounting for impact area, as defined in *4.3.3.3 Bureau Veritas (PSPY/PBS)*

n= Navigation coefficient, as defined in *Table 4.3.6 Navigation coefficient (BV)*

Table 4.3. 6 Navigation coefficient (BV)



Navigation notation	Navigation coefficient n
• Unrestricted navigation or navigation limited to 60 nautical miles • Design category A and B (EC Directive)	1,00
• Coastal area • Design category C (EC Directive)	0,80
• Sheltered area • Design category D (EC Directive)	0,65
Note 1: The categories A, B, C and D are defined by the EC Directive 9425 as amended 2003/44.	

Regarding catamarans BV sets different requirement for external and internal side shell. For external side shell equation *4.3.5* is to be used. In the case of internal side shell equation *4.3.6,* which is also applicable for the underside of the cross-deck structure, along with the location areas shown in *Figure 4.3.7 Load areas for the impact pressure on internal side shell on catamaran (BV).*

$$p_{smin} = 80 \cdot n \cdot K_2 \quad kN/m^2$$

- in areas 5

$$p_{smin} = 50 \cdot n \cdot K_2 \quad kN/m^2 \qquad (4.3.6)$$

- in areas 6

$$p_{smin} = 120 \cdot n \cdot K_2 \quad kN/m^2$$

- in area 7

Where,

K_2 = factor accounting for impact area, as defined in *4.3.3 Bureau Veritas (PSPY/PBS)*

n= Navigation coefficient, as defined in *Table 4.3.6 Navigation coefficient (BV)*

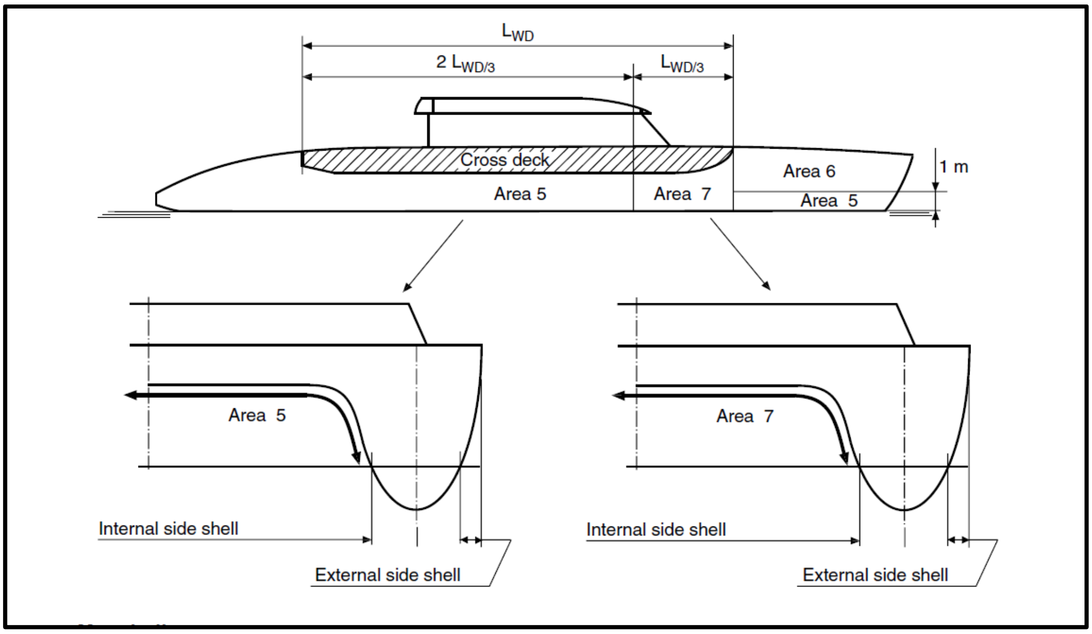


Figure 4.3. 7 Load areas for the impact pressure on internal side shell on catamaran (BV)

4.3.4.4 Det Norske Veritas – Germanischer Lloyd (PSPY/PSS)

In cases of mono-hull high speed and multi-hull motor yachts design side shell pressures according to *4.2.4.4 Det Norske Veritas - Germanischer Lloyd (HSC/PSS)* is applicable, as it is mentioned in sections 4 and 5 of DNV-GL's *Rules for Classification: Yachts (October 2016).*

As regards mono-hull motor yachts that are not high-speed, indications made in *4.4.4.4 Det Norske Veritas - Germanischer Lloyd (DSY/PSS)* are to be applied.

4.3.4.5 Registro Italiano Navale (PSPY/PSS)

Alike pressures on the bottom shell, RINA requirements on side shell pressure reckon in impact pressure due to slamming, hydrostatic heads and wave load into one equation, as referred in *Rules for Yachts Designed for Commercial Use (January 2019).*

Nevertheless pressure on side structure for plating and stiffeners is to be taken as given by equation *4.3.7.*

$$p_1 = 66{,}25 \cdot (a + 0{,}024) \cdot (0{,}15 \cdot L - h_0)\ \ kN/m^2 \tag{4.3.7}$$

Where,

L = Scantling length, in m, as defined in *4.1.2.5 Registro Italiano Navale (D)*

h_0 = vertical distance, in m, from the pdr (pdr as defined in *4.1.2.5 Registro Italiano Navale (D)*) to the full load waterline

a = coefficient function of the longitudinal pdr, equal to:

- 0,036 aft of 0,5 L
- 0,04/(C_B - 0,024) in way of $P_{P_{AV}}$(as defined in *4.1.2.5 Registro Italiano Navale (D)*)
- values for intermediate positions obtained by linear interpolation

C_B = Block coefficient as defined in *4.1.2.5 Registro Italiano Navale (D)*

RINA supplements: *"The pressure p_1 in any case, not to be assumed as < 10 h1"*

Where,

h_1 = Distance, in m, from the pdr to the straight line of the beam of the highest continuous deck.

Especially for the zones located forward of 0,3 from $P_{P_{AV}}$ (forward perpendicular as defined in *4.1.2.5 Registro Italiano Navale (D)*), RINA suggest that is side pressure is not to be taken less than the following equation.

$$p_2 = C_1\{k_V[0{,}6 + sen\gamma \cdot \cos(90-\alpha)] + C_2 \cdot L^{0,5} sen(90-a)\}^2 \;\; kN/m^2 \qquad (4.3.8)$$

Where,

L = Scantling length, in m, as defined in *4.1.2.5 Registro Italiano Navale (D)*
C_1 = coefficient given by *Figure 4.3.8 Coefficient C1 (RINA)* as a function of the load surface A, in m^2, bearing on the element considered; for plating, A = 2,5s is to be taken
s = stiffener spacing, in m
C_2 = coefficient given by *Figure 4.3.9 Coefficient C2 (RINA)* as a function of C_B and the longitudinal position of the element considered
k_V = 0,625 · $L^{0,5}$ + 0,25 V
V = Maximum speed, in knots
a = angle formed at the point considered by the side and the horizontal axis, see *Figure 4.3.10 Angle α (RINA)*
C_B = Block coefficient as defined in *4.1.2.5 Registro Italiano Navale (D)*
γ = angle formed by the tangent at the waterline, corresponding to the draught T, taken at the point of intersection of the transverse section of the element considered, with the above waterline and the longitudinal straight line crossing the above intersection, see *Figure 4.3.11 Angle γ (RINA)*

In any case p_2 should not be greater that the half of the bottom design pressure, as defined in *4.3.3.5 Registro Italiano Navale (PSPY/PBS).*

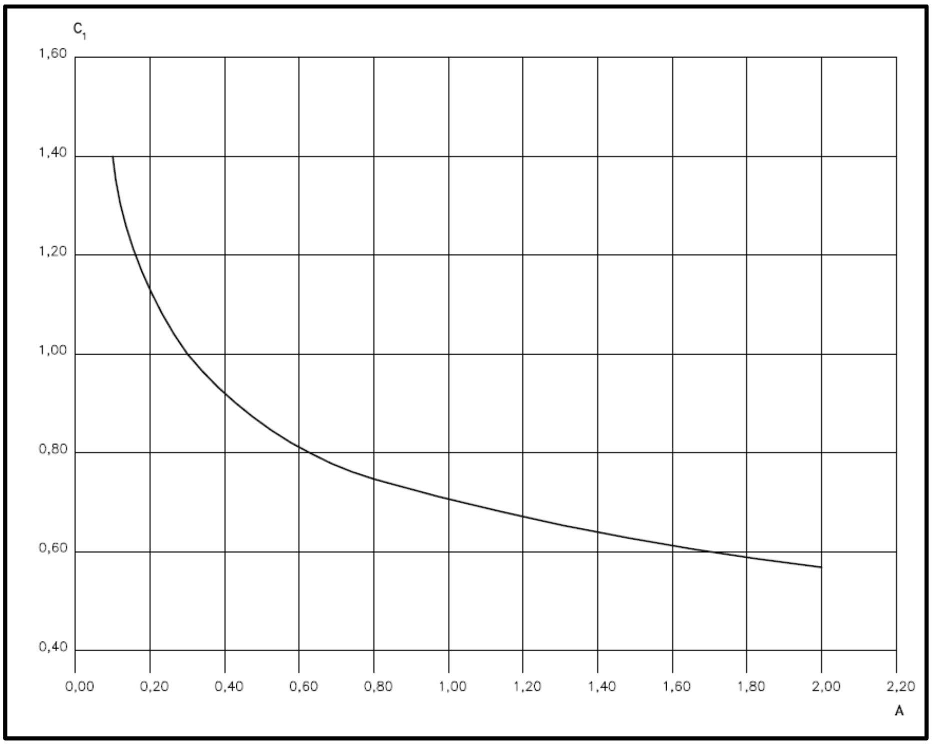


Figure 4.3. 8 Coefficient C1 (RINA)

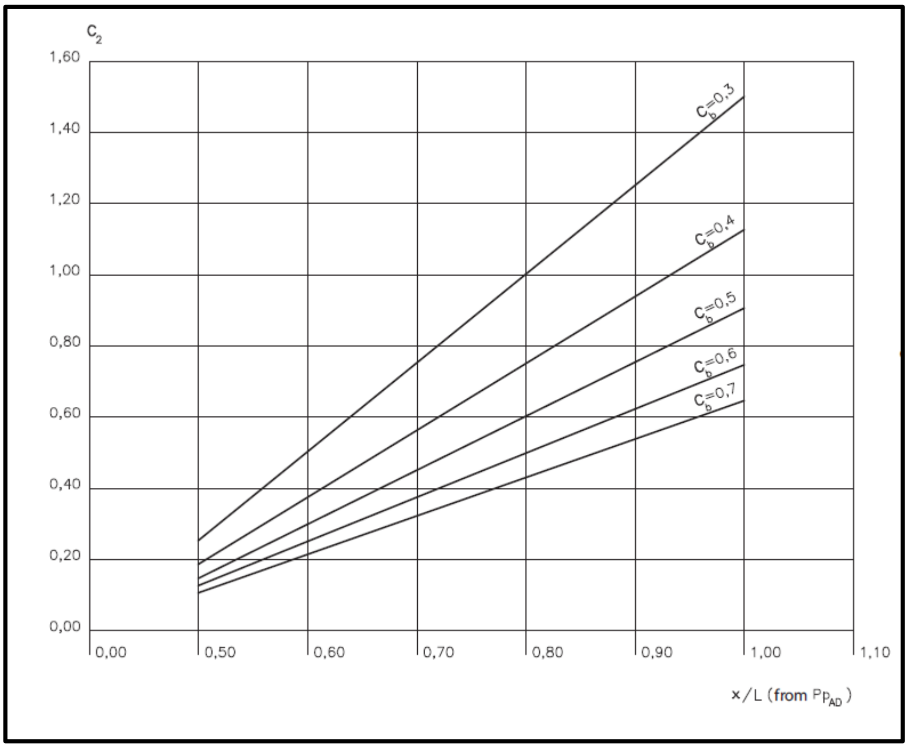


Figure 4.3. 9 Coefficient C2 (RINA)

Where,

$P_{P_{AD}}$ = aft perpendicular as defined in *4.1.2.5 Registro Italiano Navale (D)*

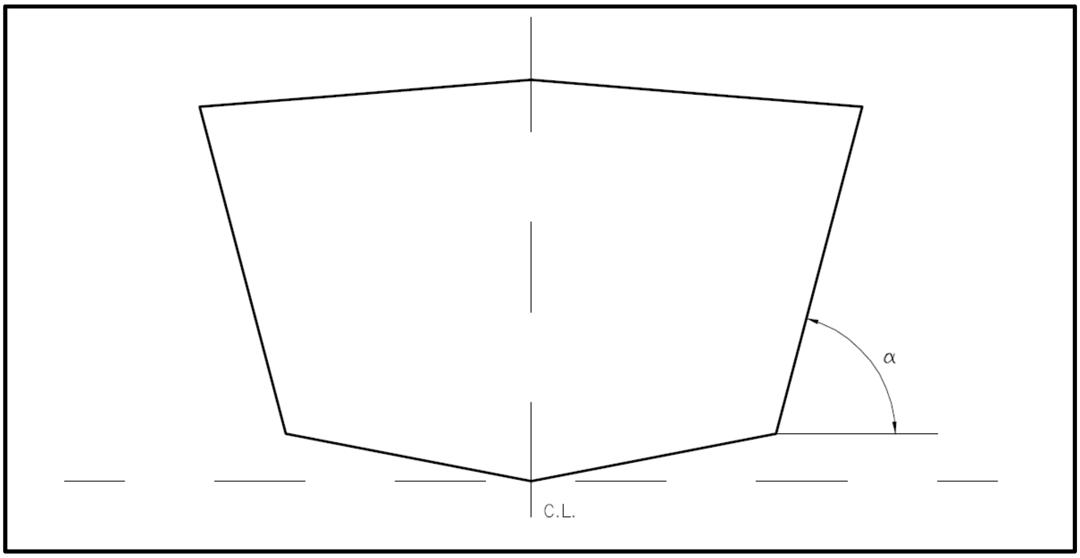


Figure 4.3. 10 Angle α (RINA)

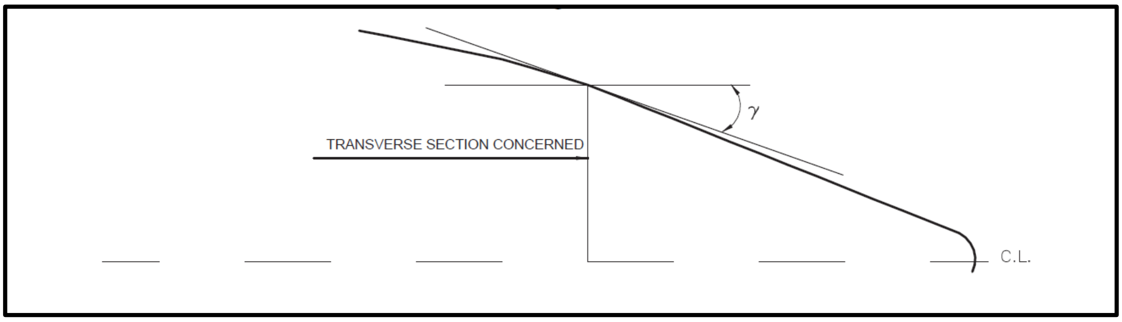


Figure 4.3. 11 Angle γ (RINA)

4.3.4.6 Conclusion (PSPY/PSS)

On the discrepancies given in *4.2.4.6 Conclusion (HSC/PSS)*, BV impact pressure on side shell come to be added, since it does not present similarities with any else classification societies' corresponding calculation. BV requirements set a minimum value of pressure to be calculated at a load point, without proposing any further calculations.

However neither RINA requirements reminiscent of anyone else's regulations, as, alike in the case of bottom pressure, a general equation for the side shell is suggested, not separate calculations for sea and impact pressures. Nevertheless RINA equation, *4.3.8,* has resemblance to DNV-GL impact pressure given in *4.2.4.4 Det Norske Veritas – Germanischer Lloyd (HSC/PSS),* as the both strongly depend on craft's speed, length and angle between the waterline and a longitudinal line measured at the point considered.

4.3.5 Pressures on Weather/Interior/Wet Decks (PSPY/PD: Pressure on Decks)

4.3.5.1 Lloyd’s Register (PSPY/PD)

LR and *Rules and Regulations for the Classification of Special Service Craft (July 2018)* find application in several type of crafts, including yachts. Also, LR does not give distinct equation on pressures decks depending on the type of craft, but rather distinguish them per operating mode and number of hulls. Therefore, formulas on calculating design pressures of planing or semi planing yachts shall be obtained from *4.2.4.1 Lloyd’s Register (HSC/PD),* as applicable. Pressure on wet deck structure of multi hull are also included, while pressures on cargo deck are not applicable to yachts crafts.

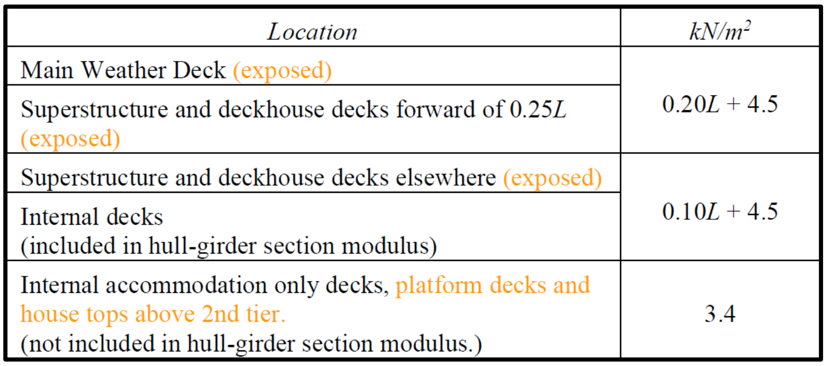
Furthermore, it should be reminded that LR’s regulations, referring to non-displacement mode, apply to craft operating in full planing or semi planing modes.

4.3.5.2 American Bureau of Shipping (PSPY/PD)

Alike the rules that concern HSCs, ABS deck pressure requirements are characterized by its compactness, as they are submitted, in *Rules for Building and Classing Yachts (October 2018)* Pt. 3,Ch. 2, Sec. 2, placed on a table, which includes several regions of the craft.

The data of this table, referring to design deck pressures are given in *Table 4.3.7 Deck Design Pressure, Pd (ABS),* while the locations included in it are described by *Figure 4.3.12 Deck, Superstructure and Deckhouse Pressures I (ABS)* and *Figure 4.3.13 Deck, Superstructure and Deckhouse Pressures II (ABS).*

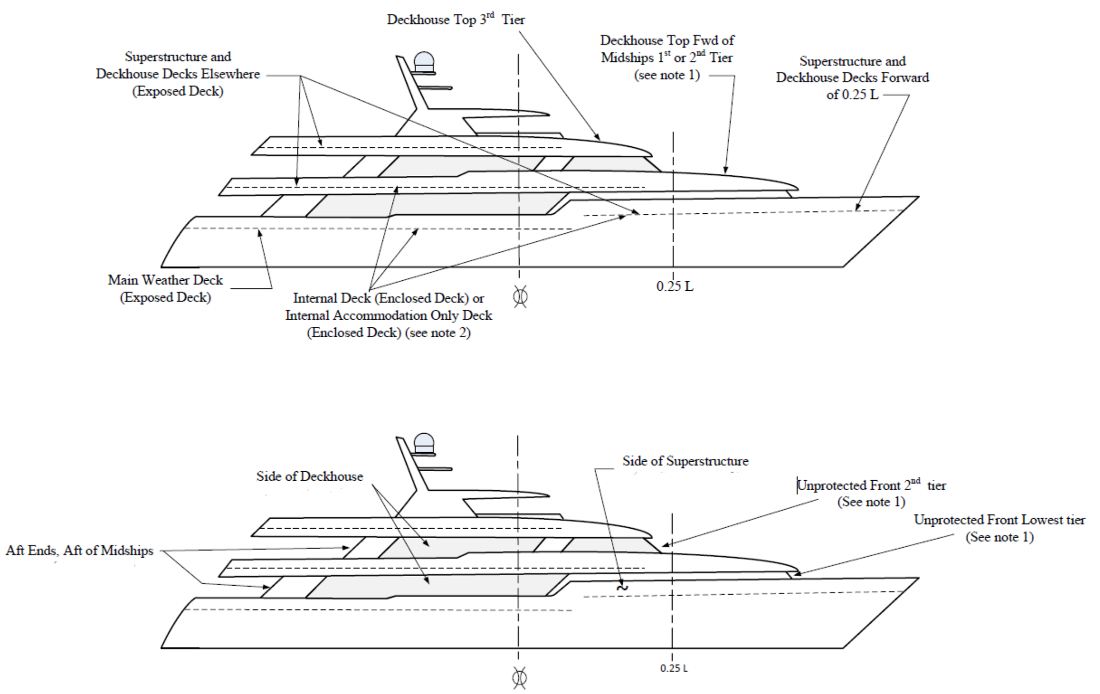
Table 4.3. 7 Deck Design Pressure, Pd (ABS)



Location	*kN/m²*
Main Weather Deck (exposed)	$0.20L + 4.5$
Superstructure and deckhouse decks forward of $0.25L$ (exposed)	
Superstructure and deckhouse decks elsewhere (exposed)	$0.10L + 4.5$
Internal decks (included in hull-girder section modulus)	
Internal accommodation only decks, platform decks and house tops above 2nd tier. (not included in hull-girder section modulus.)	3.4

Where,

L_{WL} = craft length as defined in



NOTES: 1. Where the deck, deckhouse top or bulkhead is located greater than, or equal to, 1 standard superstructure height above the weather deck, in accordance with the International Convention on Load Lines, the deck, deckhouse top or bulkhead can be considered 2nd Tier. Where it is located 2 standard superstructure heights above the weather deck it can be considered 3rd tier.

2. Where an accommodation deck is needed in the calculation of the hull girder section modulus it is to be considered an internal deck

Figure 4.3. 12 Deck, Superstructure and Deckhouse Pressures I (ABS)

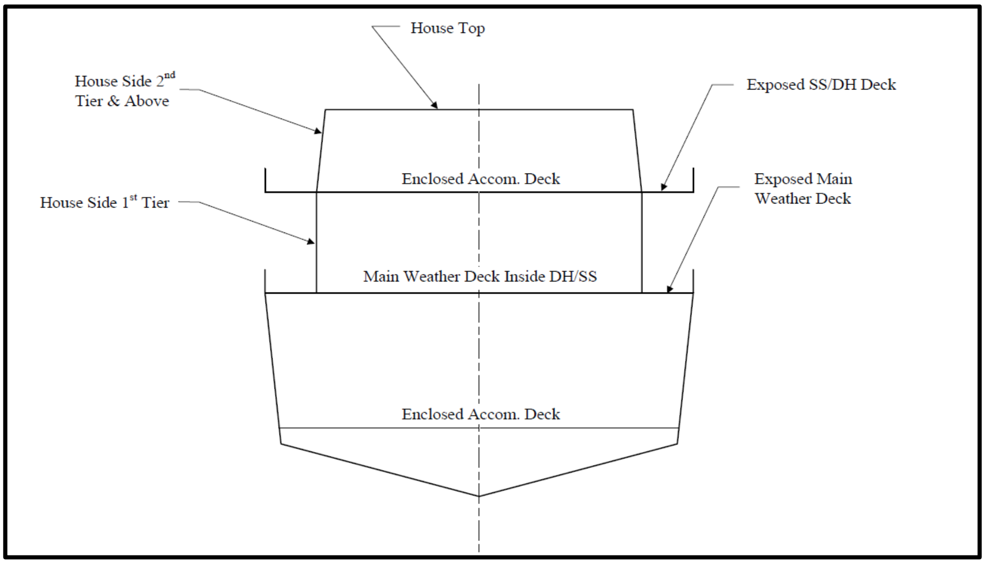


Figure 4.3. 13 Deck, Superstructure and Deckhouse Pressures II (ABS)

In similar manner to LR, ABS include regulation on pressure acting on wet deck structure which is to be taken as indicated by equation *4.2.40,* see *4.2.5.2 American Bureau of Shipping (HSC/PD).*

4.3.5.3 Bureau Veritas (PSPY/PD)

Rules for Yachts (March 2012), by BV, contains requirements on deck location, which are related to the ones that ABS indicates, in Pt. B, Ch. 4, Sec. 4. Such locations are exposed decks, accommodation and superstructure decks, regulated by following equation *4.3.9, 4.3.10* and *4.3.11, not* correspondingly.

Concerning exposed decks, equation *4.3.9* is to be used in order to determine the sea pressure acting at any load point on them. Supplementary, the sea pressure is not to be taken greater than P_{dmin} as defined by equation *4.3.10,* in which the areas referred are depicted by *Figure 4.3.2 Load areas and coefficient Xi for the external side shell and bottom sea pressure (BV).*

$$P_s = (p_0 - z_D \cdot 9.807) \cdot \varphi_1 \cdot \varphi_3 \; kN/m^2 \geq P_{dmin} \qquad (4.3.9)$$

Where,

p_0 = Taken equal to the sea bottom pressure P_s in the considered area, in kN/m^2, calculated according to *4.3.3.3 Bureau Veritas (PSPY/PBS)* with: z = 0

P_{dmin} = Minimum sea pressure on deck as defined in equation *4.3.10,* which is given below

φ_1 = Reduction coefficient depending of the location of the considered deck with respect to the full load waterline:

- for freeboard deck**(m)** as defined in *4.1.2.3 Bureau Veritas (D)*: $\varphi_1 = 1{,}00$
- for the first deck just above the freeboard deck(m), : $\varphi_1 = 0{,}75$
- for the decks above: : $\varphi_1 = 0{,}50$

φ_3 = Reduction coefficient, to be taken equal to 0,7, when the exposed deck is partially protected and not directly exposed to green sea effect

z_D = Vertical distance, in m, between the deck at side at the considered transverse section and:

- the full load waterline for sailing yacht monohull
- the baseline for other type of yacht

Especially for sea pressure of primary deck structures BV suggests that is to be determined also by equation *4.3.9,* but reduced by factor $(1 - 0{,}05 \cdot l) > 0{,}8$, where l is the length of the stiffener. Minimum values of deck pressure and specification on primary deck structure are two features that neither LR nor ABS include.

$$P_{dmin} = 19{,}6 \cdot n \cdot \varphi_1 \cdot \varphi_2 \cdot \varphi_3 \; \geq 7 \; kN/m^2$$

- in areas 1 and 2

$$P_{dmin} = 17{,}6 \cdot n \cdot \varphi_1 \cdot \varphi_2 \cdot \varphi_3 \; \geq 5 \; kN/m^2 \qquad (4.3.10)$$

- in areas 3 and 4

$$P_{dmin} = 3 \; kN/m^2$$

- for exposed decks not accessible to passengers or crew members

Where,

φ_1 = As defined, previously, in equation *4.3.9*

φ_3 = As defined, previously, in equation *4.3.9*

φ_2 = Coefficient taken equal to:

- 0,42 if $L_{WL} < 50\,m$
- $L_{WL}/120$ if $L_{WL} \geq 50\,m$

n = Navigation coefficient as defined in *4.1.2.3 Bureau Veritas (D)*

According to BV, requirements, described by the previous two paragraphs, apply also to superstructure decks.

In respect of accommodation decks, the pressure is not to be taken less than given in equation *4.3.11*. BV's indication are similar to ABS's, as they both provide constant values of pressure on accommodation decks. However, BV value varies depending to a specified area of accommodation and it is stated that it is a minimum value.

$$p_s = 5 \ kN/m^2$$

- in large spaces (lounges, cinema, restaurant, kitchens, etc.)

$$p_s = 3 \ kN/m^2 \qquad (4.3.11)$$

- in cabins

$$p_s = 10 \ kN/m^2$$

- in technical spaces and machinery space

As mentioned in relevant segment, the pressure acting on the underside of 'wet' deck structure is be taken as applicable by equation *4.3.6* and *Figure 4.3.6 Load areas for the impact pressure on internal side shell on catamaran (BV),* given in *4.3.4.3 Bureau Veritas (PSPY/PSS)*

4.3.5.4 Det Norske Veritas – Germanischer Lloyd (PSPY/PD)

In cases of mono-hull high speed and multi-hull motor yachts design deck loads according to *4.2.5.4 Det Norske Veritas - Germanischer Lloyd (HSC/PD)* is applicable, as it is mentioned in sections 4 and 5 of DNV-GL's *Rules for Classification: Yachts (October 2016).*

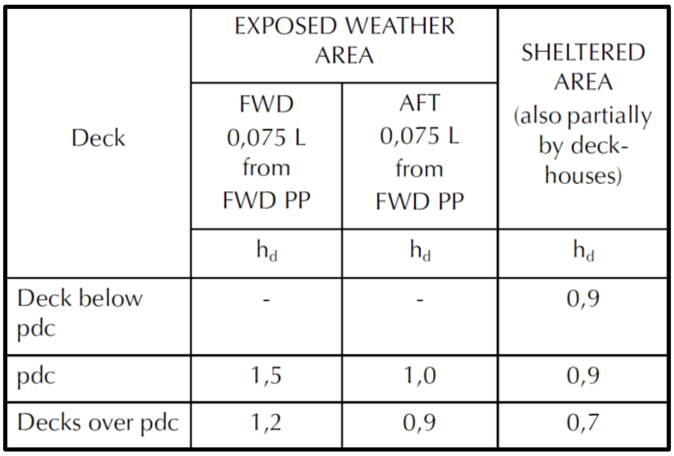
As regards mono-hull motor yachts that are not high-speed, indications made in *4.4.5.4 Det Norske Veritas - Germanischer Lloyd (DSY/PD)* are to be applied.

4.3.5.5 Registro Italiano Navale (PSPY/PD)

In contrast to the other classification societies, RINA recommends common design deck pressure for planing, semi-planing, displacement and sailing yacht, as not differentiations are directed for any type of craft in *Rules for Yachts Designed for Commercial Use (January 2019)*, Pt B, Ch 1, Sec 5.

Design heads are given by RINA for various decks, as shown in *Table 4.3.8 Design heads for decks (RINA)*, which are to be used along with the hydrostatic pressure of a liquid, $\rho \cdot g \cdot h$, where ρ is the density of the water, g the gravity acceleration and h as h_d. Sheltered areas are intended to mean decks intended for accommodation.

Table 4.3. 8 Design heads for decks (RINA)



Deck	EXPOSED WEATHER AREA		SHELTERED AREA (also partially by deck-houses)
	FWD 0,075 L from FWD PP	AFT 0,075 L from FWD PP	
	h_d	h_d	h_d
Deck below pdc	-	-	0,9
pdc	1,5	1,0	0,9
Decks over pdc	1,2	0,9	0,7

Where,

pdc = Design deck, intended as the first deck above the full load waterline, extending for at least 0,6 L and constituting an effective support for side structures.

4.3.5.6 Conclusion (PSPY/PD)

In terms of components included, there are no differentiations among the societies as everyone include weather, interior and superstructure decks, except the fact that DNV-GL misses to refer specifically to interior (enclosed) decks.

Furthermore there are no notable similarities among the requirements presented, as each classification society gives distinct method of calculating deck design pressures. Only LR equation is depended on vertical acceleration, ABS calculations rely only to the length of the craft, BV is affected by sea pressures acting on the bottom, DNV-GL is using its general sea pressure formula and RINA gives certain design load heads.

4.3.6 Pressures on Forebody (PSPY/PF: Pressure on Forebody)

4.3.6.1 Lloyd’s Register (PSPY/PF)

LR and *Rules and Regulations for the Classification of Special Service Craft (July 2018)* find application in several type of crafts, including yachts. Also, LR does not give distinct equation on design pressures acting to the forebody of the craft depending on the type of craft, but rather distinguish them per operating mode and number of hulls. Therefore, formulas on calculating design pressures of planing or semi planing yachts shall be obtained from *4.2.6.1 Lloyd’s Register (HSC/PF),* as applicable.

Furthermore, it should be reminded that LR regulations, referring to non-displacement mode, apply to craft operating in full planing or semi planing mode.

4.3.6.2 American Bureau of Shipping (PSPY/PF)

Regulations on calculating design hydrostatic and bottom slamming pressure are included in *Guide for Building and Classing Yachts (October 2018)* Pt. 3, Ch. 2, Sec. 2. The formulas provided are similar to those presented in *4.2.6.2 American Bureau of Shipping (HSC/PF).*

Specifically, in order to calculate side design pressure that acts at the fore end of the craft, for forward of 0,125L from the stem, equation *4.2.46* shall be used appropriately.

4.3.6.3 Bureau Veritas (PSPY/PF)

While BV does not set particular requirements on pressure acting at the fore end of the ship, in *Rules for Yachts (March 2012)*, instruction given in *4.3.3.3 Bureau Veritas (PSPY/PBS)* and *4.3.4.3 Bureau Veritas (PSPY/PSS)* may be used appropriately. As in equations contained in to those two segments there are factors directing the calculation to fore region of the craft.

4.3.6.4 Det Norske Veritas – Germanischer Lloyd (PSPY/PF)

In cases of mono-hull high speed and multi-hull motor yachts design forebody pressures according to *4.2.6.4 Det Norske Veritas - Germanischer Lloyd (HSC/PF)* is applicable, as it is mentioned in sections 4 and 5 of DNV-GL's *Rules for Classification: Yachts (October 2016).*

4.3.6.5 Registro Italiano Navale (PSPY/PF)

Alike DNV-GL, RINA does not give specifications about the region of the fore end of the yachts. Correspondingly, it may be assumed the methodology that refers to bottom pressures, given *4.3.2.5 Registro Italiano Navale (PSPY/PBS)*, should be used appropriately.

4.3.6.6 Conclusion (PSPY/PF)

Since the forebody of the craft is not considered by all classification societies as region to be treated specially no conclusions can be drawn.

As per LR's and ABS' requirements indication of *4.2.6.6 Conclusion (HSC/PF)* apply as well.

4.3.7 Pressures on Other Components (PSPY/POC: Pressure on Other Components)

4.3.7.1 Lloyd's Register (PSPY/POC)

LR and *Rules and Regulations for the Classification of Special Service Craft (July 2018)* find application in several type of crafts, including yachts. Therefore, formulas on calculating design pressures of planing or semi planing yachts shall be obtained from *4.2.7.1 Lloyd's Register (HSC/POC),* as applicable. Design load of deckhouses, superstructures, watertight and deep tank bulkheads, pillars and bulwarks are part of the referenced segment.

4.3.7.2 American Bureau of Shipping (PSPY/POC)

In ABS regulations, are contained almost all of the components that LR includes, except the fact that ABS does not set special requirements on pillars and bulwarks. The rest of the regions are included in *Guide for Building and Classing Yachts (October 2018),* Pt. 3, Ch. 2, Sec.2, as presented in the following paragraphs.

The superstructure and deckhouse design pressure shall be taken as indicated by equation *4.3.12,* in conjunction with following *4.3.13.* Additionally, for location descriptions, *Figure 4.3.12 Deck, Superstructure and Deckhouse Pressures I (ABS)* and *Figure 4.3.13 Deck, Superstructure and Deckhouse Pressures II (ABS)* are to be taken into consideration.

$$P_d = N_3 \cdot h \ \ kN/m^2 \qquad (4.3.12)$$

Where,

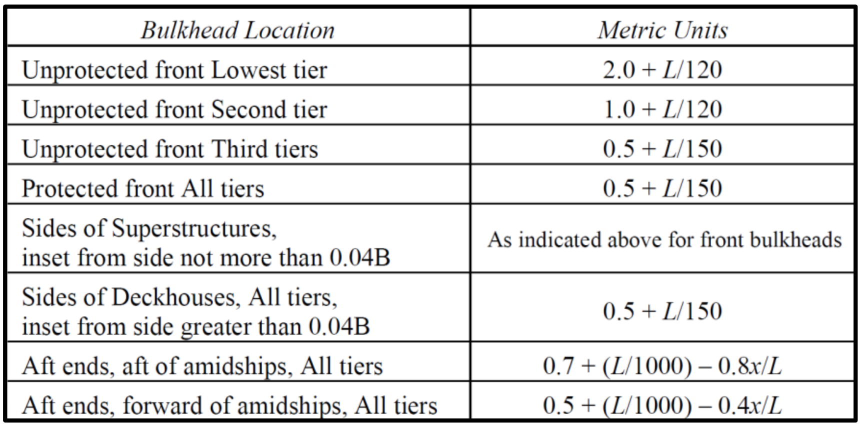
h = Design head in m, given in equation *4.3.13,* bellow
N_3 = 9,8

$$h = a \cdot k \cdot [(b \cdot f) - y] \cdot c \qquad m \qquad (4.3.13)$$

Where,

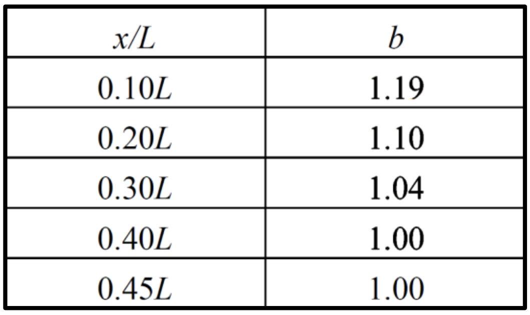
a = factor relating to bulkhead location and yacht length, given in *Table 4.3.9 Values of a (ABS)*
k = service factor
= 1,0 for Yachting Service, Commercial Yachting Service
= 0.85 for restricted yachting service notation R, which in according to ABS will be assigned to vessels designed for restricted pleasure yachting service and built to the applicable requirements
b = factor based on longitudinal location, given in *Table 4.3.10 Values of b (ABS)*
f = factor based on yacht length, given in *Table 4.3.11 Values of f (ABS)*
y = vertical distance, in m, from the design waterline or load waterline, to the midpoint of the stiffener or panel
c = 1,0 for superstructures
= 0,85 for deckhouses
x = distance, in m, between the after perpendicular and the bulkhead being considered. Deckhouse side bulkheads are to be divided into equal parts not exceeding 0.10L in length, and x is to be measured from the after perpendicular to the center of each part considered

Table 4.3. 9 Values of a (ABS)



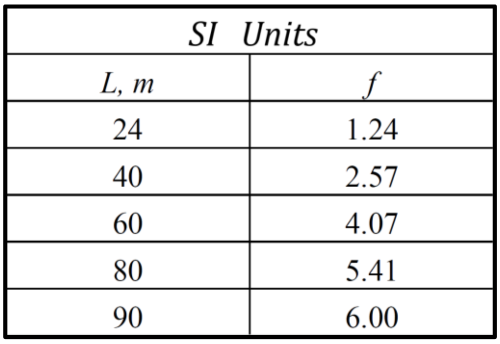
Bulkhead Location	*Metric Units*
Unprotected front Lowest tier	$2.0 + L/120$
Unprotected front Second tier	$1.0 + L/120$
Unprotected front Third tiers	$0.5 + L/150$
Protected front All tiers	$0.5 + L/150$
Sides of Superstructures, inset from side not more than 0.04B	As indicated above for front bulkheads
Sides of Deckhouses, All tiers, inset from side greater than 0.04B	$0.5 + L/150$
Aft ends, aft of amidships, All tiers	$0.7 + (L/1000) - 0.8x/L$
Aft ends, forward of amidships, All tiers	$0.5 + (L/1000) - 0.4x/L$

Table 4.3. 10 Values of b (ABS)



x/L	b
$0.10L$	1.19
$0.20L$	1.10
$0.30L$	1.04
$0.40L$	1.00
$0.45L$	1.00

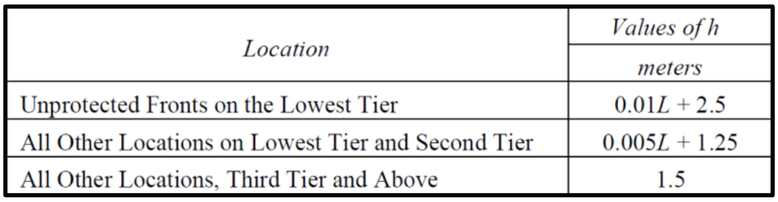
Table 4.3. 11 Values of f (ABS)



SI Units	
L, m	f
24	1.24
40	2.57
60	4.07
80	5.41
90	6.00

In addition to the above, h at the locations shown below is not to be less than 1,5 m or as indicated in the *Table 4.3.12 Maximum Values of h (ABS).*

Table 4.3. 12 Maximum Values of h (ABS)



Location	*Values of h*
	meters
Unprotected Fronts on the Lowest Tier	$0.01L + 2.5$
All Other Locations on Lowest Tier and Second Tier	$0.005L + 1.25$
All Other Locations, Third Tier and Above	1.5

Concerning bulkhead design pressures, ABS proposes calculations to be made on the design pressures of tank and watertight boundaries. For tank boundaries, either equation *4.3.12* is to be used, where h is as defined below, or equation *4.3.14,* whichever is greater.

Design head for tank boundaries:

h = greatest of the following distances, in m, from lower edge of plate panel or center of area supported by stiffener, to:

i) 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.

ii) A point located at two-thirds of the distance to the main weather deck.

iii) A point located above the top of the tank, not less than the greater of the following:
0.01L + 0.15 m
0.46 m

L = where L is the yacht length as defined in *4.1.2.2 American Bureau of Shipping (D)*

$$P_t = \rho \cdot g \cdot (1 + 0{,}5 \cdot n_{xx})/h_2 \quad kN/m^2 \geq P_{smin} \tag{4.3.14}$$

Where,

$\rho \cdot g$ = specific weight of the liquid, not to be taken less than 10.05 kN/m^3

n_{xx} = Vertical acceleration, in g's, at the center of the tank, as defined in *4.2.2 American Bureau of Shipping (PSPY/VA)*

h_2 = distance from lower edge of plate panel or center of area supported by stiffener to the top of the tank, in m

As per watertight boundaries design pressure, equation *4.3.12* also applies. Where h is redefined below.

Design head for watertight boundaries:

h = distance, in m, from the lower edge of plate panel or the center of area supported by the stiffener to the bulkhead deck at centerline

4.3.7.3 Bureau Veritas (PSPY/POC)

BV requirements on the subject refer to the same craft locations as ABS. As *Rules for Yachts (March 2012),* Pt. B, Ch. 4, Sec. 4 points out, BV includes regulations on load on superstructure, watertight bulkhead and tanks.

On this subject, as you may notice in the following paragraphs, BV requirements refer to all types of yachts crafts, planing, sailing yachts etc.

Starting with superstructures, the sea pressure acting on its walls shall be taken according to equation *4.3.15,* along with *Table 4.3.13 Coefficient a (BV)* and *Table 4.3.14 Minimum pressures P_{smin} (BV).*

$$p_s = 7 \cdot a \cdot c \cdot n \cdot (b \cdot f - z_s) \ kN/m^2 \geq P_{smin} \tag{4.3.15}$$

Where:

a = Coefficient given in *Table 4.3.13* Coefficient a *(BV)*

c = Coefficient equal to:

- for mono-hull motor yacht: $c = 0{,}3 + 0{,}7 \cdot b_i/B_i$
- for mono-hull sailing yachts: $c = 1{,}0$
- for catamarans (sailing motor): : $c = 5{,}0$

c = Coefficient equal to:

$f = \frac{-2 \cdot L_w{}^2}{8000} + 0{,}1 \cdot L_w - 1$

b_i = Breadth of hull, in m, at the considered longitudinal section

B_i = Breadth of superstructure or deckhouse, in m, at the considered longitudinal section.

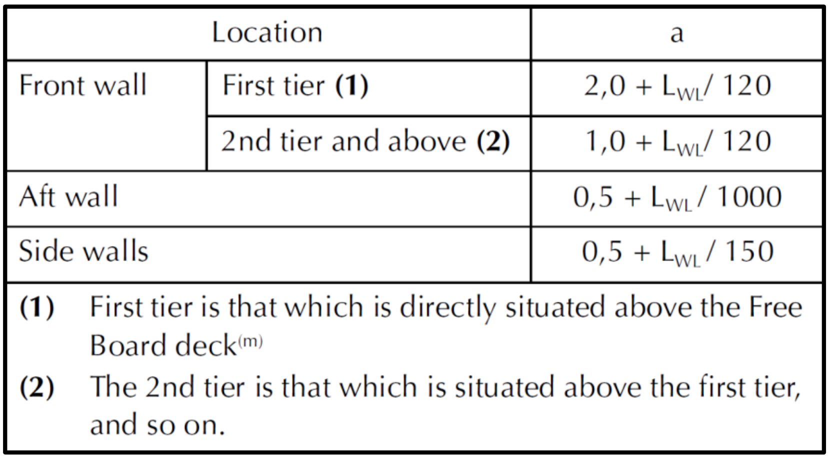
L_w = Wave length, in m, as defined

z_s = vertical distance, in m, between the full load waterline and calculation point, located as follows:

- for plating: mid-height of the elementary plate panel
- for stiffeners: mid-span

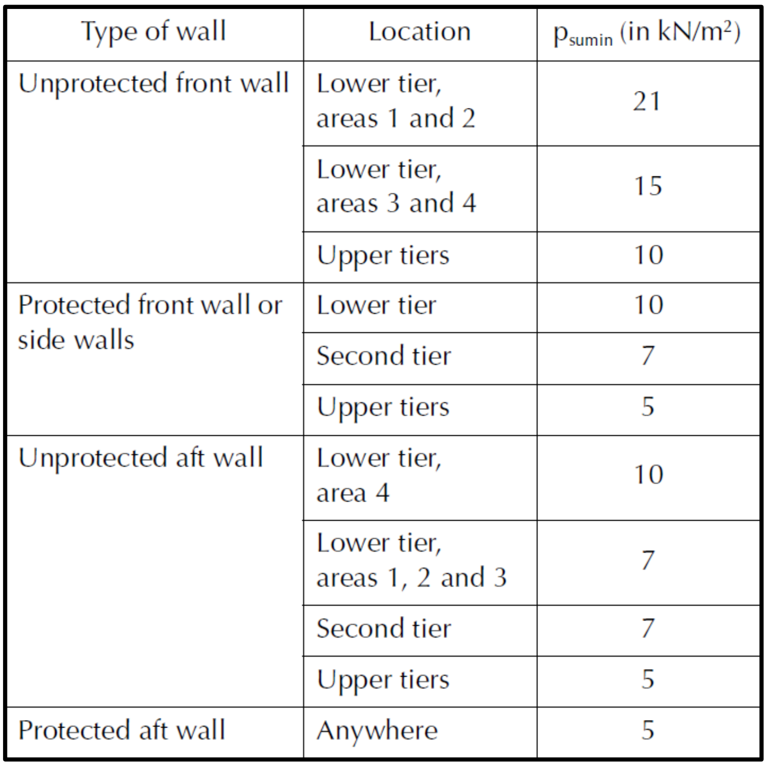
P_{smin} = Minimum sea pressure, in kN/m^2, as defined in *Table 4.3.14 Minimum pressures* P_{smin} *(BV)*

Table 4.3. 13 Coefficient a (BV)



Location		a
Front wall	First tier **(1)**	$2{,}0 + L_{WL}/120$
	2nd tier and above **(2)**	$1{,}0 + L_{WL}/120$
Aft wall		$0{,}5 + L_{WL}/1000$
Side walls		$0{,}5 + L_{WL}/150$
(1) First tier is that which is directly situated above the Free Board deck$^{(m)}$ **(2)** The 2nd tier is that which is situated above the first tier, and so on.		

Table 4.3. 14 Minimum pressures P_{smin} (BV)



Type of wall	Location	p_{sumin} (in kN/m^2)
Unprotected front wall	Lower tier, areas 1 and 2	21
	Lower tier, areas 3 and 4	15
	Upper tiers	10
Protected front wall or side walls	Lower tier	10
	Second tier	7
	Upper tiers	5
Unprotected aft wall	Lower tier, area 4	10
	Lower tier, areas 1, 2 and 3	7
	Second tier	7
	Upper tiers	5
Protected aft wall	Anywhere	5

An interesting addition by BV, is that in the table that is suggested for determining pressure in tanks, it corresponds the design pressure to a testing pressure calculation, as given in *Table 4.3.15 Tank design and testing pressures (BV).* A useful insertion especially during the preliminary design study phase.

Table 4.3. 15 Tank design and testing pressures (BV)

Type of tanks	Design pressure, in kN/m^2	Testing pressure, in kN/m^2
Water ballast or fresh water tank	$p_S = 10\,(z_1+0,5d_{AP})$ or $p_S = 10\,a_z\,z_1$	$p_T = 10\,(d_{AP} + z_1)$ $> 100\,p_{pv}$
Fuel-oil tank	$p_S = 10\,(z_1+0,5d_{AP})\,\rho$ or $p_S = 10\,a_z\,z_1\,\rho$	$p_T = 10\,(d_{AP} + z_1)\,\rho$ or $p = 10\,(2,4 + z_1)\,\rho > p_{pV}$

Where,

d_{AP} = Vertical distance, in m, between the top of the tank and the top of the air pipe
z_1 = Vertical distance, in m, between the calculation point and the top of the tank
p_{pV} = Safety pressure of valves, if applicable, in bar
a_z = vertical acceleration measured at the tank center of gravity, to be taken equal to:

- For high speed motor yacht:
  $a_z = a_{cg} > 1,3$
  Where a_{cg} vertical acceleration as defined in, *4.3.2.3 Bureau Veritas (PSPY/VA)*
- For mono-hull sailing yacht:
  $a_z = a_v + a_h > 1,3$
  Where a_v and a_h is as defined in *4.4.2.3 Bureau Veritas (DSY/VA)*
- For other type of yacht:

$$a_z = 1,3$$

p = Density, in t/m^3 of the fuel oil carried.

Lastly the design pressure on ordinary bulkheads and watertight bulkheads forming boundary of a liquid tank is given also by a tables, see *Table 4.3.16 Watertight bulkheads design pressure (BV).* Furthermore BV notes that non-watertight bulkheads are not subjected to any design lateral pressure.

Table 4.3. 16 Watertight bulkheads design pressure (BV)

Type of bulkheads	Design pressure, in kN/m^2
Watertight bulkhead other than collision bulkhead	$p_S = 10\,(1.3T - z) > 0$
Collision bulkhead	$p_S = 10\,(D - z) > 0$

Where,

T = Full draught, in m,
D = Depth as defined in *4.1.2.3 Bureau Veritas (D)*
z = Vertical distance, in m, between the base line and the calculation point

4.3.7.4 Det Norske Veritas – Germanischer Lloyd (PSPY/POC)

In cases of mono-hull high speed and multi-hull motor yachts design pressures acting on various components according to *4.2.7.4 Det Norske Veritas - Germanischer Lloyd (HSC/POC)* is applicable, as it is mentioned in Pt. 3, Ch. 3, sections 4 and 5 of DNV-GL's *Rules for Classification: Yachts (October 2016).* The referenced segment contains regulations on superstructures, bulkheads, tanks etc.

4.3.7.5 Registro Italiano Navale (PSPY/POC)

RINA, via *Rules for Yachts Designed for Commercial Use (January 2019)*, provides regulations, in respect of watertight bulkheads, requirements for subdivision bulkheads and tank structures.

For which components, the design heads are defined by RINA. As regards subdivision bulkhead, the design head h_B, equals to the vertical distance, in m, from the pdr (pdr: *see 4.1.2.5 Registro Italiano Navale (D))* to the highest point of the bulkhead.

As per tank structure, the design head is either the vertical distance from the pdr (pdr: *see 4.1.2.5 Registro Italiano Navale (D))* to a point located at a height h, in m, above the highest point of the tank given by equation *4.3.16,* or the 2/3 of the vertical distance from the pdr to the top of the overflow pipe.

$$h_T = [1 + 0{,}05 \cdot (L - 50)]\, m \tag{4.3.16}$$

Where the value of L is to be taken no less than 50 m and no greater than 80 m.

No further indication are made by RINA on any other component of the ship, concerning design loads.

4.3.7.6 Conclusion (PSPY/POC)

Besides RINA who misses to include requirements on superstructures and deckhouses, the other classes include similar components. However they propose calculations to be conducted differently.

Quite practical for preparing primary scantlings of the craft are BV's regulations, as they include minimum values for certain components and specifically for tank structure the design pressures are corresponded to testing pressures.

<u>Section</u>

4.4 Displacement Motor and Sailing Yachts

4.4.1 General (Displacement and Sailing Yachts: DSY)

In the present section rules and regulations will be presented that refer to displacement motor yachts and sailing yachts.

Displacement motor yacht's weight of the craft is fully or predominantly supported by hydrostatic forces. This is an attribute that applies also to sailing yachts and for that reason some of the classification societies are suggesting rules that are common for these type of yachts, which is also the reason their requirement are presenting together on the present section.

4.4.2 Vertical Acceleration (DSY/VA: Vertical Acceleration)

4.4.2.1 Lloyd's Register (DSY/VA)

LR and *Rules and Regulations for the Classification of Special Service Craft (July 2018)* find application in several type of crafts, including yachts. Also, LR does not give distinct equation on vertical acceleration depending on the type of craft, but rather distinguish them per operating mode and number of hulls. Therefore, formulas on calculating vertical acceleration of displacement and sailing yachts shall be obtained from *4.2.2.1 Lloyd's Register (HSC/VA),* as applicable.

Furthermore, it is suggested that in order to estimate vertical acceleration of sailing or a displacement yachts, the formulas referring to crafts operating in displacement mode are to be used.

4.4.2.2 American Bureau of Shipping (DSY/VA)

In *Guide for Building and Classing Yachts (October 2018)* there are no regulation on calculating vertical acceleration of a displacement or a sailing yachts. Such instructions are not necessary as ABS provides design heads in order to estimate design pressures acting on both craft types, see *4.4.3.2 American Bureau of Shipping (DSY/PBS).*

4.4.2.3 Bureau Veritas (DSY/VA)

BV instructions on design vertical acceleration given in *Rules for Yachts (March 2012)* Pt. B, Ch. 4, Sec. 3 does not present similarities neither with LR, neither with ABS corresponding rules.

According to BV*,* the vertical design acceleration for mono-hull sailing yacht is calculated on the basis of the combination of heave and pitch accelerations, while for slow speed motor yachts and for multihulls sailing yachts, no specific acceleration is to be calculated. In terms of slow speed motor yachts and for multihulls sailing yachts, the effect of yacht motions are taken into consideration in BV's rules formulae for the determination of wave loads.

For mono-hull sailing yacht, firstly, the heave design acceleration is to be calculated using equation *4.4.1,* presented below.

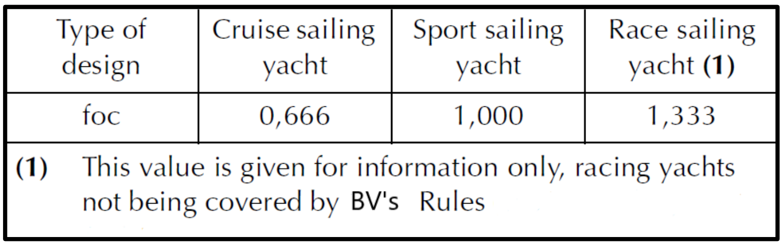
$$a_H = 2{,}7 \cdot foc \cdot Soc \quad g's \tag{4.4.1}$$

Where,

foc = As defined in *Table 4.4.1 foc for sailing yacht (BV)*

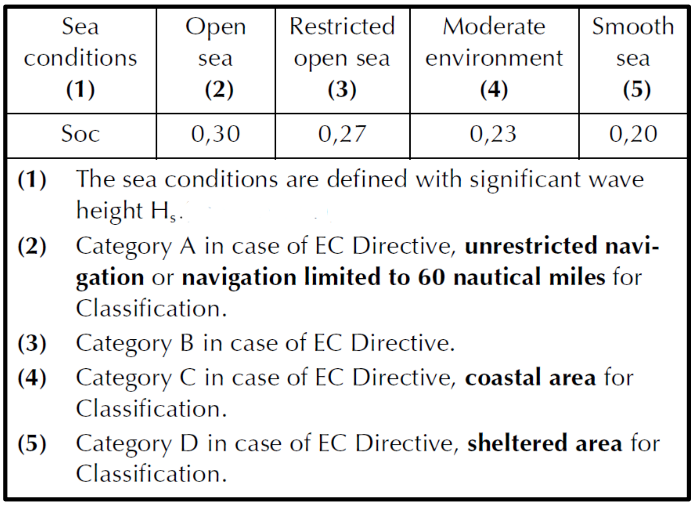
Soc = As defined in *Table 4.4.2 Soc for sailing yacht (BV)*

Table 4.4. 1 foc for sailing yacht (BV)



Type of design	Cruise sailing yacht	Sport sailing yacht	Race sailing yacht **(1)**
foc	0,666	1,000	1,333
(1) This value is given for information only, racing yachts not being covered by BV's Rules			

Table 4.4. 2 Soc for sailing yacht (BV)



Sea conditions **(1)**	Open sea **(2)**	Restricted open sea **(3)**	Moderate environment **(4)**	Smooth sea **(5)**
Soc	0,30	0,27	0,23	0,20
(1) The sea conditions are defined with significant wave height H_s. **(2)** Category A in case of EC Directive, **unrestricted navigation** or **navigation limited to 60 nautical miles** for Classification. **(3)** Category B in case of EC Directive. **(4)** Category C in case of EC Directive, **coastal area** for Classification. **(5)** Category D in case of EC Directive, **sheltered area** for Classification.				

Where,

H_s = Significant wave height as defined in *Table 4.3.3 Soc for motor yacht (BV), see 4.3.2.3 Bureau Veritas (PSPY/VA)*

Subsequently, the pitch design acceleration is to be determined, which is dependent to heave design acceleration as shown in equation *4.4.2,* also expressed in g's and distributed in the longitudinal axis as in *Figure 4.4.2 Pitch acceleration longitudinal distribution (BV).*

- For $x < x_K$

$$a_P = 0 \quad g's \tag{4.4.2}$$

$$a_P = a_{PFP} \cdot \frac{x - x_K}{L_{WL} - x_K} > 0$$

- For $x > x_K$

Where,

x_K = Distance, in m, from the aft end (AE) to the centre of gravity of the keel

x = Distance, in m, from the aft end (AE) to the calculation points located as shown on *Figure 4.4.1 Calculation points for slamming pressure (BV)*

a_{PFP} = Pitch vertical acceleration at fore end (FE) to be taken equal to:

  - $3a_H$ for race sailing yacht (value given for information)
  - $2{,}1a_H$ for bulb keel sailing yacht
  - $1{,}5a_H$ for sailing yacht with bar keel
  - a_H for lifting keel yachts

a_H = Heave acceleration, in g, calculated according to equation *4.4.1*

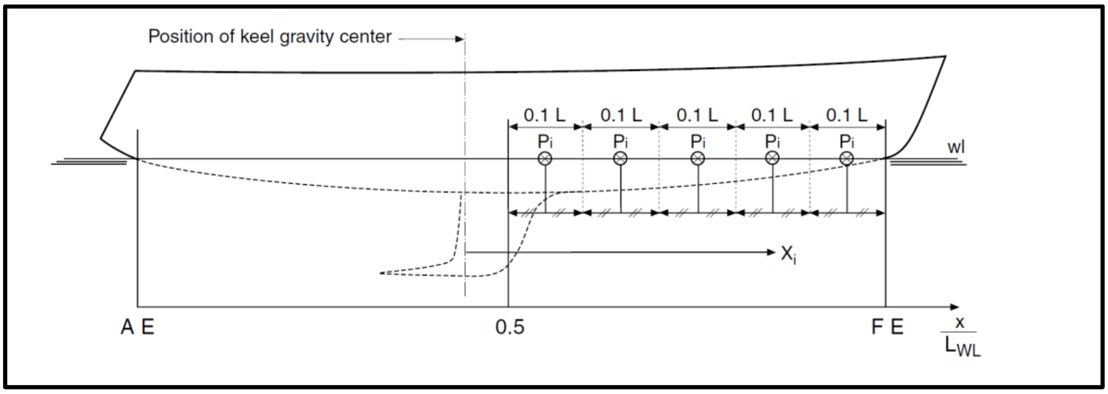


Figure 4.4. 1 Calculation points for slamming pressure (BV)

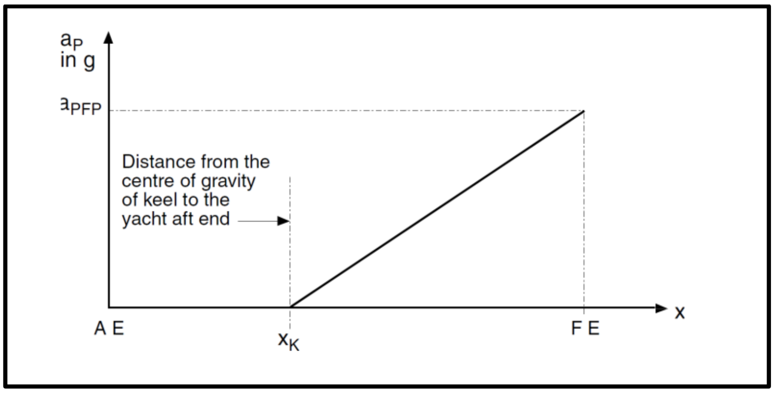


Figure 4.4. 2 Pitch acceleration longitudinal distribution (BV)

Finally the design vertical acceleration of a mono-hull sailing yacht is calculated y adding the two previously defined acceleration as shown in equation *4.4.3.*

$$a_V = a_H + a_P \quad g's \qquad (4.4.3)$$

Where,

a_H = Heave acceleration, in g's, as defined in equation *4.4.1*

a_P = Pitch acceleration, in g's, as defined in equation *4.4.2*

4.4.2.4 Det Norske Veritas – Germanischer Lloyd (DSY/VA)

Alike ABS, neither DNV-GL rules on design loads are depended on vertical acceleration. However in Pt. 3, Ch. 3, Sec. 2 of *Rules for classification: Yachts (October 2016),* the design speed is defined, which is necessary for determining following design loads for sailing yachts and is to taken as in equation *4.4.4.*

$$v_0 = 0{,}692 \cdot L^{0{,}33} \cdot c_{vs} \cdot C_c \quad knots \tag{4.4.4}$$

Where,

L = Rule length, in m, as defined in *4.1.2.4 Det Norske Veritas - Germanischer Lloyd (D)*
c_{vs} = $(\frac{L}{\rho \cdot \Delta^{0{,}333}})$, where $6{,}5 \leq c_{vs} \leq 9{,}5$
Δ = displacement of the yacht, in t, at draught *T or T_H,* respectively
ρ = Density of the water, in t/m^3
c_c = $0{,}385 \cdot \frac{(GZ \cdot L)^{0{,}5}}{\Delta^{0{,}33}}$,where $c_{min} = 0{,}95$
GZ = is the maximum righting moment lever at heeling angles below 60°, with all stability-increasing devices such as canting keel, water ballast and crew, in their most effective position for upwind sailing, determined at displacement Δ.

According to DNV-GL, the design speed of a multi-hull sailing yacht is to be determined similarly, but taking *GZ* as in equation *4.4.5.*

$$Gz = \frac{B_{c-c}}{2} \quad m \tag{4.4.5}$$

Where,

B_{c-c} = breath between hull centres

As per any motor yachts that is not high-speed, in *Rules for Classification: Yachts (October 2016),* Pt. 3, Ch. 3, Sec. 3, DNV-GL provides formula on vertical acceleration for dynamic load cases, in g, and is to be taken as follows:

$$a_z = a_0 \cdot k_v \cdot f_Q \tag{4.4.6}$$

Where,

a_0 = acceleration parameter, to be taken as:
= $\frac{c_0 \cdot c_B}{L^2} \cdot (0{,}6 \cdot v_0 + 2{,}3 \cdot \sqrt{L})^2$
L = rule length, as defined in *4.1.2.4 Det Norske Veritas - Germanischer Lloyd (D)*
v_0 = expected maximum speed, in knots
c_0 = wave coefficient
= $(\frac{L}{25} + 4{,}1) \cdot C_{RW}$ for *L* < 90 m
= $[10{,}75 - (\frac{300-L}{100})^{1{,}5}] \cdot C_{RW}$ for 90 ≤ L < 300 m
C_{RW} = service range coefficient
= 1.0 for unlimited service range and **R0**
= 0.90 for restricted service area **R1**
= 0.75 for restricted service area **R3**
= 0.60 for restricted service area **RE**

for other restricted service to be determined on a case by case basis, see also Pt.1 Ch.2 Sec.5 /// as defined in *4.1.2.4 Det Norske Veritas - Germanischer Lloyd (D)*

c_B = block coefficient at draught T

k_v = distribution factor, see also *Figure 4.4.3 Distribution factor kv (DNV-GL)*

= 1.8 – (8/3)·(x/L) for x/L < 0.3

= 1.0 for 0.3 ≤ x/L ≤ 0.6

= 5.5 (x/L) – 2.3 for x/L > 0.6

f_Q = Probability factor

Q = 10^{-8} for fixed elements such as masts, etc.

= 10^{-6} for ship safety equipment

= 10^{-5} for loose equipment, content of tanks, deck loads, etc.

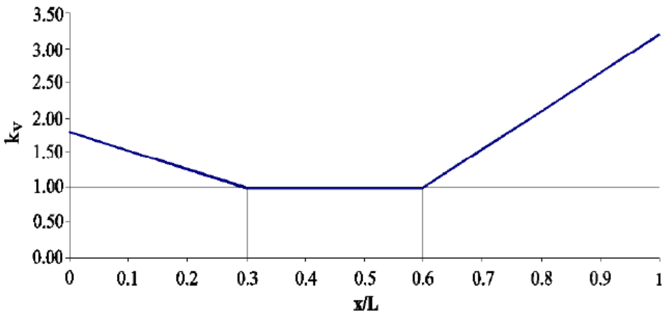


Figure 4.4. 3 Distribution factor kv (DNV-GL)

4.4.2.5 Registro Italiano Navale (DSY/VA)

While, neither in RINA requirements on design loads is the vertical acceleration applied, in *Rules for Yachts Designed for Commercial Use (January 2019)* there are no indications that prevent the use of formulas given in *4.3.2.5 Registro Italiano Navale (PSPY/VA)* in order to estimate the vertical acceleration of a sailing or a displacement yacht.

4.4.2.6 Conclusion (DSY/VA)

In contrast to ABS and RINA requirements, which present no dependency on vertical acceleration in terms of design loads, for LR, BV and DNV-GL calculation of vertical acceleration is necessary.

However vertical acceleration neither for BV nor for DNV-GL is necessary for both sailing and displacement yachts. BV states that it is not needed to calculate any acceleration for displacement yacht, as yacht motions effects has been taken into consideration in its formulas and as per DNV-GL, only the design speed is to be determined for sailing yachts.

4.4.3 Pressures on Bottom Shell (DSY/PBS: Pressure on Bottom Shell)

4.4.3.1 Lloyd's Register (DSY/PBS)

LR and *Rules and Regulations for the Classification of Special Service Craft (July 2018)* find application in several type of crafts, including yachts. Also, LR does not give distinct equation on vertical acceleration depending on the type of craft, but rather distinguish them per operating mode and number of hulls. Therefore, formulas on calculating bottom design pressure of displacement and sailing yachts shall be obtained from *4.2.3.1 Lloyd's Register (HSC/PBS),* as applicable.

Furthermore, it is suggested that in order to estimate design bottom pressure of a sailing or a displacement yachts, the formulas referring to crafts operating in displacement mode are to be used.

4.4.3.2 American Bureau of Shipping (DSY/PBS)

As previously mentioned, ABS regulation on design pressures of displacement yachts and sailing yachts, presented in *Guide for Building and Classing Yachts (October 2018)*, Pt. 3, Ch. 2, Sec. 2, are given as design heads to be used in conjunction with the hydrostatic pressure formula.

The design heads for several locations of a displacement yacht, such as bottom, side, decks, tanks, bulkheads, are summarized by ABS in a table, data of which are given in *Table 4.4.3 Displacement Yachts – Design Heads, h (ABS).* Only the design heads of superstructures are not included and are to be discussed in *4.7.2 American Bureau of Shipping (DSY/POC).*

Additionally, the bottom forward slamming head, H_{sf}, is to be calculated, as in equation *4.4.7,* for bottom and side fore slamming.

Table 4.4. 3 Displacement Yachts – Design Heads, h (ABS)

Location		*Design Head, h, measured in m*
Bottom Structure		Distance to main weather deck at side, from lower edge of plate panel for plating and from center of area supported for internals, but not less than $L/10$ or 2,15 m whichever is greater.
Bottom Structure, Fore Slamming		H_{fs}, see equation *4.4.6*
Side Structure		Distance to main weather deck at side, from lower edge of plate panel for plating, and from center of area supported for internals, but not less than 0,66D or L/15, whichever is greater.
Side Structure, Fore Slamming		H_{fs}, see equation *4.4.6*, to apply at the waterline and reducing to 0.40 H_{fs} at the weather deck
Deep Tanks		Distance from lower edge of plate panel for plating or from the center of area supported for internals to the greater of the following, 1. A point at two-thirds the distance to the main weather or bulkhead deck. 2. A point at two-thirds of the distance from the top of the tank to the top of the overflow. 3. A point above the top of the tank, not less than 0,01L + 0,15 m or 0,46 m.
Watertight Bulkheads		Distance from the lower edge of the plate for plating or from the center of area supported for internal to the main weather or bulkhead deck at centerline.
Decks (see *Figure 4.3.13 Deck, Superstructure and Deckhouse Pressures I (ABS))*	Main Weather Deck (exposed)	(0,02L + 0,46) m
	Superstructure and Deckhouse Decks Forward of 0,25L (exposed)	
	Superstructure and Deckhouse Decks elsewhere (exposed) Deckhouse top, First tier	(0,01L + 0,46) m
	Deckhouse tops above 2nd tier (used as weather coverings only)	(0,01L + 0,15) m
	Internal accommodation decks (included in hull-girder section modulus)	(0,01L + 0,30) m
	Internal accommodation decks (not included in hull-girder section modulus)	0,35 m

$$H_{sf} = N_4 \cdot K_s \cdot \left[19 - 2720 \cdot \left(\frac{d}{L_w}\right)^2\right] \cdot \sqrt{L_w \cdot V} \quad m \qquad (4.4.7)$$

Where,

N_4 = 0,1045
K_s = 0,09 at forward end of L_w
= 0,18 at 0,1L from forward end of L_w
= 0,18 at 0,2L from forward end of L_w
= 0 at 0,5L from forward end of L_w and aft
d = stationary draft, in m, 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.
L_w = length of the waterline at the design displacement, in m
V = maximum design speed in calm water, knots

Design heads for sailing yachts are regulated, by ABS, in a similar manner but with the following differentiation. In order to estimate the design head of a particular location, firstly, the basic head, h_b, is to be determined, using to equation *4.4.8,* and then modified according to *Table 4.4.4 Sailing Yachts – Design Heads, h (ABS)* for the location under consideration.

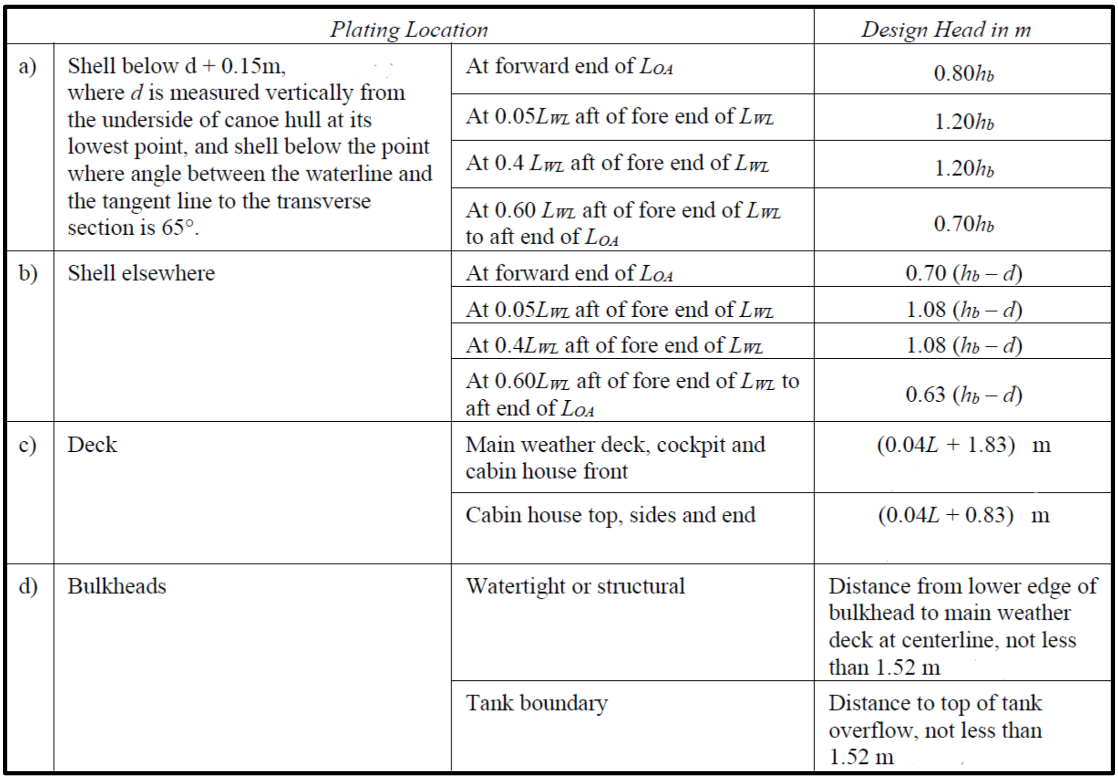
The referenced table contains instructions on various regions of the craft, as displacement yacht's corresponding table. Moreover, ABS apposes *Figure 4.4.4 Sailing Yacht Pressures – Profile (ABS)* and *Figure 4.4.5 Sailing Yacht Pressures – Transverse Section (ABS)* in order to assist the design pressure calculation of sailing yachts.

$$h_b = 0{,}3 \cdot d + 0{,}14 \cdot L + 1{,}62 \quad m \qquad (4.4.8)$$

Where,

L = yacht length as defined in *4.1.2.2 American Bureau of Shipping (D)*
d = draft as defined in *4.1.2.2 American Bureau of Shipping (D)*, not to be taken less than 0,048L + 0,091 m

Table 4.4. 4 Sailing Yachts – Design Heads, h (ABS)



	Plating Location		*Design Head in m*
a)	Shell below d + 0.15m, where *d* is measured vertically from the underside of canoe hull at its lowest point, and shell below the point where angle between the waterline and the tangent line to the transverse section is 65°.	At forward end of L_{OA}	$0.80h_b$
		At $0.05L_{WL}$ aft of fore end of L_{WL}	$1.20h_b$
		At 0.4 L_{WL} aft of fore end of L_{WL}	$1.20h_b$
		At 0.60 L_{WL} aft of fore end of L_{WL} to aft end of L_{OA}	$0.70h_b$
b)	Shell elsewhere	At forward end of L_{OA}	$0.70\ (h_b - d)$
		At $0.05L_{WL}$ aft of fore end of L_{WL}	$1.08\ (h_b - d)$
		At $0.4L_{WL}$ aft of fore end of L_{WL}	$1.08\ (h_b - d)$
		At $0.60L_{WL}$ aft of fore end of L_{WL} to aft end of L_{OA}	$0.63\ (h_b - d)$
c)	Deck	Main weather deck, cockpit and cabin house front	$(0.04L + 1.83)$ m
		Cabin house top, sides and end	$(0.04L + 0.83)$ m
d)	Bulkheads	Watertight or structural	Distance from lower edge of bulkhead to main weather deck at centerline, not less than 1.52 m
		Tank boundary	Distance to top of tank overflow, not less than 1.52 m

Notes:

1. Shell design heads between locations given above are to be obtained by interpolation.
2. d = draft, as defined in *4.1.2.2 American Bureau of Shipping (D)* except that in calculation of basic head, d is not to be taken less than 0,048L + 0,091 m
3. Design head for bottom structure to be not less than 1,33D and for side shell not less than 0,66D.

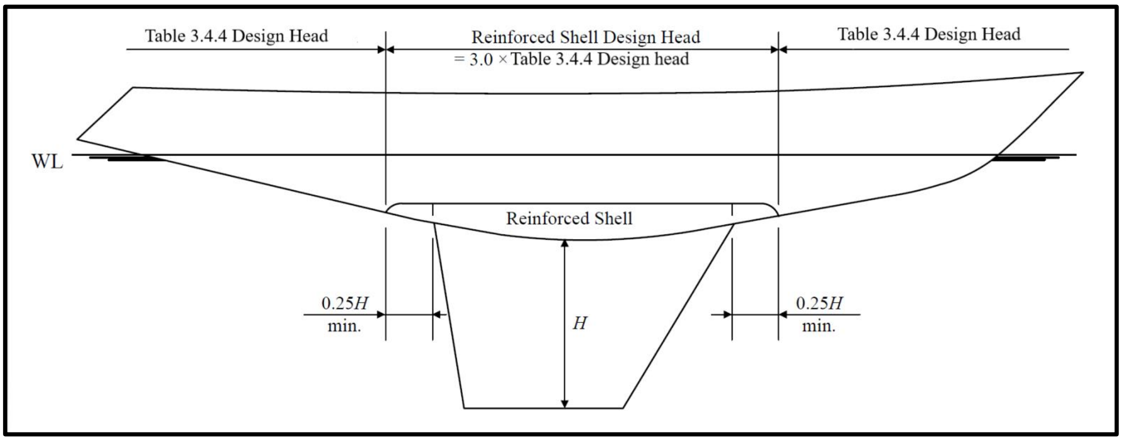


Figure 4.4. 4 Sailing Yacht Pressures – Profile (ABS)

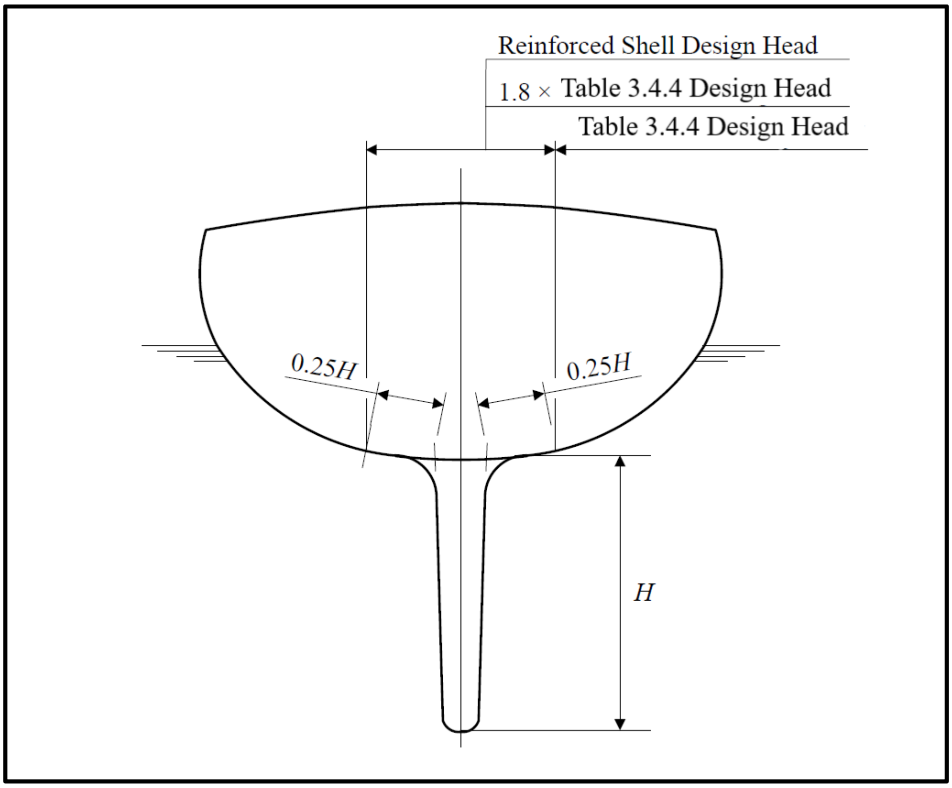


Figure 4.4. 5 Sailing Yacht Pressures – Transverse Section (ABS)

4.4.3.3 Bureau Veritas (DSY/PBS)

BV and *Rules for Yachts (March 2012)* Pt B, Ch 4, Sec 3, contain information on calculating both wave loads and bottom slamming pressures of sailing yacht, as LR. While for displacement yacht only the rules on wave loads are applied.

Directives referring to wave loads are common for the platings, secondary stiffeners and primary stiffeners scantling of all type of yacht and have already been presented on this thesis. Hence, in order to determine the wave loads values in the different areas of the hull equation *4.3.3* is to be used as given in *4.3.3.3 Bureau Veritas (PSPY/PBS).*

Especially, for mono-hull sailing yacht, the bottom slamming pressure is to be taken as in equation *4.4.9.* BV also notes that the longitudinal location of the different calculation points where the total vertical acceleration a_v and the slamming pressure p_{sl} are to be calculated is shown on *Figure 4.4.1 Calculation points for slamming pressure (BV).*

$$p_{sl} = 70 \cdot \frac{\Delta}{S_r} \cdot K_2 \cdot K_3 \cdot a_v \ \ kN/m^2 \qquad (4.4.9)$$

Where,

K_2, K_3 = Factors as defined in *4.3.3.3 Bureau Veritas (PSPY/PBS)*
S_r = As defined in *4.2.3.3 Bureau Veritas (HSC/PBS)*
Δ = Displacement, in tonnes
a_v = total design vertical acceleration, g's, as defined in *4.4.2.3 Bureau Veritas (DSY/VA)*

4.4.3.4 Det Norske Veritas – Germanischer Lloyd (DSY/PBS)

While in *Rules for classification: Yachts (October 2016),* by DNV-GL, are included rules for mono-hull and multi-hull sailing yacht, displacement yachts are not mentioned.

However, in Pt. 3, Ch. 3, Sec. 3, of the referenced document, provides specifications on local design loads for any mono-hull motor yacht that is not a high speed motor yacht, hence the bottom design pressures of a displacement yacht is to be determined accordingly.

DNV-GL regulations suggest formula to be applied, for displacement yachts, at any load point on hull and weather exposed areas, see *Figure 4.4.6 Definition of different parts of the ship's surface exposed to the sea (DNV-GL)*, similarly to the corresponding rules on high-speed crafts. As in general design loads consists of a static and a dynamic factor, DNV-GL indicates formula for the computation of each counterpart.

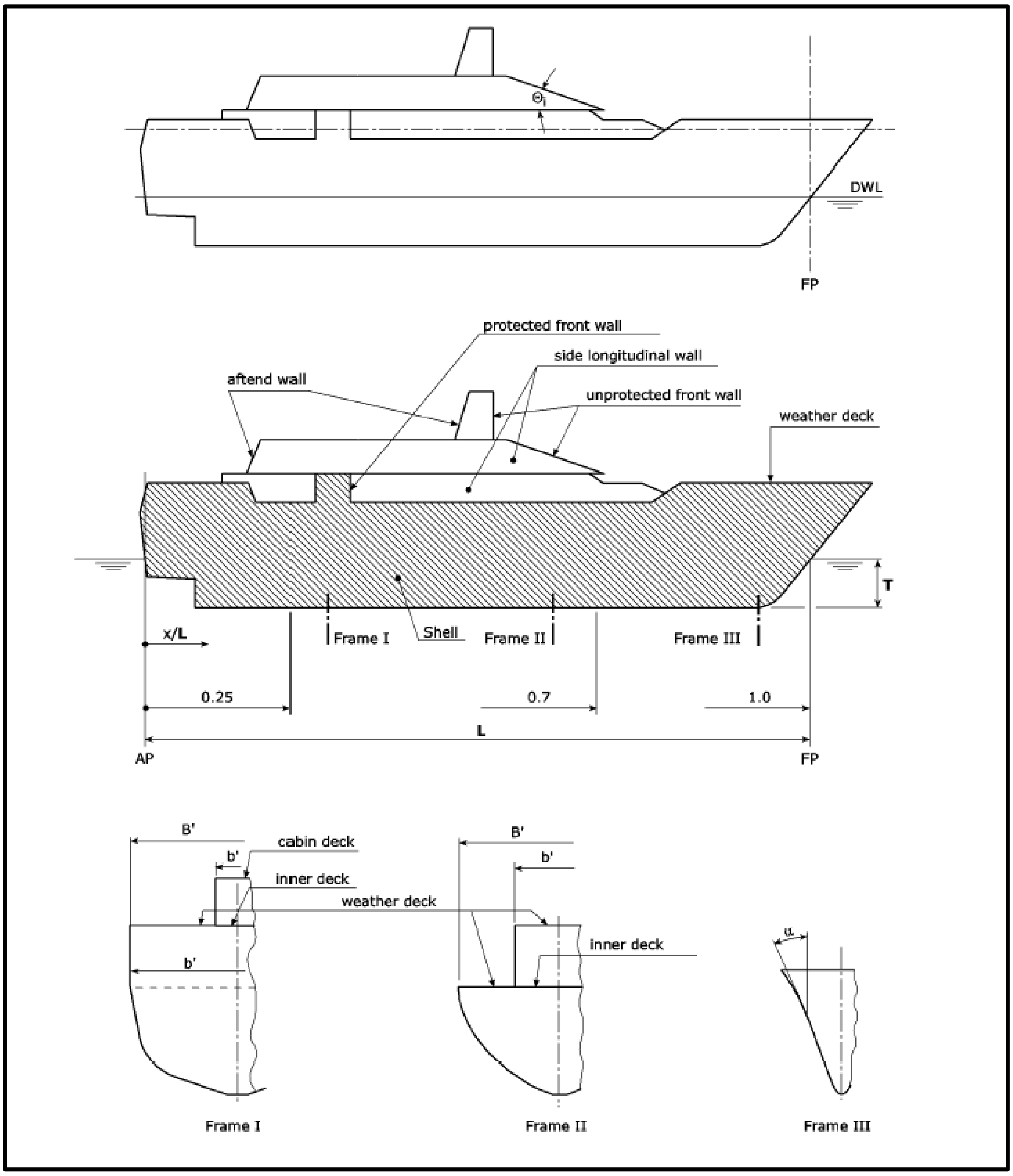


Figure 4.4. 6 Definition of different parts of the ship's surface exposed to the sea (DNV-GL)

The hydrostatic design pressure shall be taken as:

$$\begin{aligned} p_{Stat} &= 10 \cdot (T - z) \quad kN/m^2 \text{ for } z < T \\ &= 0 \text{ for } z \geq T \\ &\geq p_{Smin} \end{aligned} \qquad (4.4.10)$$

Where,

T = moulded draught, in m

z = z coordinate along vertical axis, in m

p_{Smin} = 4,0 kN/m^2 for weather decks in general and unprotected front walls

= 2,5 kN/m^2 for roofs or cabin decks

= 3,0 kN/m^2 for walls, except unprotected front walls

The hydrodynamic design pressure shall be taken as:

$$\begin{aligned} p_{Sdyn} &= p_0 \cdot K_F \cdot C_p \cdot \left[1 - \left(\frac{z}{T}\right)^{0,75}\right] \quad kN/m^2 \text{ for } z < T \\ &= p_0 \cdot K_F \cdot C_p \cdot \left[0,25 + \frac{1,75}{1+\frac{z-T}{c_0}}\right] \cdot n_1 \cdot n_2 \cdot n_3 \; kN/m^2 \text{ for } z \geq T \\ &\geq p_{Smin} \end{aligned} \qquad (4.4.11)$$

Where,

p_0 = basic external dynamic load, in kN/m^2

= $5{,}0 \cdot \sqrt{c_B} \cdot c_0 \cdot c_v \cdot f_Q$

c_B, c_0, f_Q = as defined in *4.4.2.4 Det Norske Veritas – Germanischer Lloyd (DSY/VA)*

c_v = velocity coefficient

= $\sqrt[3]{\frac{v_0}{1{,}6 \cdot \sqrt{L}}} \geq 1$ with $1{,}6 \cdot \sqrt{L} \geq 14$

v_0 = expected maximum speed, in knots

K_F = Distribution factor according to *Table 4.4.5 Distribution factor K_F, height factor c_Z and factor n_4 (DNV-GL)*

n_1, n_2, n_3 = ship's surface coefficients as defined in *Table 4.4.6 Ship's surface coefficients (DNV-GL)*

C_p = $1{,}1 - 0{,}2 \cdot l$

= 1.0 for plates and pillars

≥ 0.75 for stiffeners (secondary members)

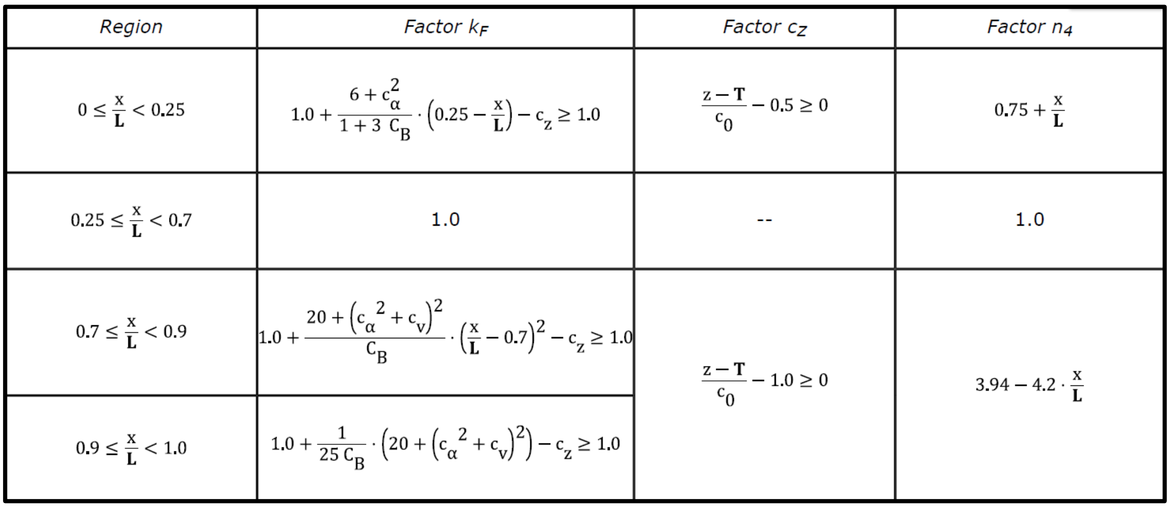
≥ 0.6 for girders (primary members

l = length of girders or stiffeners.

p_{Smin}, z, T = As defined in previous equation

The lateral design pressure acting on a mono-hull motor yacht results from sum of the two pressures.

Table 4.4. 5 Distribution factor K_F, height factor c_z and factor n_4 (DNV-GL)



Region	*Factor k_F*	*Factor c_Z*	*Factor n_4*
$0 \leq \frac{x}{\mathbf{L}} < 0.25$	$1.0 + \frac{6 + c_\alpha^2}{1 + 3\ C_B} \cdot \left(0.25 - \frac{x}{\mathbf{L}}\right) - c_z \geq 1.0$	$\frac{z - \mathbf{T}}{c_0} - 0.5 \geq 0$	$0.75 + \frac{x}{\mathbf{L}}$
$0.25 \leq \frac{x}{\mathbf{L}} < 0.7$	1.0	--	1.0
$0.7 \leq \frac{x}{\mathbf{L}} < 0.9$	$1.0 + \frac{20 + \left(c_\alpha{}^2 + c_v\right)^2}{C_B} \cdot \left(\frac{x}{\mathbf{L}} - 0.7\right)^2 - c_z \geq 1.0$	$\frac{z - \mathbf{T}}{c_0} - 1.0 \geq 0$	$3.94 - 4.2 \cdot \frac{x}{\mathbf{L}}$
$0.9 \leq \frac{x}{\mathbf{L}} < 1.0$	$1.0 + \frac{1}{25\,C_B} \cdot \left(20 + \left(c_\alpha{}^2 + c_v\right)^2\right) - c_z \geq 1.0$		

Where,

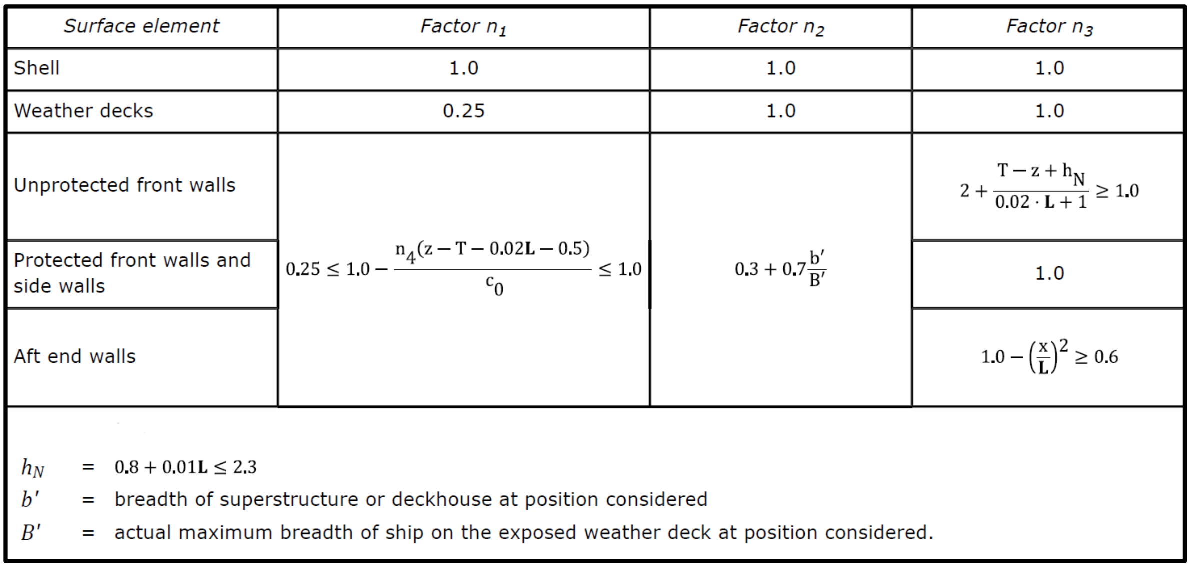
C_a = flare factor

= $0{,}4/(1{,}2 - 1{,}09 \cdot \sin a)$ in general

≥ 1.0 for bow doors and stem structures

≥ 0 for decks and walls

Table 4.4. 6 Ship's surface coefficients (DNV-GL)



Surface element	*Factor n_1*	*Factor n_2*	*Factor n_3*
Shell	1.0	1.0	1.0
Weather decks	0.25	1.0	1.0
Unprotected front walls	$0.25 \leq 1.0 - \frac{n_4(z - \mathrm{T} - 0.02\mathbf{L} - 0.5)}{c_0} \leq 1.0$	$0.3 + 0.7\frac{b'}{B'}$	$2 + \frac{\mathrm{T} - z + h_N}{0.02 \cdot \mathbf{L} + 1} \geq 1.0$
Protected front walls and side walls			1.0
Aft end walls			$1.0 - \left(\frac{x}{\mathbf{L}}\right)^2 \geq 0.6$

h_N = $0.8 + 0.01\mathbf{L} \leq 2.3$

b' = breadth of superstructure or deckhouse at position considered

B' = actual maximum breadth of ship on the exposed weather deck at position considered.

Concerning mono-hull sailing yachts, DNV-GL, in Pt. 3, Ch. 3, Sec. 2 of the referenced document, provides equation *4.4.12*, which is used to determine sea pressure on the yacht's hull and transom. In any case pressure, p_H, is not be taken less than indicated by equation *4.4.13.*

$$p_H = 10 \cdot T_H \cdot \left(1 - \frac{z}{H}\right) + c_p \cdot c_L \cdot L \cdot \left(1 + \frac{v_0}{3 \cdot \sqrt{L}}\right) \cdot \cos\left(\frac{a}{1{,}5}\right) \ kN/m^2 \qquad (4.4.12)$$

Where,

v_0 = Design speed in knots, as defined in *4.4.2.4 Det Norske Veritas – Germanischer Lloyd (DSY/VA)*

z = vertical distance between the load point and the moulded base line, in m

c_p = panel size factor as a function of f, *see Figure 4.4.7 Panel size factor c_p (DNV-GL)*

f = $\frac{(l-0{,}25)}{0{,}055 \cdot L+0{,}55}$

l = length of girders or stiffeners between supports [m], for the purpose of determining sea pressures not to be taken less than 0.25 m or greater than 1.3 m

L = rule length, in m, as defined in

c_L = hull longitudinal distribution factor, see *Figure 4.4.8 Hull longitudinal distribution factor c_L (DNV/GL)*

- for x/L<0:
  $c_L = 0{,}80$ for L = 24 m
  $c_L = 0{,}60$ for L ≥ 48 m
- for 0 ≤ x/L ≤ 0.65:
  $c_L = 0{,}80 + 0{,}615 \cdot x/L$ for L = 24 m
  $c_L = 0{,}60 + 0{,}538 \cdot x/L$ for L ≥ 48 m
- for x/L ≥ 0.65:
  $c_L = 1.20$ for L = 24 m
  $c_L = 0{,}95$ for L ≥ 48 m

a = β – 20°, α not smaller than 0°

β = deadrise angle at load point

T_H = maximum draught of the canoe body, in m

H = moulded depth of yacht, in m

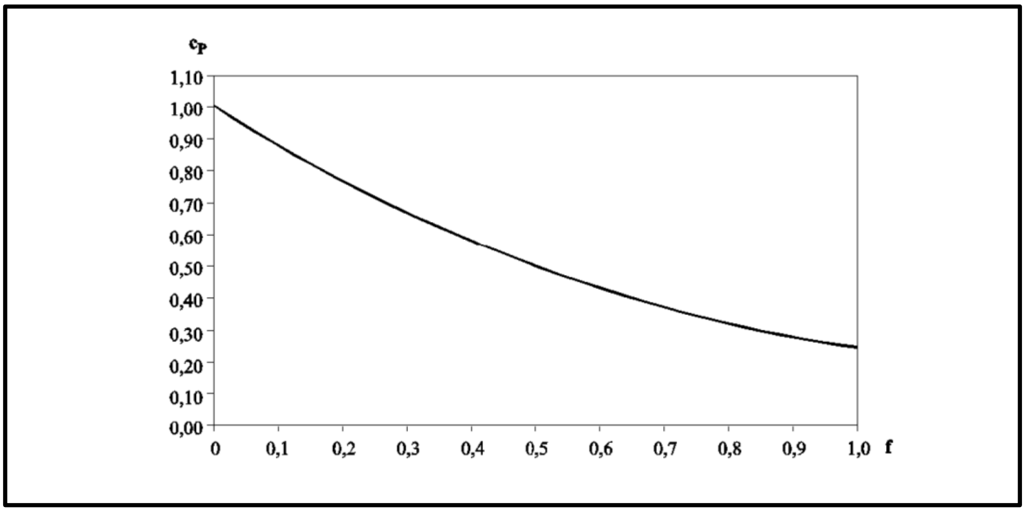


Figure 4.4. 7 Panel size factor c_p (DNV-GL)

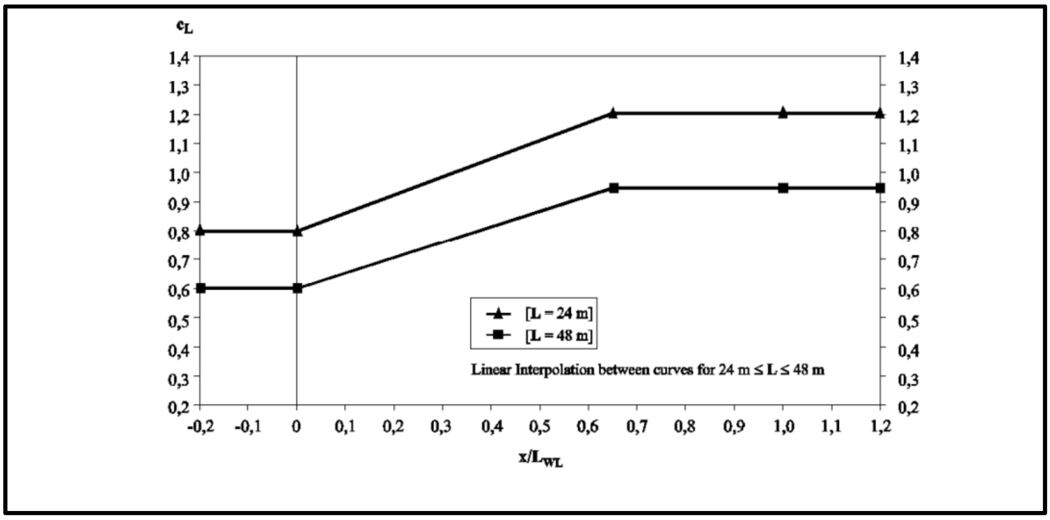


Figure 4.4. 8 Hull longitudinal distribution factor c_L (DNV/GL)

- $p_{Hmin} = 10 \cdot H \quad kN/m^2$
  for the area of the hull below the full displacement waterline
- $p_{Hmin} = 5 \cdot H \quad kN/m^2$
  for the area of the hull above the full displacement waterline

(4.4.13)

Where,

H = moulded depth of yacht, in m

Especially for forward hull bottom, DNV-GL provides formula to calculate slamming pressure, see equation *4.4.14*, which is to be applied if its value is greater than the pressures that defined above. DNV-GL also states that p_{sl} *"shall be applied to the hull bottom in an area where the local deadrise is lower than 50° in upright floatation or below design waterline, whichever gives a greater area"*.

$$P_{sl} = 3 \cdot K_2 \cdot K_3 \cdot K_{WD} \cdot v_0 \cdot v_{sl} \quad kN/m^2 \qquad (4.4.14)$$

Where,

v_{sl} = relative impact velocity, in m/s
= $4 \cdot \frac{H_S}{\sqrt{L}} + 1$
H_S= relevant critical significant wave height, in m
= $\frac{L^{1,333}}{36}$
K_2 = factor accounting for impact area, equal to:
$K_2 = 0{,}455 - 0{,}35 \cdot \frac{u^{0,75} - 1{,}7}{u^{0,75} + 1{,}7}$, with:

K_2 ≥ 0,50 for plating
K_2 ≥ 0,45 secondary supporting, e.g. for stiffeners and beams
K_2 ≥ 0,35 primary supporting, e.g. for girders, floors and frames
K_2 ≥ 0,35 primary supporting, e.g. for girders, floors and frames
K_2 ≥ 0,175 for global strength calculations
$u = 100 \cdot \frac{s}{s_r}$

where s is the area, in m^2, supported by the element (plating, stiffener, floor or girder). For plating, the supported area is the spacing between the stiffeners multiplied by their span, without taking for the latter more than three times the spacing between the stiffeners

S_r = Reference area, in m^2, equal to $S_r = 0{,}7 \cdot \frac{\Delta}{T_H}$

For catamaran, Δ in the above formula is to be taken as half the craft displacement

T_H = maximum draught of the canoe body, in m

K_3 = factor accounting for shape and deadrise of hull:

= $\frac{100-\alpha}{70}$

α = mean local deadrise of slamming area, may not be taken smaller than 30°. Slamming is applicable up to α = 50°

K_{WD} = longitudinal bottom slamming distribution factor, see *Figure 4.4.9 Longitudinal bottom slamming factor (DNV-GL)*

= 0 aft of (LCG-15% L)

= 6.67 · x/L – [(LCG-0.15L)/0.15L] between (LCG-15%) and LCG

= 1.0 forward of 0.6 L.

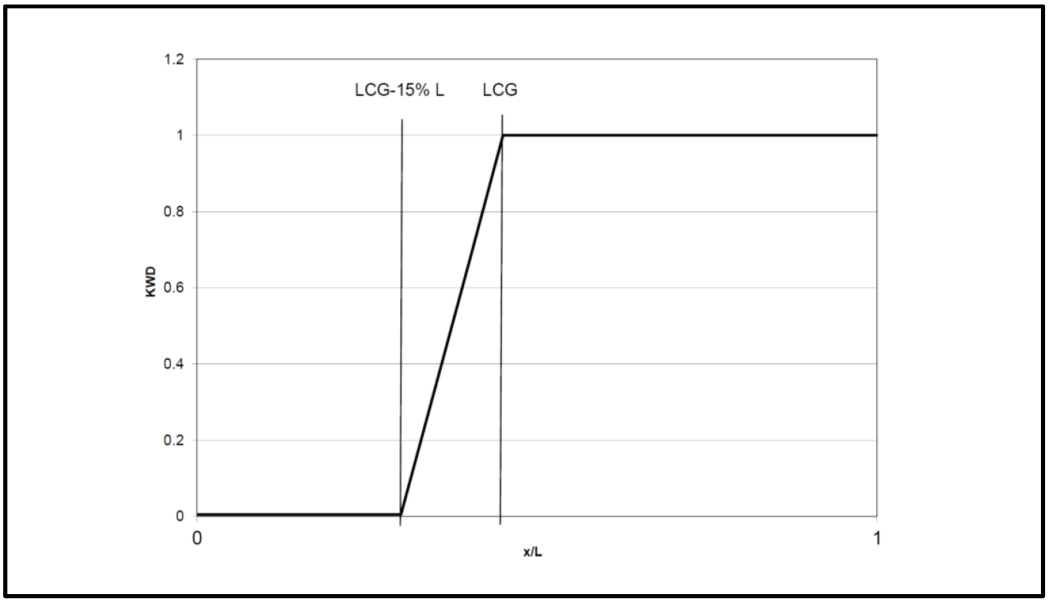


Figure 4.4. 9 Longitudinal bottom slamming factor (DNV-GL)

For multihull sailing yachts the lateral design pressures according to the corresponding calculations for mono-hull sailing yachts given in the present sub-section are applicable, but taking into consideration DNV-GL notes quoted below:

> *“For multihull sailing yachts with very slender hulls with wave-piercing ability, all hull design pressures except for slamming pressure shall be superimposed by an individual design head wedge, starting forward of mast with value zero and increasing to a value similar to local freeboard at the bow (this value will be individually assigned by the Society).*
>
> *An alternative method is to find the potential submersion by setting a negative trim angle of 20° (bow down), taken at a point where the design waterline intersects with the mast longitudinal axis.”*

4.4.3.5 Registro Italiano Navale (DSY/PBS)

As referenced in several occasion in *Rules for Yachts Designed for Commercial Use (January 2019)* by RINA, for the purpose of the evaluation of the design pressure for the bottom, sailing yachts with or without auxiliary engine are also included as displacement yachts.

Furthermore, in Pt. B, Ch. 1, Sec. 5 of referenced rulebook, displacement yacht's pressure acting below the full load waterline is to be taken as defined by equation *4.3.3*, in *4.3.3.5 Registro Italiano Navale (PSPY/PBS).* The supplementary note given about minimum value by RINA, also applies.

4.4.3.6 Conclusion (DSY/PBS)

To begin with, LR and RINA provide common methods on calculating bottom pressures for displacement and sailing yachts, regulating rules that are generally to be used for crafts operating in the displacement mode. On the other hand ABS and DNV-GL propose distinct methods for each craft type. BV stands in the middle as it suggest common equation for calculating sea loads but refers only to sailing yachts concerning bottom slamming pressures.

Another discrepancy among the classification societies is about including or not regulations for both sea pressures and bottom slamming pressures. In summary LR, BV and DNV-GL cover hydrostatic and slamming pressures, but concerning BV and DNV-GL that applies only for sailing yachts. On the contrary, ABS provides design heads for bottom structure and fore slamming only for displacement yachts, while concerning sailing yacht ABS gives design head in order to calculate general pressure acting on the bottom. Lastly RINA requirements involve one general equation to be used for both craft types.

Noteworthy is the fact that the design head for bottom slamming pressure that ABS provides, multiplied by gravity and density of the water $(p \cdot g)$, results to the impact pressure due to bottom slamming for displacement yacht that LR gives. In addition, interesting is the fact that according to their indication the bottom slamming pressure reaches maximum value between 0,8L and 0,9L from aft end and reduces at L from aft end.

4.4.4 Pressures on Side Shell (DSY/PSS: Pressure on Side Shell)

4.4.4.1 Lloyd's Register (DSY/PSS)

LR and *Rules and Regulations for the Classification of Special Service Craft (July 2018)* find application in several type of crafts, including yachts. Also, LR does not give distinct equation on vertical acceleration depending on the type of craft, but rather distinguish them per operating mode and number of hulls. Therefore, formulas on calculating side design pressure of displacement and sailing yachts shall be obtained from *4.2.4.1 Lloyd's Register (HSC/PSS),* as applicable.

Furthermore, it is suggested that in order to estimate design side shell pressure of a sailing or a displacement yacht, the formulas referring to crafts operating in displacement mode are to be used.

4.4.4.2 American Bureau of Shipping (DSY/PSS)

In ABS *Rules for Building and Classing Yachts (October 2018),* design heads of displacement and sailing yacht, that refer to several regions of the craft including side shell, are provided. In ABS' document they are located in Pt. 3, Ch. 2 Sec. 2, while in this thesis they already have been presented in Ch. 3, sub-segment *4.4.3.2 American Bureau of Shipping (DSY/PBS),* by *Table 4.4.3 Displacement Yachts – Design Heads, h (ABS)* and *Table 4.4.4 Sailing Yachts – Design Heads, h (ABS)*.

4.4.4.3 Bureau Veritas (DSY/PSS)

BV, via *Rules for Yachts (March 2012)* Pt B, Ch 4, Sec 3, contains information on calculating both wave loads and side impact pressures of sailing yacht, as LR.

Directives referring to wave loads and impact pressures acting on side shell are common for all type of yacht and have already been presented on this thesis. Hence, in order to determine the wave load and side impact pressure values, indications given in *4.3.4.3 Bureau Veritas (PSPY/PSS)* shall be followed.

4.4.4.4 Det Norske Veritas – Germanischer Lloyd – (DSY/PSS)

The sea pressures acting on the sailing yacht's hull and transom, thus also on side shell, provided by DNV-GL's *Rules for classification: Yachts (October 2016)*, are given in *4.4.3.4 Det Norske Veritas – Germanischer Lloyd – (DSY/PBS).* There are indication for both mono-hull and multi-hull sailing yachts.

Moreover, in Pt. 3, Ch. 3, Sec. 3, of the referenced document, it is stated that for any mono-hull motor yacht that is not a high speed motor yacht, the design loads, hence the side design pressures of a displacement yacht, are to be provided by regulations given in segment *4.4.3.4 Det Norske Veritas – Germanischer Lloyd (DSY/PBS).* In that segment a methodology presented on calculating sea pressures, according to DNV-GL, including side walls and shell and is to be used as applicable, for mono-hull motor yachts.

4.4.4.5 Registro Italiano Navale (DSY/PSS)

As referenced in several occasion in *Rules for Yachts Designed for Commercial Use (January 2019)* by RINA, for the purpose of the evaluation of the design pressure for the side shell, sailing yachts with or without auxiliary engine are also included as displacement yachts.

Furthermore, in Pt. B, Ch. 1, Sec. 5 of referenced rulebook, displacement yacht's pressure acting above the full load waterline is to be taken as defined by equation *4.3.7*, in *4.3.4.5 Registro Italiano Navale (PSPY/PSS).* The supplementary note given about minimum value by RINA, also applies.

4.4.4.6 Conclusion (DSY/PSS)

As the regulations given for the shell structure by all societies refer to both bottom and shell structure, implications given in *4.4.3.6 Conclusion (DSY/PBS)* also apply. However it must be mentioned that unlike bottom structure, BV and DNV-GL do not regulate impact pressure due to slamming that affect the side shell.

4.4.5 Pressures on Decks (DSY/PD: Pressure on Decks)

4.4.5.1 Lloyd's Register (DSY/PD)

LR and *Rules and Regulations for the Classification of Special Service Craft (July 2018)* find application in several type of crafts, including yachts. Also, LR does not give distinct equation on vertical acceleration depending on the type of craft, but rather distinguish them per operating mode and number of hulls. Therefore, formulas on calculating deck design pressure of displacement and sailing yachts shall be obtained from *4.2.5.1 Lloyd's Register (HSC/PD),* as applicable.

Furthermore, it is suggested that in order to estimate deck design pressures of a sailing or a displacement yacht, the formulas referring to crafts operating in displacement mode are to be used.

4.4.5.2 American Bureau of Shipping (DSY/PD)

In *Rules for Building and Classing Yachts (October 2018),* by ABS, design heads of displacement and sailing yacht, that refer to several regions of the craft including decks, are provided. In ABS' document they are located in Pt. 3, Ch. 2 Sec. 2, while in this thesis they already have been presented in Ch. 3, sub-segment *4.4.3.2 American Bureau of Shipping (DSY/PBS),* by *Table 4.4.3 Displacement Yachts – Design Heads, h (ABS)* and *Table 4.4.4 Sailing Yachts – Design Heads, h (ABS)*.

4.4.5.3 Bureau Veritas (DSY/PD)

Directives referring to deck loads, given by BV in *Rules for Yachts (March 2012)* Pt B, Ch 4, Sec 4, are common for all type of yacht and have already been presented on this thesis. Hence, in order to determine deck pressure values, indications given in *4.3.5.3 Bureau Veritas (PSPY/PD)* shall be followed, as applicable.

4.4.5.4 Det Norske Veritas – Germanischer Lloyd (DSY/PD)

DNV-GL, in *Rules for classification: Yachts (October 2016)*, Pt. 3, Ch. 3, Sec. 2, includes regulations, referring to mono-hull and multi-hull sailing yachts, on pressure on weather decks, superstructure decks and accommodation decks, which are to be determined according to equation *4.4.15, 4.4.16* and *4.4.17,* respectively.

$$p_D = 2{,}7 \cdot C_D \cdot \sqrt{\frac{L}{T_H + z_{WL}}} \quad kN/m^2 \qquad (4.4.15)$$

Where,

p_{Dmin} = $6{,}0\ kN/m^2$
z_{WL} = local height, in m, of weather deck above design waterline
c_D = deck longitudinal distribution factor, see *Figure 4.4.10 Deck longitudinal distribution factor* c_D *(DNV-GL)*, c_D is:
= 1.20 for x/L < 0.05
= 1.25 – x/L for 0.05 ≤ x/L < 0.25
= 1.00 for 0.25 ≤ x/L ≤ 0.70
= 2.5 x/L – 0.75 for 0.70 < x/L < 0.90
= 1.50 for x/L ≥ 0.90
T_H = vertical distance, in m, of superstructure deck above design waterline

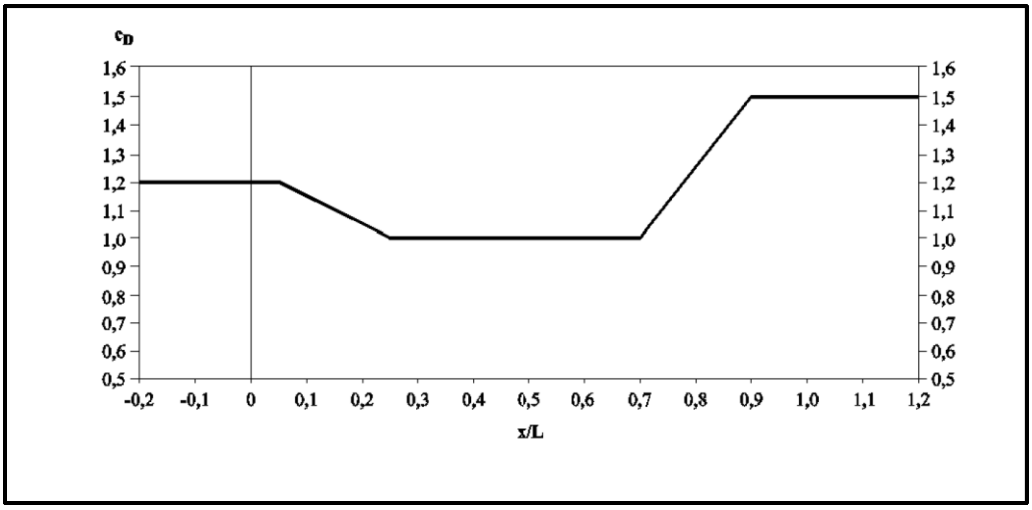


Figure 4.4. 10 Deck longitudinal distribution factor c_D (DNV-GL)

As equation *4.4.16* points out, pressure on superstructure decks is depended directly from weather deck pressure.

$$p_{DA} = p_D \cdot n \quad kN/m^2 \qquad (4.4.16)$$

Where,

p_{DAmin} = $4{,}0\ kN/m^2$
p_D = Pressure on weather decks, in kN/m^2,as defined in equation *4.4.15*
n = $1 - \frac{z-(H-T_H)}{10}$
z = 1.20 for x/L < 0.05
T_H = vertical distance, in m, of superstructure deck above design waterline
H = moulded depth of yacht, in m

$$p_L = p_C \cdot c_D \quad kN/m^2 \tag{4.4.17}$$

p_C = to be defined by the designer in connection with the owner's specification

p_{Cmin} = $3{,}5\ kN/m^2$

c_D = deck longitudinal distribution factor, see *Figure 4.4.10 Deck longitudinal distribution factor* c_D *(DNV-GL)*

For multihull sailing yachts the cross deck design pressures shall be determined according to *4.2.5.4 Det Norske Veritas – Germanischer Lloyd (HSC/PD)* (slamming pressure on flat cross structures), but without the minimum pressure defined therein. Instead, the cross deck design pressures shall not be less than the sea pressures according to equations *4.4.12*, *4.4.13* and *4.4.14*, given in *4.4.3.4 Det Norske Veritas – Germanischer Lloyd (DSY/PBS).*

In addition, while calculating slamming cross deck structures, a_{cg} is to be taken equal to 1,0 g and for cats with very slender forward demi hulls, the k_t (longitudinal distribution factor) shall refer to the longitudinal extent of the cross deck, not that of the vessel i.e. should the cross deck start only 40% L aft of the bow, this location is not considered as 0,6 L, but as 1,0 L.

According to Pt. 3, Ch. 3, Sec. 3, of the referenced document, the deck design pressures for any mono-hull motor yacht that is not a high speed motor yacht, hence including displacement yachts, are to be taken as in segment *4.3.3.4 Det Norske Veritas – Germanischer Lloyd (PSPY/PBS)*.

In relevant segment a methodology presented on calculating sea pressures, , according to DNV-GL, including weather decks, cabin decks and is to be used as applicable, in order to estimate deck design loads. Furthermore minimum values of minimum dynamic pressure is given for each.

In addition, DNV-GL acknowledges that the static and dynamic pressure due to distributed loads are to be defined by the designer, but nevertheless indicates minimum values, as given in equation *4.3.18,* for several deck locations.

p_{Dtat} $\geq$ $3{,}5\ kN/m^2$ in general (4.3.18)

$=$ $8{,}0\ kN/m^2$ for platforms of machinery decks

$=$ $6{,}0\ kN/m^2$ for platforms of mooring decks

$=$ $3{,}5\ kN/m^2$ for accommodation decks

$=$ $3{,}0\ kN/m^2$ for hangar deck

p_{Ddyn} $=$ $a_Z \cdot P_{Dstat}\ \ kN/m^2$ for platforms of machinery decks

Where,

a_z = Vertical acceleration, as defined in *4.4.2.4 Det Norske Veritas – Germanisher Lloyd (DSY/VA)*

4.4.5.5 Registro Italiano Navale (DSY/PD)

While in RINA's *Rules for Yachts Designed for Commercial Use (January 2019)* it is not clearly mentioned and since there are no distinguish requirements on deck loads depended on the type of the yacht, reasonably it should be assumed that deck pressures of displacement or sailing yacht shall be taken according to *4.3.5.5 Registro Italiano Navale (PSPY/PD).*

4.4.5.6 Conclusion (DSY/PD)

LR, BV and RINA requirements are applicable to both displacement and sailing yachts, while ABS and DNV-GL regulate the two craft types separately. Notable in ABS regulations that refer to sailing yachts is the absence of specification acting on superstructure decks.

Similarities do not exist between the classification societies' formulas on deck design pressure. ABS and RINA may both provide design heads for the deck pressure, but ABS calculations are depend and affected by the length of the craft, while RINA gives constant values.

4.4.6 Pressures on Forebody (DSY/PF: Pressure on Forebody)

4.4.6.1 Lloyd's Register (DSY/PF)

LR and *Rules and Regulations for the Classification of Special Service Craft (July 2018)* find application in several type of crafts, including yachts. Also, LR does not give distinct equation on design pressures acting to the forebody of the craft depending on the type of craft, but rather distinguish them per operating mode and number of hulls. Therefore, formulas on calculating design pressures of displacement or sailing yachts shall be obtained from *4.2.6.1 Lloyd's Register (HSC/PF),* as applicable.

Furthermore, it is suggested that in order to estimate pressures acting on the forebody of a sailing or a displacement yacht, the formulas referring to crafts operating in displacement mode are to be used.

4.4.6.2 American Bureau of Shipping (PSPY/PF)

In respect of displacement and sailing yachts, ABS does not underline a specific pressure to be calculated concerning the forebody of the craft. Nevertheless the tables, contained in *Guide for Building and Classing Yachts (October 2018)* Pt. 3, Ch. 2, Sec. 2 and presented on this thesis in *4.4.3.2 American Bureau of Shipping (DSY/PBS),* correspond design heads to various locations of craft, including directives to the forebody.

4.4.6.3 Bureau Veritas (PSPY/PF)

While BV does not set particular requirements on pressure acting at the fore end of the ship, in *Rules for Yachts (March 2012)*, instruction given in *4.4.3.3 Bureau Veritas (DSY/PBS)* and *4.4.4.3 Bureau Veritas (DSY/PSS)* may be used appropriately. As in equations contained in to those two segments there are factors directing the calculation to fore region of the craft.

4.4.6.4 Det Norske Veritas – Germanischer Lloyd (DSY/PF)

In *Rules for Classification: Yachts (October 2016)* Pt. 3, Ch. 3, Sec. 2 DNV-GL provides formula on estimating slamming on forward hull bottom of mono-hull sailing yacht, which has already been presented in *4.4.3.4 Det Norske Veritas – Germanischer Lloyd (DSY/PBS)* and applies also to multi-hull yachts*.* Beyond this, no further comments was made on the matter.

There are no specific indication made by DNV-GL, in *Rules for Classification: Yachts (October 2016),* on calculating pressure acting on the fore end of the hull, nor directives that this region of the craft is affiliated to a more general location. Hence it may be assumed the methodology that refers to bottom pressures, given *4.4.2.4 Det Norske Veritas – Germanischer Lloyd (DSY/PBS)*, should be used appropriately for mono-hull motor yachts.

Furthermore DNV-GL suggests that specifically the forward of 0,5 *L* of the craft, equation *4.4.25,* which is presented in following segment *4.4.7.4 Det Norske Veritas – Germanischer Lloyd (DSY/POC),* shall be considered for the slamming pressure.

4.4.6.5 Registro Italiano Navale (PSPY/PF)

Alike BV, RINA does not give specifications about the region of the fore end of the yachts. Correspondingly, it may be assumed the methodology that refers to bottom pressures, given *4.4.2.5 Registro Italiano Navale (DSY/PBS)*, should be used appropriately.

4.4.6.6 Conclusion (PSPY/PF)

Since the forebody of the craft is not considered by all classification societies as region to be treated specially no conclusions can be drawn.

4.4.7 Pressures on Other Components (DSY/POC: Pressure on Other Components)

4.4.7.1 Lloyd's Register (DSY/POC)

LR and *Rules and Regulations for the Classification of Special Service Craft (July 2018)* find application in several type of crafts, including yachts. Therefore, formulas on calculating design pressures of displacement or sailing yacht shall be obtained from *4.2.7.1 Lloyd's Register (HSC/POC),* as applicable. Design load of deckhouses, superstructures, watertight and deep tank bulkheads, pillars and bulwarks are part of the referenced segment.

4.4.7.2 American Bureau of Shipping (DSY/POC)

In *4.4.3.2 American Bureau of Shipping (DSY/PBS),* design heads for several regions of a displacement yacht were given, see *Table 4.4.3 Displacement Yachts – Design Heads, h (ABS)*, including deep tanks and watertight bulkheads.

Moreover, as stated in *Guide for Building and Classing Yachts (October 2018)* Pt. 3, Ch. 2 Sec. 2*,* design heads for superstructures and deckhouses are to be taken as noted in *4.7.2 American Bureau of Shipping (PSPY/POC)* by equation *4.3.13* and not greater than given in *Table 4.3.12 Maximum Values of h (ABS).*

Similarly, in terms of sailing yachts, design heads was given by ABS in *Guide for Building and Classing Yachts (October 2018)* Pt. 3, Ch. 2 Sec. 2, for design pressure calculation. In

Table 4.4.4 Sailing Yachts – Design Heads, h (ABS) are contained information on bulkheads and on cabin house top, sides, front and end, see *4.4.3.2 American Bureau of Shipping (DSY/PBS).*

No further indication are made by ABS on any other component of the ship, concerning design loads.

4.4.7.3 Bureau Veritas (DSY/POC)

Requirements given in *4.7.3 Bureau Veritas (PSPY/POC)* are referring to all type of yachts and in the case of displacement and sailing yachts shall be followed as applicable.

4.4.7.4 Det Norske Veritas – Germanischer Lloyd (DSY/POC)

In *Rules for classification: Yachts (October 2016)* Pt. 3, Ch. 3, Sec. 2 regulations on design loads acting on superstructures/deckhouses walls, bulkheads and tank structures, that refer to mono-hull sailing yachts and apply also to multi-hull sailings as indicated to Pt. 3, Ch. 3, Sec. 5 of the referenced document are included.

The design loads on superstructure and deckhouse walls are to be taken as *4.4.19, 4.4.20* and *4.4.21,* for front, side and aft walls respectively

$$p_{AFW} = 1{,}5 \cdot p_D \quad kN/m^2 \tag{4.4.19}$$

Where,

p_{AFW} = Design load acting on superstructure ore deckhouse front walls

p_D = Pressure on weather decks, in kN/m^2,as defined in *4.4.5.4 Det Norske Veritas – Germanischer Lloyd (DSY/PD)*

$$p_{ASW} = 1{,}2 \cdot p_D \quad kN/m^2 \tag{4.4.20}$$

Where,

p_{ASW} = Design load acting on superstructure ore deckhouse side walls

p_D = Pressure on weather decks, in kN/m^2,as defined in *4.4.5.4 Det Norske Veritas – Germanischer Lloyd (DSY/PD)*

$$p_{AAW} = 0{,}8 \cdot p_D \quad kN/m^2 \tag{4.4.21}$$

Where,

p_{AAW} = Design load acting on superstructure ore deckhouse aft walls

p_D = Pressure on weather decks, in kN/m^2,as defined in *4.4.5.4 Det Norske Veritas – Germanischer Lloyd (DSY/PD)*

As per bulkheads, DNV-GL not only provides formulas on design pressure acting on collision and watertight bulkhead, see equation *4.4.22* and *4.4.23* respectively, but also suggest that hull and deck lateral design pressures, global shear and torque and local loads shall be taken into consideration as they subject bulkhead to in-plane loading.

$$p_{BH} = 11{,}5 \cdot z_{BH} \quad kN/m^2 \tag{4.4.22}$$

Where,

p_{BH} = Design load acting on collision bulkhead

z_{BH} = vertical distance from the load centre to the top of the bulkhead or to the highest point in the compartment, in m

$$p_{BH} = 10{,}0 \cdot z_{BH} \quad kN/m^2 \tag{4.4.23}$$

Where,

p_{BH} = Design load acting on other watertigh bulkhead

z_{BH} = vertical distance from the load centre to the top of the bulkhead or to the highest point in the compartment, in m

Loads on tank structures of sailing yacht are to be as in following equation *4.4.24.* DNV-GL supplement, without further proof, that a default design pressure of 20 kN/m^2 shall be adopted for tank baffles.

$$p_T = 10{,}0 \cdot z_T \quad kN/m^2 \tag{4.4.24}$$

Where,

z_T = vertical distance from the load centre to the top of the tank overflow, in m, this also needs to be considered in heeled situation

= not to be taken less than 2.0 m.

In the case of mono-hull slow speed motor yachts, requirements on various regions are presented in section 3 of the referenced document, where indications are made on design pressures of tanks, bulkheads and single point loads and wheel loads. In addition special mention is made by DNV-GL on the hydrodynamic pressure on bilge keels.

The hydrodynamic pressure acting on bilge keels is an aspect examined only by DNV-GL, and for ships with length between 50 and 200 metres is to be taken as shown in equation *4.4.25*. DNV-GL adds on the subject that for ships with length lesser than 50 m or greater than 200 the load acting on bilge keels would be under special consideration.

$$p_{BK} = 1{,}85 \cdot \frac{52000 \cdot \rho}{(L + 240)^{1.1}} \quad kN/m^2 \tag{4.4.25}$$

Where,

ρ = Density of seawater, $1{,}025\ t/m^3$

L = rule length, in m, as defined in

The hydrostatic and dynamic pressure acts on tanks is divided into three loads that may applied on this region. Generally, equation *4.4.26* shall be used to determine static and dynamic loads at any point of the tank.

$$\begin{aligned} p_{T1tat} &= \rho \cdot g \cdot h_1 + 100 \cdot \Delta p \ \ kN/m^2 \text{ in upright condition} \\ &= \rho \cdot g \cdot h_1 \cdot \cos\varphi + 100 \cdot \Delta p \ \ kN/m^2 \text{ in heeled condition} \end{aligned} \tag{4.4.26}$$

$$\begin{aligned} p_{T1dyn} &= \rho \cdot g \cdot h_1 \cdot a_z \ \ kN/m^2 \text{ in upright condition} \\ &= \rho \cdot g \cdot (0{,}3 \cdot b + y) \ \ kN/m^2 \text{ in heeled condition} \end{aligned}$$

Where,

ρ = Density of seawater, $1{,}025\ t/m^3$
g = gravity acceleration, $9{,}81\ m/s^2$
h_1 = distance, in m, from load centre to tank top
φ = design heeling angle, in degree, for tanks
= $(f_{BK} \cdot H/B)$ in general
f_{BK} = 0,5 for ships with bilge keel without fins and stabilizers
= 0,6 for ships without bilge keel
H = moulded depth of yacht
B = moulded breadth of yacht
Δp = additional pressure component, in bar, created by overflow systems
a_z = Vertical acceleration, as defined in *4.4.2.4 Det Norske Veritas – Germanisher Lloyd (DSY/VA)*
y = distance, in m, from load centre to the vertical longitudinal central plane of tank
b = upper breadth of tank, in m

In cases where a fuel or a ballast tank is connected with an overflow system, the pressure increases, due to overflowing, and equation *4.4.27* shall be taken into account, which is defined by DNV-GL as maximum design pressure.

$$\begin{aligned} p_{T2tat} &= \rho \cdot g \cdot h_2 + 100 \cdot \Delta p \ \ kN/m^2 \\ p_{T2dyn} &= 0 \end{aligned} \tag{4.4.26}$$

Where,

ρ = Density of seawater, $1{,}025\ t/m^3$
g = gravity acceleration, $9{,}81\ m/s^2$
h_2 = distance, in m, from tank top to top of overflow
= not less than 2,5 m or 10 Δp, respectively
Δp = additional pressure component, in bar, created by overflow systems

The last load refers to filled space of moderate size, of which hydrostatic and hydrodynamic pressure is expressed by equation *4.4.27.*

$$\begin{aligned} p_{T3tat} &= \rho \cdot g \cdot h_3 \ \ kN/m^2 \\ p_{T3dyn} &= \rho \cdot g \cdot h_3 \cdot a_z \ \ kN/m^2 \end{aligned} \tag{4.4.27}$$

Where,

ρ = Density of seawater, $1{,}025\ t/m^3$
g = gravity acceleration, $9{,}81\ m/s^2$
h_3 = distance, in m, from load centre to top of filled space, i.e. top of chain locker pipe etc.
a_z = Vertical acceleration, as defined in *4.4.2.4 Det Norske Veritas – Germanisher Lloyd (DSY/VA)*

Alike ABS, DNV-GL's regulations for watertight bulkheads design pressures are directed to watertight boundaries. Of which pressure, the static and dynamic components are given in equation *4.4.28.*

$$p_{WTtat} = \rho \cdot g \cdot (T_{dam} - z) \ kN/m^2 \quad (4.4.28)$$
$$p_{WTdyn} = \rho \cdot g \ \ kN/m^2$$

Where,

ρ = Density of seawater, $1{,}025 \ t/m^3$
g = gravity acceleration, $9{,}81 \ m/s^2$
T_{dam} = draught, in m, for the extreme damage waterline above base line. For ships without proven damage stability, the height of the bulkhead deck above baseline shall be used.
z = z coordinate along vertical axis, in m

Lastly, another aspect of the matter investigated only by DNV-GL refer to single points loads, such as wheels or, in cases where a craft is designed to carry one, loads of helicopter.

According to DNV-GL, the wheel load are distributed over the contact area f, wheel print area, which in In case of narrowly spaced wheels these may be grouped together to one wheel print area and is defined below.

f = $F_{Estat}/(100 \cdot p)$ for vehicle in general
= $0{,}3 \cdot 0{,}3 m^2$ for wheel or skids of helicopter
p = specific tyre pressure, in bar..

The method of estimating static and dynamic forces, generated by the presence of vehicles or a helicopter are described as follows:

F_{Estat} = $g \cdot W/n \ \ kN$ for vehicle in general
= $0{,}5 \cdot g \cdot MTOW \ \ kN$ for wheels or skids of helicopter acting simultaneously with p=2.0 kN/m^2 evenly distributed over the entire landing deck (for taking snow or etc. into account)
W = axle load of a vehicle in t
n = number of wheels or twin wheels per axle
$MTOW$ = maximum take-off weight, in t, of the helicopter, including deadweight, crew, fuel, cargo, etc.
F_{Edyn} = $a_Z \cdot F_{Estat} \ kN$
F_{Imp} = $1{,}5 \cdot F_{Estat} \ kN$ at two point simultaneously
a_z = Vertical acceleration, as defined in *4.4.2.4 Det Norske Veritas – Germanisher Lloyd (DSY/VA)*
p = $0{,}5 \ \ kN/m^2$ (evenly distributed over the entire landing deck)
$dead\ load$= $0{,}3 \cdot 0{,}3 m^2$ for wheel or skids of helicopter
$wind\ loading$= If unknown, $v_W = 25 \ m/s$ shall be used
a_z = Vertical acceleration, as defined in *4.4.2.4 Det Norske Veritas – Germanisher Lloyd (DSY/VA)*

Emergency/crash landing

F_{Imp} = $2{,}5 \cdot F_{Estat} \ kN$ at two point simultaneously

4.4.7.5 Registro Italiano Navale (DSY/POC)

Alike BV, RINA requirements about pressures on various components apply to all type of yachts, as recommended by *Rules for Yachts Designed for Commercial Use (January 2019)*. Such regulations have already been presented in *4.3.7.5 Registro Italiano Navale (DSY/POC)*, and shall be used appropriately in respect of displacement and sailing yachts.

4.4.7.6 Conclusion (DSY/POC)

The classification societies achieve to include the most crucial components of the crafts, such as superstructures, bulkheads and tanks. Particular is the insertion made by DNV-GL, who alike ABS on high-speed crafts, set requirements for the carriage of a helicopter by a displacement yacht and the design pressure that are going to occur.

Furthermore it should be mentioned that all the societies propose design heads for calculating pressure acted by those components. Only exception to this concerns pressures of deckhouses and superstructures given by LR and DNV-GL (DNV-GL's sailing yacht requirements), which are to be taken, according to both, as a function of deck pressure.

5 Conclusions

- With regards to metallic materials DNV-GL rules and regulations seem to be the most informative among the societies and in many a case like high strength steels, the ones to certify only the best quality products. Besides classifying the quality of common metallic materials, DNV-GL also has the biggest grade variety in low temperature service steels and aluminium alloys. Moving on, indications of LR are explicit, especially factoring in that their testing procedures are quite thorough. In addition, DNV-GL alongside BV, classifies the stronger low temperature service steel. ABS also include a large variety of aluminium alloy grades and in some cases, they are flexible in classifying a product of lower quality.
- LR, RINA and DNV-GL provide important information on the mechanical properties of the composite materials, but the ability of DNV-GL to introduce sufficiency requirements for fibre reinforcements and to include fire retardant resins, which are widely used in recent years, in their evaluation, distinguish them from the other societies. It should be mentioned that BV rules could be employed for immediate calculating purposes, since they provide minimum characteristic values for composite constituents and in addition, methods to calculate the ones concerning the whole laminate.
- In terms of ship components included and the expected design loads acting on them, there doesn't seem to be any notable omission by any of the societies and the most significant parameters are shared in their respective equations. Differences may occur due to different safety factors assumed by each society, which are better disambiguated in the application example.
- DNV-GL uses the highest safety factor in their equation for vertical acceleration, which is fixed, while for the rest of the societies it depends strongly on the trim angle. An interesting study would be to examine which society gives higher vertical acceleration with respect to the trim and its maximum allowed values.
- Overall ABS indications are systematically the highest, while the indications of the rest don't follow a particular order in every category. For example, LR predictions for the load acting on the side shell are the second highest, while this place hold BV predictions in terms of deck design pressures.
- The sole category in which ABS featured values are not the highest is that of bottom design pressures. Specifically, ABS postulations concerning bottom design pressures surpass everyone else's at positions $0{,}5L$ and $0{,}75L$, but LR and DNV-GL regulations indicate higher bottom design pressure at $0{,}25L$. The reason for ABS predicted values being lower at 0,25L lies with the longitudinal distribution factors that each society postulates for each longitudinal position
- Generally, it can be inferred that exactly which society comes up with the highest estimations for bottom pressure, is dependent on the longitudinal position under examination. Ascertaining the mechanism that gives rise to this exception could be the object of a more extensive study.
- As far as side design pressures are concerned, there appears to be a systematic underestimation on the part of DNV–GL, which postulates the lowest values comparing

to the rest of the societies. Notably, the discrepancy between DNV – GL and ABS is the widest one, with DNV – GL suggesting a value that is by 50% lower than the one of the latter.

- It is noteworthy that LR is the only classification society who clearly states that the side plating shall be arranged similarly to the bottom plating, reckoning that the pressure acting on the side shell is equal to the pressure acting on the bottom. Subsequently, this assumption renders the side pressure values assessed by LR, higher than these of the rest of the societies by 50%. So overall, it is established that LR sets the most conservative requirements. As a caveat it should be mentioned that If the requirements of *4.2.8 Local design criteria by Lloyd's Register* were ignored, the side design pressure requirements of LR would indeed be similar to those of ABS.
- When it comes to deck design pressure, again DNV – GL, as with the side shell design pressure application example, comes up with the lowest values. Here, most societies don't include distinctive stipulations with respect to longitudinal position and as a result the same trend prevails for 0,25L, 0,50L and 0,75L. ABS's estimations are significantly higher throughout, with the exception of 0,75L where they are comparable to those made by BV and RINA. ABS equation on deck design pressure appears to be minimalistic, as it contains only the ship's length as a parameter, but nonetheless it results to the highest design pressure values.

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