REPUBLIC OF TÜRKİYE

YILDIZ TECHNICAL UNIVERSITY

GRADUATE SCHOOL OF SCIENCE AND ENGINEERING

INVESTIGATION OF THE STABILITY OF THE SURFACED AND SUBMERGED BB2 JOUBERT SUBMARINE ACCORDING TO DNV RULES

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MASTER OF SCIENCE THESIS

Department of Naval Architecture and Marine Engineering

Naval Architecture and Marine Engineering Program

Supervisor

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July, 2023

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A thesis submitted by Serdar EKEN in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE is approved by the committee on 20/07/2023 in Department of Naval Architecture and Marine Engineering, Naval Architecture and Marine Engineering Program.

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Serdar EKEN

Signature

ACKNOWLEDGEMENTS

I would like to thank my supervisor Asst. Prof. Yasemin ARIKAN ÖZDEN for her support, patience, motivation, and enthusiasm. Her guidance helped me in all the time of the study and writing of this thesis.

Serdar EKEN

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LIST OF SYMBOLS

AP	Aft Perpendicular
B	Buoyancy
Δ	Displacement (ton)
T	Draft (m)
FP	Fore Perpendicular
FSC	Free Surface Correction (m)
L_{DWL}	Length of Design Waterline (m)
LCB	Longitudinal Centre of Buoyancy (m)
LCF	Longitudinal Centre of Flotation (m)
LCG	Longitudinal Centre of Gravity (m)
KM_L	Longitudinal Metacentric Height (m)
BMl	Longitudinal Metacentric Radius (m)
GM	Metacentric Height (m)
MTC	Moment Change Trim One Centimeter (ton.m/cm)
h_{rem}	Remaining Righting Lever (Righting Lever - Sum of Heeling Levers) (m)
SG	Specific Gravity (t/m^3)
TPC	Tonnes per Centimetre Immersion (ton/cm)
TCB	Transverse Centre of Buoyancy (m)
TCF	Transverse Centre of Flotation (m)
TCG	Transverse Centre of Gravity (m): port [-], starboard [+]
KM_T	Transverse Metacentric Height (m)
BMt	Transverse Metacentric Radius (m)
KB	Vertical Centre of Buoyancy (m)
VCB	Vertical Centre of Buoyancy (m)
KGf	Vertical Centre of Gravity (Free Surface Effect Included) (m)
KG	Vertical Centre of Gravity (m)
VCG	Vertical Centre of Gravity (m)
BG, B↓G	Vertical Distance between the Center of Buoyancy and the Center of Gravity of the Submerged Submarine (m)
WPA	Waterplane Area (m^2)
W	Weight
WSA	Wetted Surface Area (m^2)

LIST OF ABBREVIATIONS

ATT	After Trim Tank
DNV	Det Norske Veritas
FF	Free Flooding Areas
FTT	Forward Trim Tank
MBT	Main Ballast Tank

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ABSTRACT

Investigation of the Stability of the Surfaced and Submerged BB2 Joubert Submarine According to DNV Rules

Serdar EKEN

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Naval Architecture and Marine Engineering Program

Master of Science Thesis

Supervisor: Asst. Prof. Yasemin ARIKAN ÖZDEN

In this study, the variation of the GM (Metacentric Height) and BG (Vertical Distance between the Center of Buoyancy and the Center of Gravity of the Submerged Submarine) values for submarines of different displacement is investigated using a generic submarine geometry. For this the intact and damaged stability characteristics of the generic submarine BB2 Joubert are carried out in surfaced and submerged conditions. The BB2 Joubert submarine geometry is a generic submarine model geometry which is extensively used in submarine hydrodynamic studies. In the literature there are various experimental and computational studies on manoeuvring, resistance, and propulsion where generic submarine geometries are used. However submarine stability studies are very limited in the open literature and there is no examples for the application of submarine intact and damaged stability rules on a submarine. So, the aim of this study is to generate a sample tank arrangement plan for a generic submarine and to conduct the stability analysis according to the DNV Submarine Rules. The original BB2 Joubert submarine is 70.13 m. long and has a depth of 10.6 m. in full scale. In the open literature a simple general arrangement plan is proposed for the submarine. At the beginning of the study the pressure hull design, tank arrangement and tank capacities are determined according to

the suggested general arrangement plan of the full scale submarine. Weight estimation is made according to the submerged condition of the submarine to reach the neutral stability condition. The main ballast tank capacities are designed so that the %10 reserve buoyancy limit is reached. The vertical center of gravity is determined in the submerged condition as a limit of the vertical centre of gravity (KG) value. The stability analysis is made according to the Stability Rules of DNV (Det Norske Veritas) for Submarines Edition January 2018 with the use of a commercial stability software AVEVA Marine. Eight different loading conditions are investigated in the intact and damaged stability analysis for one water density. Four loading conditions are defined for the surfaced condition and four loading conditions are defined for the submerged condition. The righting lever and heeling levers due to free liquid surface, turning circle and wind are defined and the required remaining righting levers are examined. After the examination of the full scale submarine three other submarine geometries are created, namely 30 m., 48 m. and 100 m. Stability analysis for the other scaled geometries are conducted in the same methodology as for the full scale submarine for the same tank arrangements. Since DNV rules suggest different GM and BG values for submarines of different displacement, a formula to calculate the KG value in dependence of the submarine displacement is suggested for the use in the early design phase of a submarine.

Keywords: BB2 Joubert Submarine, Submarine Stability, Submarine Tank Arrangement, Submarine Intact Stability, Submarine Damaged Stability.

ÖZET

BB2 Joubert Denizaltısının Satıhta ve Dalmış Durumda Stabilitesinin DNV Kurallarına Göre İncelenmesi

Serdar EKEN

Gemi İnşaatı ve Gemi Makineleri Mühendisliği Anabilim Dalı

Yüksek Lisans Tezi

Danışman: Dr. Öğr. Üyesi Yasemin Arıkan Özden

Bu çalışmada, farklı deplasmanlara sahip denizaltılar için GM (Metasentrik Yükseklik) ve BG (Dalmış Durumdaki Denizaltının Sephiye Merkezi ile Ağırlık Merkezi Arasındaki Düşey Mesafe) değerlerinin değişimi jenerik bir denizaltı geometrisi kullanılarak incelenmiştir. Bu amaçla jenerik denizaltı BB2 Joubert'in hasarsız ve hasarlı stabilite karakteristikleri satıhta ve dalmış durumda incelenmiştir. BB2 Joubert denizaltı geometrisi, hidrodinamik çalışmalarda yaygın olarak kullanılan jenerik bir denizaltı modeli geometrisidir. Literatürde, jenerik denizaltı geometrilerinin kullanıldığı manevra, direnç ve sevk ile ilgili çeşitli deneysel ve hesaplamalı çalışmalar bulunmaktadır. Bununla birlikte, açık literatürde denizaltı stabilitesi üzerine çalışmalar oldukça sınırlıdır, hasarsız ve hasarlı denizaltı stabilite kurallarının bir denizaltı üzerinde uygulanmasına ilişkin herhangi bir örnek yoktur. Bu çalışmanın amacı, jenerik bir denizaltı için örnek bir tank planı oluşturmak ve DNV Denizaltı Kurallarına göre stabilite analizlerini gerçekleştirmektir. Orijinal BB2 Joubert denizaltısı 70.13 m uzunluğa ve 10.6 m derinliğe sahiptir. Açık literatürde, denizaltı için basit bir genel yerleşim planı önerilmiştir. Önerilen genel yerleşim planına göre mukavim tekne tasarımı, tank planı ve tank kapasiteleri çalışmanın başında belirlenmiştir. Dalmış durumdaki denizaltı nötr stabilite durumuna sahip olacak şekilde ağırlık çalışmaları yapılmıştır. Denizaltının su üstü

durumda sahip olması gereken %10 yedek sephiye gerekliliği dikkate alınarak ana dalma sarnıçları dizayn edilmiştir. Denizaltının, su altı durumunda stabilite kriterlerini sağlayacak şekilde sahip olabileceği maksimum düşey ağırlık merkezi kritik KG değeri olarak belirlenmiştir. Stabilite analizleri, DNV'nin (Det Norske Veritas) Ocak 2018 Denizaltı Kurallarına göre ticari bir yazılım olan Aveva Marine kullanılarak gerçekleştirilmiştir. Belirlenen su yoğunluğunda, hasarsız ve hasarlı stabilite kapsamında sekiz farklı yükleme durumu incelenmiştir. Bu yüklemelerden dört tanesi satıh durumunda incelerken diğer dört tanesi de dalmış durumda incelenmiştir. Doğrultucu kol ile serbest yüzey etkisi, dönüş dairesi ve rüzgar basıncı nedeniyle oluşan meyil ettirici kollar tanımlanmış ve stabilite açısından yeterli artık doğrultucu kol değerleri hesaplanarak incelenmiştir. Tam ölçekli denizaltı incelemelerinden sonra 30 m., 48 m. ve 100 m. olmak üzere üç farklı denizaltı geometrisi daha oluşturulmuştur. Oluşturulan ölçekli geometriler için stabilite analizleri, tam ölçekli denizaltı ile aynı tank yerleşimi ve metodolojiler kullanılarak gerçekleştirilmiştir. DNV kuralları, farklı deplasmana sahip denizaltılar için farklı GM ve BG değerleri önerdiğinden, bir denizaltının erken tasarım aşamasında kullanılmak üzere deplasmanına bağlı KG değerinin hesaplanacağı bir formül önerilmiştir.

Anahtar Kelimeler: BB2 Joubert Denizaltısı, Denizaltı Stabilitesi, Denizaltı Tank Yerleşimi, Denizaltı Hasarsız Stabilitesi, Denizaltı Hasarlı Stabilitesi

1 INTRODUCTION

Submarines are one of the most significant parts of navies with their advanced weapon electronic systems. Considerable steps have been taken in recent years to build a national submarine in our country. Submarines differ from surface ships in terms of stability as they must have adequate stability in both surfaced and submerged conditions. The resources in the open literature in the field of submarine stability are quite limited. With this study it is aimed to contribute to the literature in the field of submarine intact and damaged stability.

Within the scope of this study, a tank plan has been created for the generic submarine model BB2 Joubert and tank capacities have been determined. Weight calculations have been made and both intact and damaged stability analyzes have been performed in accordance with the DNV (Det Norske Veritas) Rules. To assess the applicability of the rules for submarines with different displacement, the BB2 Joubert submarine form has been scaled and three additional submarine models with different lengths have been created. Subsequently, stability analyzes, and evaluations have been conducted for these submarines too and a KG value which can be used in the early design stage of a submarine is suggested.

1.1 Literature Review

The number of studies in the open literature on submarine stability are very limited. Most of the studies are concentrated on the roll behavior of submarines. Some of the studies in the open literature are as follows. Hedberg [1] carried out in her thesis the roll motion simulation of a submarine. She used the Australian Collins Class submarine as a reference submarine in the study. Two methods were used namely; the linear analytical method in the frequency domain and the nonlinear numerical method in the time domain for evaluating how different sea states, adding appendages and varying the transverse metacenter height would affect the roll angle of the referenced submarine.

Thornhill and Hermanski [2] performed 2D CFD simulations and physical model tests of a surfaced submarine section in order to determine the effects of the roll motion of a closed and free flooding casing. They concluded that the casing opening size has a

significant impact on roll damping and that the under-casing obstructions have only a minor effect. They reported that the centre of gravity has a high impact on the roll behaviour of the submarine. Liu et al. [3] investigated in their study the influence of the stability parameter on an autonomous underwater vehicle (AUV) used for seafloor mapping. They reported that the relative position between the center of gravity and the center of buoyancy have considerable influence on the motion performance. They noted that their research could be a reference on overall design, internal layout planning, trimming and motion performance of vehicles. They verified the calculation parameters on seafloor mapping AUV developed by Tianjin University. Vogels [4] studied on the examination of roll damping of a surfaced submarine in his master thesis. He used six different rudder configurations to compare over a range of roll amplitudes, roll frequencies and forward speeds. He compared them by using a mathematical model which enables to calculate the lift and drag forces generated by rudders using thin airfoil theory. He carried out a set of tests on the 1:24 scaled model submarine in the towing tank of Delft University of Technology to validate the mathematical model. He reported that the results obtained from the tests showed that the mathematical model could be used to predict the qualitative trends in the roll damping of surfaced submarines. He explained that the trend was similar for every combination of roll amplitude, roll frequency and forward speed that was studied. The large X-rudders with bowplanes generate the most roll damping and thus he evaluated that adding bowplanes to a given aft rudder configuration always increases the roll damping. Yan et al. [5] carried out experimentally the roll stability of a blunt-nosed submarine in their study. They presented and explained the physical model design, similarity criteria and experimental procedures to simulate the behavior of a real submarine with similar properties. They modelled the roll stability kinematically and used the Froude number (Fr) and Strouhal number (St) as basis for establishing the similar relationship between the model ship and full-scale ship. It has been observed that when the drift angle is greater than 5 degrees, an excessive roll angle occurs. Scott [6] studied the longitudinal stability of surfaced submarines in his thesis. He developed a methodology and proposed a standard to ensure a surfaced submarine to satisfy the adequate longitudinal stability characteristics. He used U.S. Navy surface warship design criteria to determine the restrictions in damage scenarios. The suggested standards for the longitudinal stability required the submarine to be able to avoid excessive trim angles under five scenarios. These are: intact, routine maintenance, head on collision damage, glancing collision damage to the bow, and glancing collision

damage to the stern. He developed an Excel VBA program, Submarine Longitudinal Stability Analysis Program (SuLSA) as part of the thesis to specifically analyze submarine designs using the proposed methodology and standard. Cansız & Yıldız [7] obtained a mathematical model to predict the roll decay motion of a surfaced submarine. They used CFD to get the roll damping term. They calculated empirically the inertia and restoring terms. They calculated the roll decay motion at 0, 5, 7.5, 10 knot forward speeds with a 20 degrees initial roll angle and they stated that they got good results in comparison with numerical results.

In the study of Frühling et al [8] they mention that the stability rules of submarines of the German Navy use deterministic specifications. These specifications form also the basis of the regulations of DNV rules. And these rules mainly concentrate on the required minimum initial metacentric height. In their study they mention that the applicability of the basic assumptions to submarines was never verified. Instead, the assumptions and corresponding limiting values were adopted from existing stability regulations for ships without physical justification and transferred to submarines without adaptation. Their study aims to present a relation of the surface stability of submarines and the seakeeping behavior. They carried out a series of outdoor seakeeping model tests for the purpose of support the development of regulations regarding surface stability of submarines. They conducted the trails on the Bay of Eckernförde with two free running, remotely controlled submarine models. They provided insights into the objectives and implementation of these model tests, including first qualitative results.

1.2 Objective of the Thesis

Studies on the stability of submarines are very limited. In this study, it is aimed to contribute to the literature by making intact and damaged stability examinations and evaluations for the BB2 Joubert submarine, which is a widely used generic submarine model in scientific studies, especially in the field of ship hydrodynamics. In the open literature there is no example of the application of the intact and damaged stability rules for submarines. As mentioned in the study of Frühling et al. [8] submarine rules were adopted from rules of surface ships. So, the applicability and understanding of the rules are very important in the stage where the Turkish Navy is also working to design and construct indigenous submarines.

In this thesis a case study with the use of a generic submarine form is created. A tank arrangement plan and pressure hull design were conducted. The intact and damaged stability rules of DNV were applied on this submarine. After submarines of different displacement were scaled according to this design. The scaled submarines were investigated according to the DNV Submarine Stability rules and the changes of the required GM and BG according to displacement were shown.

1.3 Hypothesis

Within the framework of this study, intact and damaged stability analyzes, and evaluations will be made according to the DNV Submarine Rules for a generic submarine; BB2 Joubert. Subsequently, scaled geometries of the same submarine are created and the applicability of the rules have been compared across submarines of varying sizes. It is aimed to gain an inside into the applicability of intact and damaged submarine stability rules in surfaced and submerged conditions.

2
SUBMARINE STABILTY

2.1 First Principles of Flotation

The submarine has to be designed to float in the water where its weight is supported by the buoyancy forces [9].

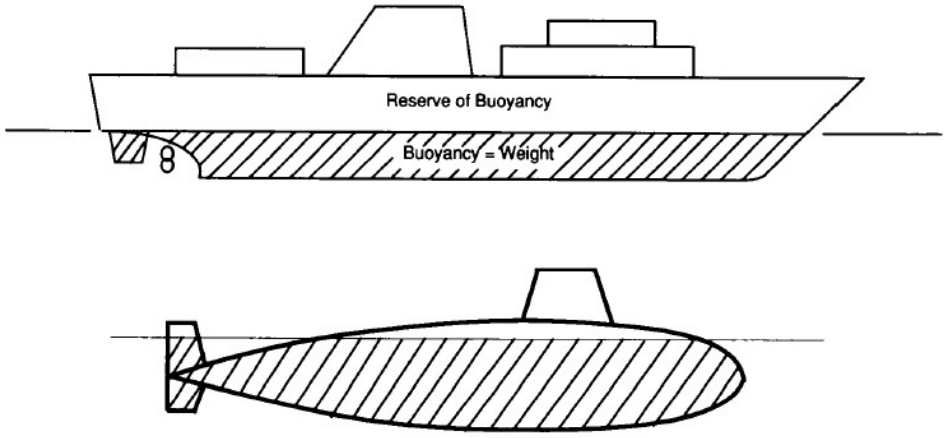

Figure 2.1 Surfaced Ship and Surface Submarine [9]

The reserve of buoyancy refers to the volume of the submarine situated above the waterline (Figure 2.2) . It serves two essential functions. Firstly, it ensures the submarine's safe floating capability in the surfaced condition following damage. Secondly, it directly influences the quantity of seawater needed to be taken into the main ballast tanks for submersion. According to the DNV (Det Norske Veritas) Rules, a minimum buoyancy reserve of 10% of the pressure tight volumes is mandatory [13].

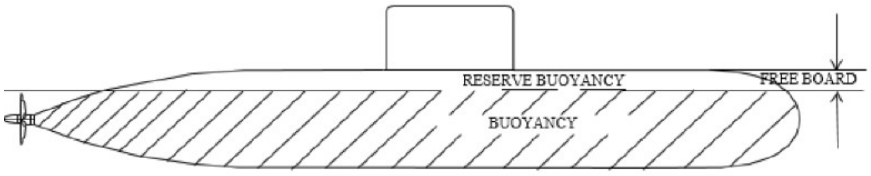

Figure 2.2 Reserve Buoyancy [10]

Surfaced submarine has similar hydrostatic principles to a surface ship. In the submerged condition, the center of buoyancy and the metacentre coincide at a single point, unlike in the surfaced condition. Consequently, the definition of GM for the surfaced submarine transforms into BG when the submarine is submerged. [9], [15].

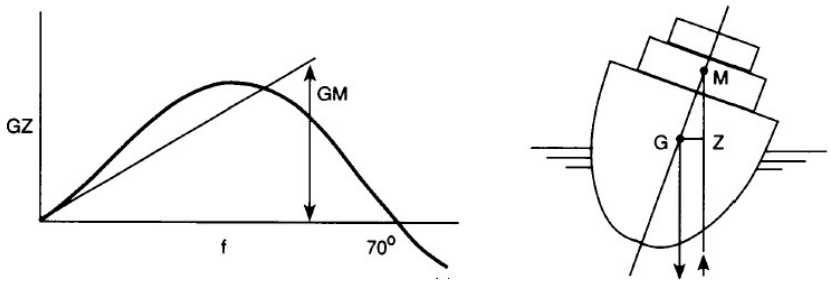

Figure 2.3 Heeled Stability Curve for Surfaced Condition [9]

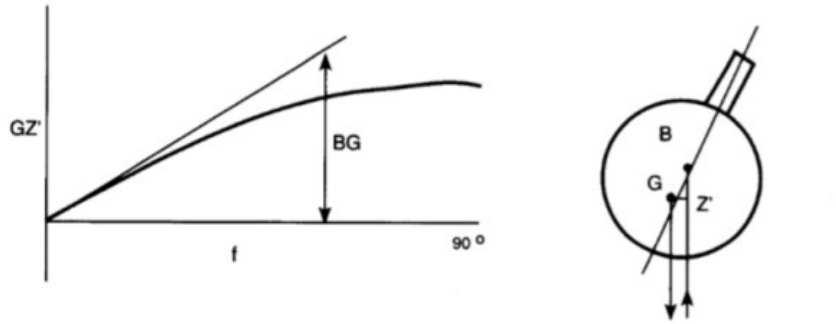

Figure 2.4 Heeled Stability Curve for Submerged Condition [9]

In this context, when the submerged submarine experiences any inclination, the position of the center of gravity becomes crucial. If the center of gravity is situated above the center of buoyancy, a heeling moment arises, whereas if it is positioned below, a righting moment is generated. Therefore, to ensure stability when the submarine is submerged, it is essential for the center of gravity to be located below the center of buoyancy [9], [15].

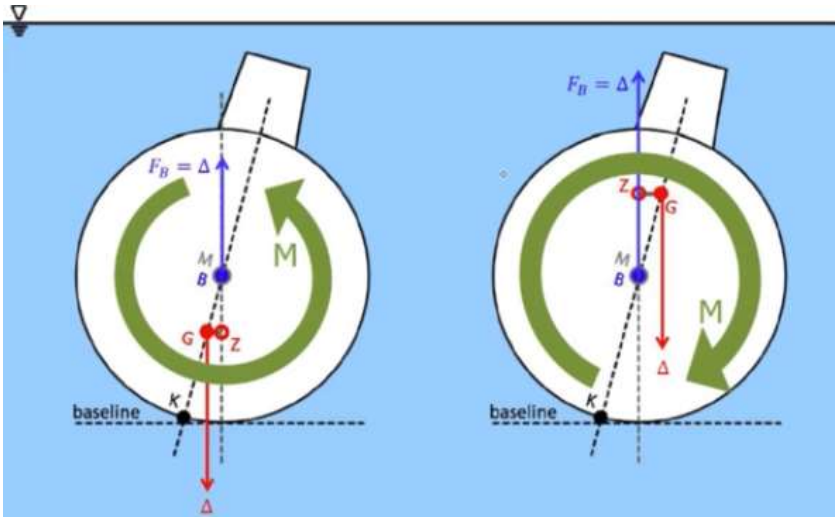

Figure 2.5 Position of the Center of Gravity of the Submerged Submarine

2.2 Surfaced and Submerged Submarine

While the primary focus in submarine design is to achieve the best submerged performance, the design must also ensure a safe surface cruising condition too [9].

In order to avoid the risk of accidental flooding in the surfaced condition, submarines must have sufficient freeboard between the pressure hull hatches and the waterline. [9].

During the transition from surfaced condition to submerged condition, the weight of the submarine must be increased, or buoyancy must be reduced. Conversely, from submerged condition to surfaced condition, submarine weight must be reduced, or buoyancy must be increased [9], [10], [11].

The necessary increase in weight to submerge the submarine is achieved by filling the main ballast tanks with sea water [9], [10], [11].

Other areas on the outer shell are called free-flooding areas. They can be fully or partially filled and they do not contribute to buoyancy [9], [10], [11].

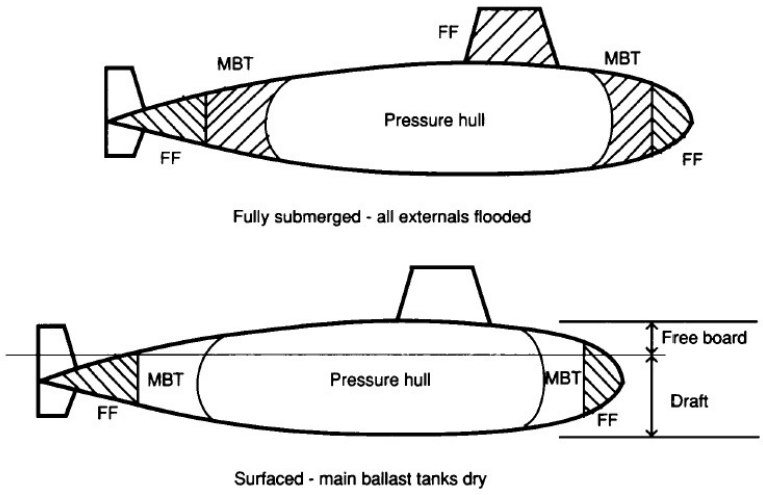

Figure 2.6 Flooded Parts of Surfaced and Submerged Submarine [9]

The hydrostatic characteristics of submarines are sensitive to both buoyancy and weight changes. When the weight is greater than the buoyancy, this condition is defined as negative buoyancy (Figure 2.7). Submarine will continue to drop unless reduce in weight or increase in buoyancy. Conversely, when the buoyancy is greater than the weight, this is called positive buoyancy (Figure 2.8). Submarine will rise above water unless increase in weight or reduce in buoyancy. The equilibrium state is achieved when the buoyancy and the weight are equal, and this condition is referred as neutral buoyancy (Figure 2.9). Alterations in buoyancy are primarily influenced by changes in seawater density, while the changes in weight occur from the factors such as fuel, tanks or weapons [9].

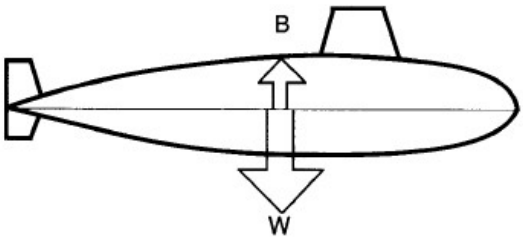

Figure 2.7 Negative Buoyancy [9]

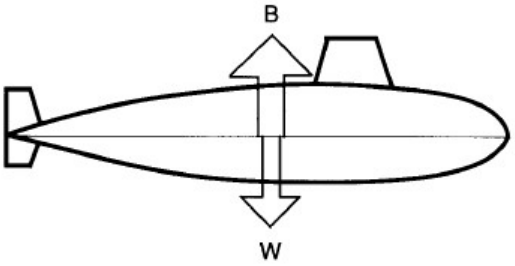

Figure 2.8 Positive Buoyancy [9]

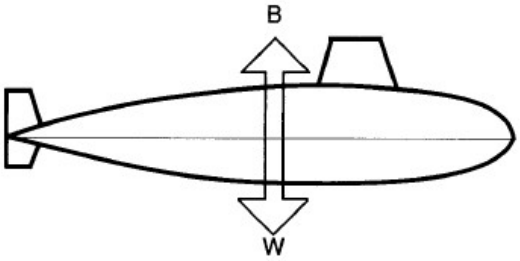

Figure 2.9 Neutral Buoyancy [9]

2.3 Buoyancy and Weight Elements

The major element that provides buoyancy to the submarine is the pressure hull. Additionally, external tanks, fore and aft ends, superstructure casing, bridge fin and control surfaces serve as significant contributing factors [9].

Buoyancy also depends on the density of the displaced water. The density of sea water varies according to the places where the submarine is cruising. The specific gravity of sea water varies between 1.00 and 1.03 depending on the location [9].

Another effect that occurs in submarines equipped with diesel fuel tanks is changes in weight or buoyancy. As the fuel in the tank is consumed, seawater can be taken into the tank. This can balance the net force on the submarine [9].

It is important to keep buoyancy and weight in balance in submarines. For designers, determining the weight of the submarine is more difficult than determining the buoyancy force. While buoyancy is related to surface geometry and seawater density, weight elements are the sum of all components entering the submarine. Large components of the fixed weight can be evaluated relatively easily. They are the pressure hull structure, main propulsion plant, batteries, and stowed weapons. The evaluation of the weight of all the minor structures, systems, and equipments to be installed is difficult. Other items of weight elements are variable weights associated with crew, their effects, stores, and the fluid contents of many tanks [9].

2.4 Diving

The submarine has two floating states, surfaced and submerged. The submarine's transition from the surfaced state to the submerged is accomplished by taking sea water into the main ballast tanks. Regarding the intake of seawater into the main ballast tanks, there exist two different interpretations. The first interpretation is that the intake of sea water results in an increase in weight. In the second interpretation, the main ballast tank is considered as a part of the sea and weight gain does not occur. Consequently, in this scenario, the weight of the submarine remains equal in both the surfaced and submerged states [12].

2.5 Arrangements of Tanks

There is a sample tank arrangement for a submarine given in the figure 2.10.

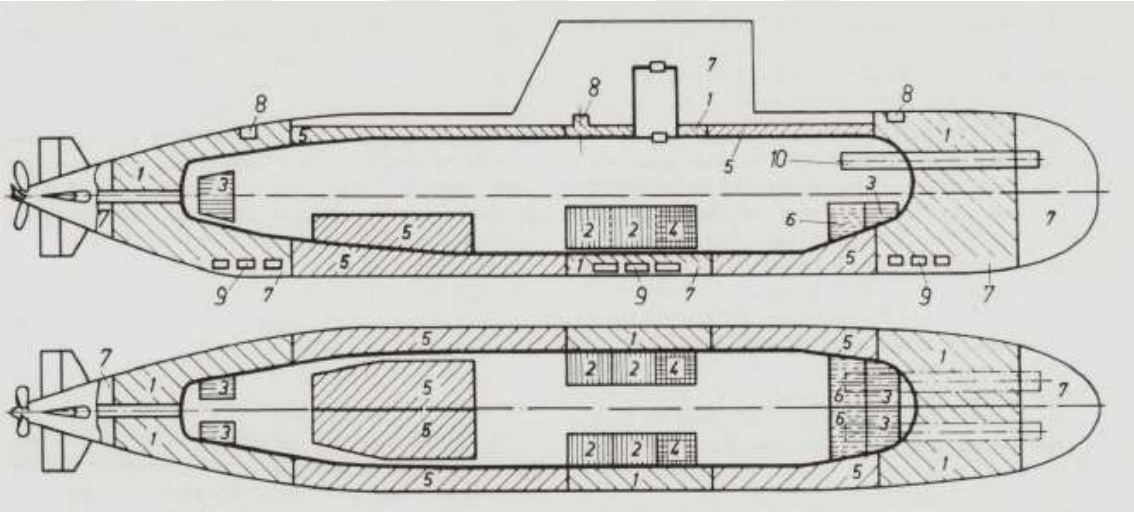

Figure 2.10 Sample Tank Arrangement for a Submarine [12]

1) Main ballast tank
2) Compensating tank
3) Trim tank
4) Negative tank
5) Fuel tank
6) Torpedo tank
7) Free-flooding area
8) Ballast tank vent
9) Flood slit for ballast tank.

2.5.1 Main Ballast Tank

When the main ballast tanks are empty, they will provide the necessary buoyancy to the submarine for surface cruising. In the submerged condition, they are filled with sea water. When submarine is submerged, the main ballast tanks are not included in the pressure-resisting displacement, as they will be in connection with the sea [12].

Sea water inlet to the main ballast tanks is provided from the flood slit. The main ballast tanks have a flood slit as deep as possible. Main ballast tank vents are located above in the main ballast tanks as much as possible. During the dive of the submarine, the air inside the main ballast tanks is discharged from these vents. Once the diving operation ends, the vents are closed again. During the resurfacing phase, when the submarine transitions from the submerged state to the surface state, seawater is given to the sea from the main ballast tanks by means of compressed air [12].

The positioning of the main ballast tanks is made by evaluating the pressure hull and the outer shell volume. Various pressure hull types are given below.

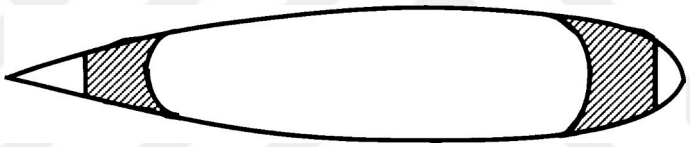

Figure 2.11 Exposed Pressure Hull Shaped to Form [9]

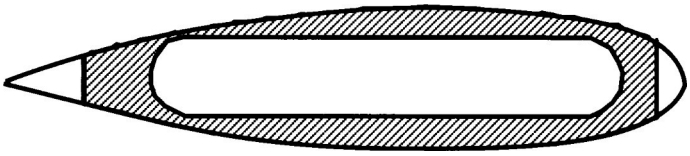

Figure 2.12 Enclosed Cylindrical Pressure Hull [9]

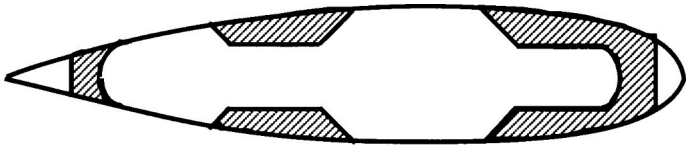

Figure 2.13 Waisted Pressure Hull Partially Exposed [9]

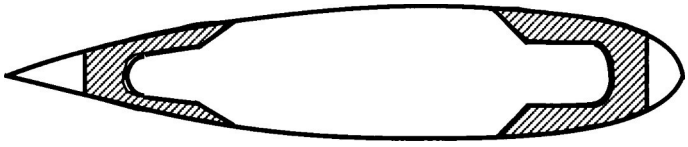

Figure 2.14 Exposed Pressure Hull Reduced at Ends [9]

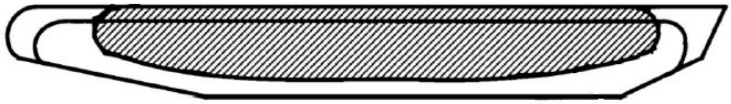

Figure 2.15 Canted Cone Pressure Hull [9]

The entire volume between the pressure hull and the outer hull may not be used for the arrangement of the tanks. Some of them are filled with equipment such as sonars, torpedo tubes, hydroplane and rudder gear, anchor, etc. Also, some of them may not be used. These parts are called free flood areas [9].

The longitudinal placement of the main ballast tanks is another significant design consideration. The center of the main ballast tanks will be required to be closely aligning with the longitudinal buoyancy center of the submerged submarine. If the main ballast tanks are located only in the fore and aft spaces, large trim angles could occur when there are alterations in the filling level of the tanks. Consequently, in order to mitigate such undesired trim effects, it is advisable to incorporate additional main ballast tanks near the central region, whenever feasible and appropriate [9].

2.5.2 Compensating Tank

Compensating tanks are used to control the weight of the submarine. It is crucial that these tanks are positioned as closely as feasible to the amidship, primarily to prevent the occurrence of undesirable trim angles during the process of filling or emptying. They are located inside the pressure hull and they are filled with seawater [12].

Compensating tanks are commonly used in weight-buoyancy equilibrium operations due to changes of seawater density. Additionally, they play a vital role in balancing the weight of the submarine in the consumption of substances such as provisions, fresh water, fuel, lubricating oil, etc [12].

2.5.3 Trim Tank

Trim tanks serve the vital purpose of stabilizing the trim angles while they are simultaneously reducing the center of gravity. To optimize their effectiveness, they are positioned in the forward and aft regions as close as possible to create high moments. The filling level of the tanks during the seaway conditions is always half of the overall trim tanks capacity. Moreover, it is also possible to combine the functions of the compensating tanks and trim tanks [12].

2.5.4 Trim and Compensating Tanks

The arrangement of trim and compensating tanks can be illustrated by considering the following exemplary systems.

2 - Tank system with only bow and stern trim tanks (Figure 2.16),

3 - Tank system is the system in which there is a compensating tank in the middle of the submarine in addition to the bow and stern trim tanks (Figure 2.17). Sea water intake is done through the compensating tank and transfer is carried out between the tanks. Trim tanks allow the adjustment of the longitudinal balance [9].

If there is not enough space for a single, large and central compensating tank, the system in which a central compensating tank and other small tanks are placed is a multiple tank system (Figure 2.18) [9].

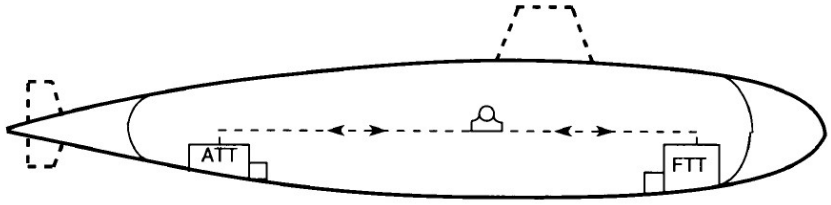

Figure 2.16 2 – Tank System [9]

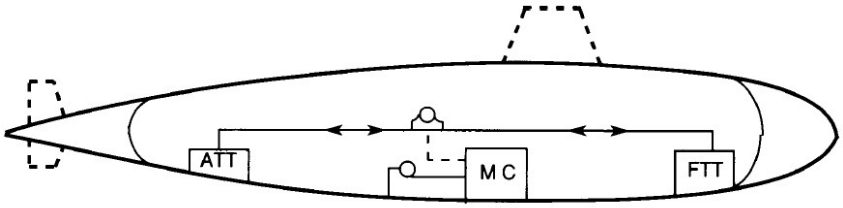

Figure 2.17 3 – Tank System [9]

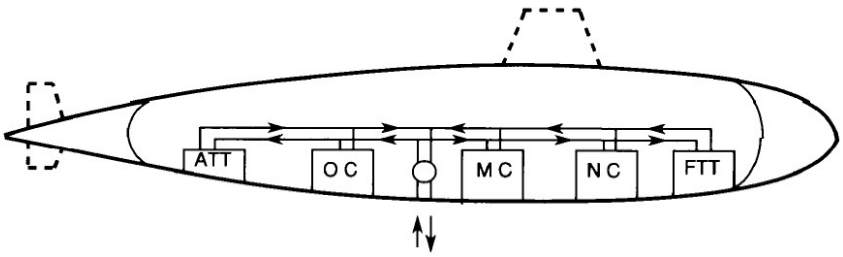

Figure 2.18 Multiple Tank System [9]

3
STABILITY RULES (DNV 2018)

This section provides an overview of the rules utilized in the stability analysis. The intact and damaged stability calculations for the BB2 Joubert Submarine were conducted in accordance with the DNV 2018 Submarine Rules. In accordance with the prescribed rules, loading conditions were created, weight margins were determined, and the righting and heeling levers were calculated.

3.1 Intact Stability

3.1.1 Loading Conditions for Stability Calculations

This study investigates various loading conditions, namely 1a, 1b, 2a, 2b, 3a, 3b, 4a, and 4b, as specified in the DNV rules. Loading conditions 1a, 1b, 2a, and 2b are analyzed with the submarine in the surfaced condition, while loading conditions 3a, 3b, 4a, and 4b are examined in the submerged condition. The tanks are completely filled in the 1a, 2a, 3a, and 4a load cases, while they are partially filled in the 1b, 2b, 3b, and 4b load cases. Compensating tanks are utilized to achieve neutral stability when the submarine is submerged, while the trimming tanks are consistently half percent full to allow weight shifting. Table 3.1 presents a summary of the stability load cases, along with the percentage ratios of tank filling according to the DNV rules. These values indicate the percentage of the maximum possible load (%) for the specified items or tanks in the respective loading conditions.

Table 3.1 Summary of Stability Cases According to DNV [13]

	1a	*1b*	*2a*	*2b*	*3a*	*3b*	*4a*	*4b*
	Surfaced				*Submerged*			
	Without ML[4]		*With ML* [4]		*Without ML*[4]		*With ML*[4]	
	All values are percentages of the maximum possible load …[%]							
Submarine [1]	100	100	100	100	100	100	100	100
Crew	100	100	100	100	100	100	100	100
Diving tanks	0	0	0	0	100	100	100	100
Trimming tanks	50	50	50	50	50	50	50	50
Compensating tanks [2]	[2]	[2]	[2]	[2]	20[3]	80[3]	10[3]	70[3]
Air	100	50	100	50	100	50	100	50
Oxygen	100	10	100	10	100	10	100	10
Hydrogen	100	10	100	10	100	10	100	10
Provisions	100	10	100	10	100	10	100	10
Fuel, lube oil	100	10	100	10	100	10	100	10
Special personnel	0	0	100	100	0	0	100	100
Other military loads	0	0	100	100	0	0	100	100

1) submarine fully equipped

2) Depending on the geometrical arrangement of the buoyancy tanks the percentage for the most unfavourable stability case shall be applied

3) Exact percentage depending on ambient conditions, e.g. seawater density

4) Military load

Descriptions of loading conditions are as follows.

- Load case 1a: Surfaced, start of the journey with 100% stocks, no military load ML
- Load case 1b: Surfaced, end of the journey with 10% stocks, no military load ML
- Load case 2a: Surfaced, start of the journey with 100% stocks, with military load ML

- Load case 2b: Surfaced, end of the journey with 10% stocks, with military load ML
- Load case 3a: Dived, start of the journey with 100% stocks, no military load ML
- Load case 3b: Dived, end of the journey with 10% stocks, no military load ML
- Load case 4a: Dived, start of the journey with 100% stocks, with military load ML
- Load case 4b: Dived, end of journey with 10% stocks, with military load ML [13].

3.1.2 Liquid Densities

The liquid densities recommended according to the DNV Rules and used in the calculations are as follows.

- freshwater 1.000 t/m^3
- bilge water 1.005 t/m^3
- waste water 1.050 t/m^3
- fuel (diesel) 0.83 t/m^3
- lubricants 0.90 t/m^3
- fire extinguishing foams 1.15 t/m^3

3.1.3 Righting Levers

The righting lever h is defined in Eq. (3.1) as follows:

$$h[m] = \frac{righting\ moment\ [mt]}{displacement\ \Delta\ [t]} \tag{3.1}$$

In this study;

h_{sw} is the righting lever of surfaced submarine,

h_{sub} is the righting lever of submerged submarine.

3.1.4 Heeling Levers

The heeling levers k is defined in Eq. (3.2) as follows:

$$k[m] = \frac{heeling\ moment\ [mt]}{displacement\ \Delta\ [t]} \tag{3.2}$$

Free liquid surfaces, turning circle and wind levers are used when calculating heeling levers.

3.1.4.1 Free Liquid Surfaces

The formula of the heeling lever k_F is as in Eq. (3.3):

$$k_F = \frac{\Sigma(p_i \,.\, b_{\varphi i})}{\Delta\uparrow} \; [m] \tag{3.3}$$

where:

k_F = heeling lever due to free surfaces in tanks

p_i = mass of liquids in tank i with free liquid surface [t]

$b_{\varphi i}$ = change of the centre of gravity in relation to the upright submarine, measured parallel to the design waterline [m]

3.1.4.2 Turning Circle

The heeling lever k_D is given in Eq. (3.4) as:

$$k_D = 0.2 \,.\, \frac{v_{0\uparrow}{}^2}{g.L_{OA}} \,.\, (KG - \frac{T}{2}).cos\varphi \tag{3.4}$$

where:

k_D = heeling lever due motion in turning circle [m]

v_0 = service speed of submarine [m/s]

g = gravitational acceleration [m/s^2]

LOA = overall length of the submarine [m]

KG-T/2 = distance between the centre of gravity above baseline and the center of the projected lateral underwater area [m]

φ = heel angle of the submarine

3.1.4.3 Wind

The wind forces are defined as in Eq. (3.5):

$$F_W = q_W.c_f.A_W \; [kN] \tag{3.5}$$

where:

q_W is the wind pressure and is calculated according to Eq. (3.6)

$$q_W = 0.5.\rho_L.v_W^2 \ [kN/m^2] \tag{3.6}$$

ρ_L = density of air [t/m^3]

v_W = wind speed [m/s]

c_f = form coefficient (=0.6 for rounded areas)

A_W = projected area exposed to wind forces [m^2],

Formula of the heeling lever k_W is given in Eq. (3.7) as follows:

$$k_W = \frac{F_W.z}{g.\Delta}.cos\varphi \tag{3.7}$$

where:

k_W = heeling lever due to wind forces [m]

F_W = wind forces

z = vertical distance between draft and center of projected area exposed to wind [m] [13]

φ = heel angle of the submarine

3.1.5 Weight Reserves

The following weight margins were included in the calculations [13].

- Design Margin : 1%
- Construction Margin : 2%
- Maintenance Margin : 1%

3.1.6 Criteria for Intact Stability

The criteria to be met in the intact stability analysis in the surfaced condition are as follows.

- The buoyancy reserve has to be %10 of the pressure tight volume of the submarine.
- Positive remaining lever h_{rem} has to be at least 0.1 m in surfaced condition.
- Minimum values for GM when surfaced and B↓G when submerged is shown in the table 3.2.

- Minimum GM has to be 0.22 m when the submarine is in surfaced condition according to the table 3.2 [13].

The criteria to be met in intact stability analysis in the submerged condition are as follows.

- Positive remaining lever h_{rem} has to be at least 0.05 m in submerged condition.
- Minimum B↓G has to be 0.35 m when the submarine in submerged condition according to the table 3.2 [13].

The recommended minimum values for GM and B↓G depending on the displacement of the submarine according to DNV are given in the table 3.2.

Table 3.2 Minimum Values for GM and B↓G According to DNV [13]

Displacement [t]	GM [m]	B↓G [m]
200 - 500	0.15	0.22
500 - 1000	0.18	0.27
1000 - 2000	0.20	0.32
> 2000	0.22	0.35

Figure 3.1 illustrates a sample curve depicting the relationship between the heeling angle and the righting lever, based on DNV Submarine Rules. Between the angle of the static balance φ_{stat} and the angle of immersion of the first unprotected opening φ_{ref} or the angle φ' of the second intersection of the curves of the heeling and righting levers or the intersection of the righting lever with the abscissa, whereas the smallest angle has to be considered, positive remaining levers hrem of at least 0.05 m in submerged condition and 0.1 m in surfaced condition have to exist [13]. In this study, all openings are considered as protected openings since they must be closed when the submarine is submerged. Therefore, stability curves are examined between static balance φ_{stat} and the angle φ' of the second intersection of the curves of the heeling and righting levers.

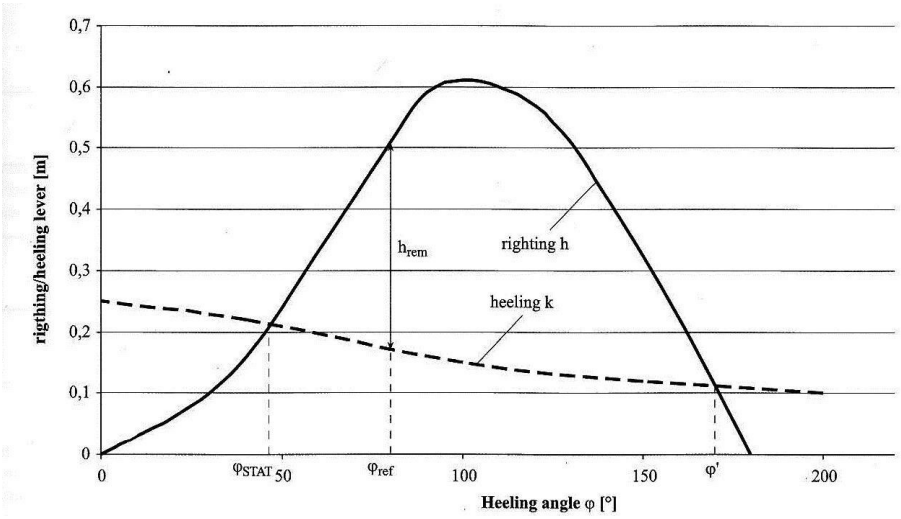

Figure 3.1 Lever Arm Curves with reference to DNV [13]

Figure 3.2 shows the characteristic centers of submarines under both surfaced and submerged conditions. Notably, the metacenter and buoyancy center coincide when the submarine is submerged.

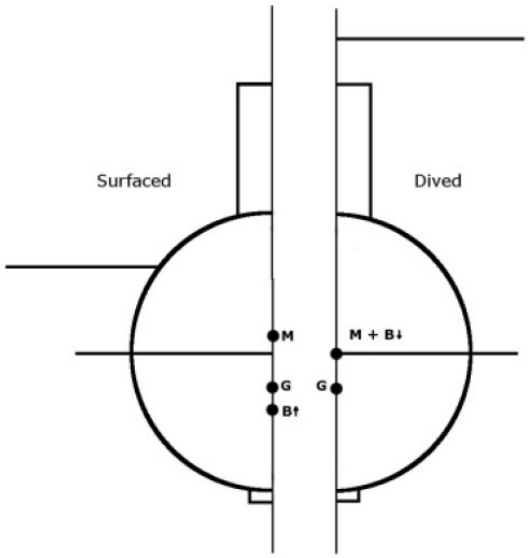

Figure 3.2 Characteristic Centers of Intact Stability with reference to DNV [13]

The calculation of the righting and heeling levers for each loading condition is based on the table 3.3. For the surfaced submarine, the considerations include free liquid surfaces, turning circle, and wind heeling levers. On the other hand, for the submerged submarine, the calculations incorporate free liquid surfaces and turning circle heeling levers.

Table 3.3 Summary of Lever Arms According to DNV [13]

Load cases		Surfaced		Submerged	
No	Designation	righting	heeling	righting	heeling
1a	100% stocks no military load	h_{SW}	$k_F + k_D + k_W$	---	---
1b	10% stocks no military load	h_{SW}	$k_F + k_D + k_W$	---	---
2a	100% stocks with military load	h_{SW}	$k_F + k_D + k_W$	---	---
2b	10% stocks with military load	h_{SW}	$k_F + k_D + k_W$	---	---
3a	100% stocks no military load	---	---	h_{sub}	$k_F + k_D$
3b	10% stocks no military load	---	---	h_{sub}	$k_F + k_D$
4a	100% stocks with military load	---	---	h_{sub}	$k_F + k_D$
4b	10% stocks with military load	---	---	h_{sub}	$k_F + k_D$

3.2 Damaged Stability

3.2.1 Extent of Damage

The scope of damaged stability is as follows.

- the pressure hull is undamaged,
- the exostructure is distorted,
- one important tank (e.g. a diving tank) within the exostructure fails because of damage
- an emergency operation of the submarine is possible without endangering the embarked persons [13].

3.2.2 Criteria for Surfaced Submarine

The criteria to be met in damaged stability analysis in the surfaced condition are as follows.

- Openings to the pressure hull shall have sufficient freeboard to avoid ingress of water into the pressure hull with hatches open.
- The heel of the submarine shall not exceed $\varphi = 22.5°$. At the same time the trim forward and sternward shall remain below 10°.
- A positive remaining lever h_{rem} shall be guaranteed. Its value shall be agreed with the Society according to the type of construction [13].

3.2.3 Criteria for Submerged Submarine

The criteria to be met in damaged stability analysis in the surfaced condition are as follows.

- The submarine has still to be able to surface in a safe way.
- The centre of weight has still to be below the centre of buoyancy [13].

4
INVESTIGATION OF THE STABILITY CHARACTERISTICS

4.1 Introduction

This section outlines the studies and assumptions made before the stability calculations. Pressure hull and tanks were created for the generic submarine model BB2 Joubert. Tank capacities were determined based on the tank plan. Furthermore, the assumptions made for the stability calculations are explained.

4.1.1 Main Dimensions

The BB2 Joubert submarine model is a generic submarine form of the SSK class, Joubert type, shared by MARIN (Maritime Research Institute Netherlands) [16]. BB2 Joubert's model was produced by MARIN, with the model number M9466 and scaled by a factor of 18.348 for conducting comprehensive experimental studies on self-propulsion, maneuvering, and seakeeping. The generic form is used in numerous experimental and numerical investigations in the fields of submarine hydrodynamics. The main dimensions of the full-scale submarine are given in Table 4.1. A perspective view and a profile view with the coordinate axes of the submarine are also given in the figure 4.1. The values in the coordinate axes are given in meters.

Table 4.1 Main Dimensions

Symbol	Description	Value	Unit
L	Length	70.13	m
B	Breadth	9.6	m
D	Depth	10.6	m
D_s	Depth (to top of sail)	16.2	m

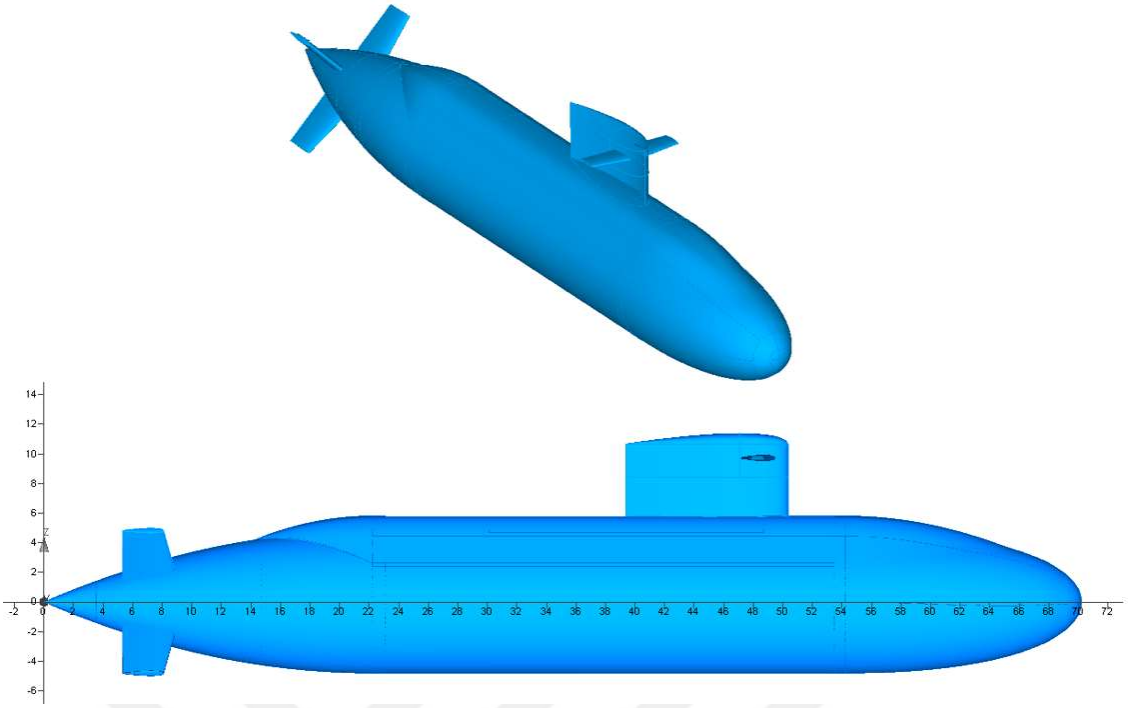

Figure 4.1 BB2 Joubert Submarine Model

4.1.2 Calculation Assumptions

In this study, stability calculations of the submarine are made according to DNV rules. Load cases 1a, 1b, 2a, 2b are created to examine the stability of surfaced submarine and load cases 3a, 3b, 4a, 4b are created to examine the stability of submerged submarine.

Sea water density was taken as 1.025 t/m^3 in the calculations. Permeabilities of the tanks are %98. Moreover, the permissible filling level of the tanks is also set at 98%. This implies that the tanks are filled up to %98 capacity when they must be full filled according to rules.

The velocities and sea state values were determined by examining submarines with similar length and displacement as the BB2 Joubert. Specifically, the velocity of the submarine is assumed to be 12 knots when surfaced and 22 knots when submerged. To establish the survivability limit of the submarine, sea state 6 is considered. According to the Beaufort Scale (Beaufort Wind Scale with Corresponding Sea States Codes) [18], sea state 6 corresponds to a strong gale with maximum wind speeds of up to 47 knots. When calculating the heeling lever resulting from wind forces, this specific wind speed value was utilized.

Table 4.2 provides a comprehensive overview of the deadweight items utilized in the calculations. The complement numbers are determined by evaluating the crew number of similar submarines. The unit weight of the crew and crew effect are determined based on the German Naval Vessel Rules (BV1030 – 1) [17] since there are no assumptions specified in the DNV Rules. The table indicates that the submarine is assumed to have a complement of 50 personnel, consisting of 15 officers, 25 petty officers, and 10 ratings. Additionally, the table shows the weights of provisions, torpedoes, special personnel, and other military loads.

Table 4.2 Fixed Deadweight Items

Item	Unit	Unit Weight [kg]	Total Weight [ton]
Complement	50	75	3.75
Officer Equipment	15	110	1.65
P.O. Equipment	25	80	2
Rating Equipment	10	80	0.8
Provisions			20
Torpedo			18
Special Personnel & Other Military Loads			1.9

It is necessary to determine the buoyancy elements for the hydrostatic and stability calculations. A pressure hull was modeled for this study. The main ballast tanks are located in the outer structure of the pressure hull. Other areas in the outer structure of the pressure hull are free flooding areas. Free flooding areas are not included in the calculations as a buoyant element because they are connected with sea water. The pressure hull is the main buoyant element in all scenarios. The main ballast tanks are also considered as buoyant elements in the surfaced condition. Since these tanks are diving tanks, they are empty in surfaced condition. In order to enter the submerged state, the main ballast tanks must be filled with sea water. There are two scenarios regarding whether the main ballast tanks filled with seawater can be considered as a buoyancy element in the submerged situation. In the first, the main ballast tanks are also buoyant in the submerged state and these tanks are considered to be filled. In this case, the submarine will become heavier in the submerged state. In the second scenario, the main ballast tanks

will not be considered as buoyant elements, like free flooding areas. In this way, the weight of the submarine will not change in the submerged state. In the submerged condition, only the pressure hull will be the buoyancy element. In this study, the second method was followed, and it was assumed that only the pressure hull provides buoyancy to the submarine in the submerged condition.

Table 4.3 Hydrostatics Table of the Submerged Submarine

Draft (m)	Displt (t)	LCB (m)	VCB (m)	LCF (m)	KMT (m)	TPC (t/cm)	MTC (t-m/cm)
-4.8	0	0	0	35.077	0	0	0
-4.4	43.7	38.472	-4.556	38.352	-0.154	1.66	3.58
-4	127.4	38.129	-4.312	37.625	-0.068	2.45	5.97
-3.6	238.4	37.742	-4.069	37.035	-0.045	3.05	8.12
-3.2	370.5	37.445	-3.827	36.853	-0.031	3.51	9.74
-2.8	521.7	37.404	-3.586	37.569	-0.023	3.99	12.1
-2.4	688.4	37.469	-3.346	37.729	-0.018	4.32	13.55
-2	867.4	37.519	-3.108	37.673	-0.015	4.6	14.86
-1.6	1056.6	37.535	-2.873	37.54	-0.012	4.84	16.02
-1.2	1254	37.523	-2.64	37.385	-0.01	5.02	17.01
-0.8	1457.6	37.498	-2.411	37.31	-0.008	5.14	17.63
-0.4	1665	37.472	-2.185	37.276	-0.007	5.21	17.98
0	1874.2	37.449	-1.963	37.265	-0.005	5.23	18.09
0.4	2083.4	37.431	-1.745	37.276	-0.005	5.21	17.98
0.8	2290.8	37.418	-1.533	37.31	-0.004	5.14	17.63
1.2	2494.3	37.412	-1.326	37.385	-0.003	5.02	17.01
1.6	2691.8	37.415	-1.126	37.54	-0.003	4.84	16.02
2	2881	37.428	-0.934	37.673	-0.002	4.6	14.86
2.4	3060	37.445	-0.75	37.729	-0.002	4.32	13.55
2.8	3226.7	37.456	-0.577	37.569	-0.001	3.99	12.1
3.2	3377.9	37.449	-0.418	36.853	-0.001	3.51	9.74
3.6	3510	37.429	-0.274	37.035	-0.001	3.05	8.12
4	3621	37.425	-0.15	37.625	0	2.45	5.97
4.4	3704.7	37.437	-0.052	38.352	0	1.66	3.58
4.6	3733.2	37.445	-0.018	38.522	0	1.12	2.11
4.8	***3748.4***	***37.449***	***0***	***35.077***	***0***	***0***	***0***

The hydrostatic values of the submerged submarine are presented in the table 4.3. The table is created by using Aveva Initial Design – Hydrostatics Module [19]. According to the table, the displacement value that the submarine must have for neutral buoyancy in the submerged state is 3748.4 tons. This value was determined as the fully loaded displacement of the submerged submarine in the calculations. The lightweight of the submarine was determined by considering tank capacities, fixed weights and margins. This value is 3295.9 tons. The summary table for the lightweight calculation is given in the table 4.4. According to DNV Rules, the vertical distance between the submerged center of gravity and the buoyancy center of the submarine should be a minimum of 0.35 meters. The maximum center of gravity that the submarine can have to meet this rule is accepted as limit KG. The vertical center of the lightweight has been determined in such a way that the center of gravity of the submerged and fully loaded condition will the limit KG value. This value is -0.16 meters relative to the reference axis and 4.64 meters relative to the baseline.

Table 4.4 Summary of Weight Calculation

Summary of Weight Calculation			
Item	Weight [t]	VCG [m] from reference point	VCG [m] from baseline
Lightweight	***3295.9***	***-0.16***	***4.64***
Liquids			
Total Diesel Fuel	174.5	-2.74	2.06
Total Fresh Water	14.8	-2.53	2.27
Total Lubricating Oil	13.1	-4.33	0.47
Total Sea Water	45.8	-3.28	1.52
Total Bilge Water / Sludge	0.0	0.00	4.80
Total LO_x	23.6	-2.38	2.42
Fixed Weights			
Complement	3.8	-0.16	4.64
Officer Equipment	1.6	-0.16	4.64
P.O. Equipment	2.0	-0.16	4.64
Rating Equipment	0.8	-0.16	4.64
Garbage	0.0	0.00	4.80
Provisions	20.0	-0.16	4.64
Torpedo	18.8	-1.50	3.30

Table 4.4 Summary of Weight Calculation (continued…)

Special Personnel & Other Military Loads	1.9	-0.16	4.64
Margins			
Design Margin	33.0	-0.16	4.64
Construction Margin	65.9	-0.16	4.64
Maintenance Margin	33.0	-0.16	4.64
Total Weight (Displacement)	***3748.4***	***-0.36***	***4.44***
Total Buoyancy	***3748.4***	***0.00***	***4.80***

There will be weight changes due to the consumption in the tanks during the cruising of the submarine. It is important to keep the weight of the submarine constant while cruising underwater. The filling rates of the compensating tanks can be changed according to the weight changes. Trim tanks are also used for weight balancing and trim correction. In this study, in order to keep the weight of the submarine in balance due to the weight changes in the fuel tanks, sea water was taken into these tanks as much as the decreasing amount of fuel. Due to the density difference between the diesel fuel and seawater, the reduced fuel will stay on upper, and the seawater will fill under the tank instead of the consumed fuel. B-index scenarios represent the arrival status. In these scenarios, it is assumed that there are both fuel and sea water in the tank. In the calculations, the liquid density in the tank was determined as follows by taking the average of the amount and density of the liquids.

$$0.1 \times 0.83 + 0.9 \times 1.025 = 1.005\ t/m^3 \tag{4.1}$$

When the tanks are filled %10 fuel and %90 sea water according to their densities 0.83 and 1.025 respectively, the average density of the liquid in these tanks in loading conditions “b” is taken as 1.005 t/m^3.

4.1.3 Tank Arrangement / Capacities

Profile view of the general arrangement of the generic submarine model BB2 Joubert is presented in the figure 4.2. Pressure hull and tanks were created for the submarine considering the general arrangement given in the figure. Two main ballast tanks were created. These are the aft main ballast tank and fore main ballast tank. The main ballast tanks are located outside the pressure hull.

In this study, unlike the figure 4.2, the longitudinal centers of gravity are given as increasing from the stern to the bow. The reference point on the longitudinal axis is chosen as the stern extreme point of the submarine. The reference point of the vertical centers of gravity is the midpoint of the pressure hull. This line is the line that extends from the stern to the bow along the submarine shown in the figure. The vertical center of gravity is presented both from the reference point and from the baseline in the calculations. The heights given from the baseline are used for the centers of gravity in the calculations of the righting-heeling lever. The vertical distance between the reference point and the baseline is 4.8 meters.

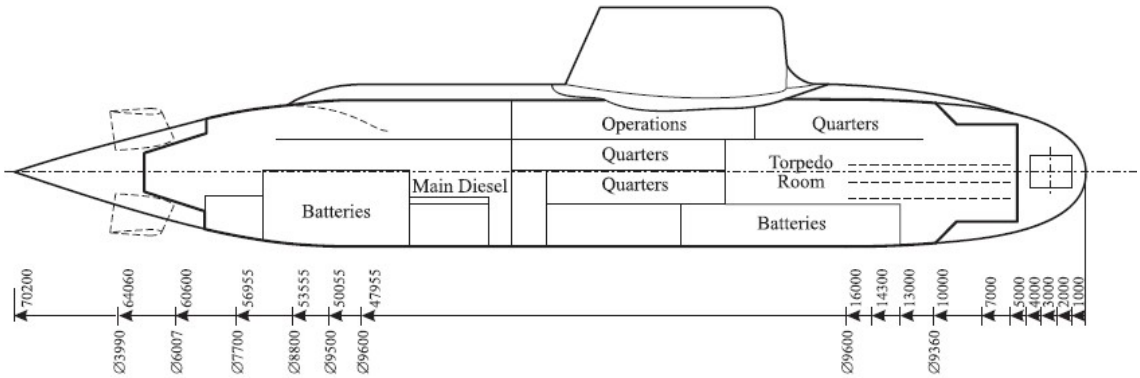

Figure 4.2 General Arrangement of Generic Submarine BB2 Joubert [14]

Top view, aft to fore view and profile view of the submarine are given in the figure 4.3. In addition, a visual of the modeled pressure hull and the outer hull of the submarine is presented together.

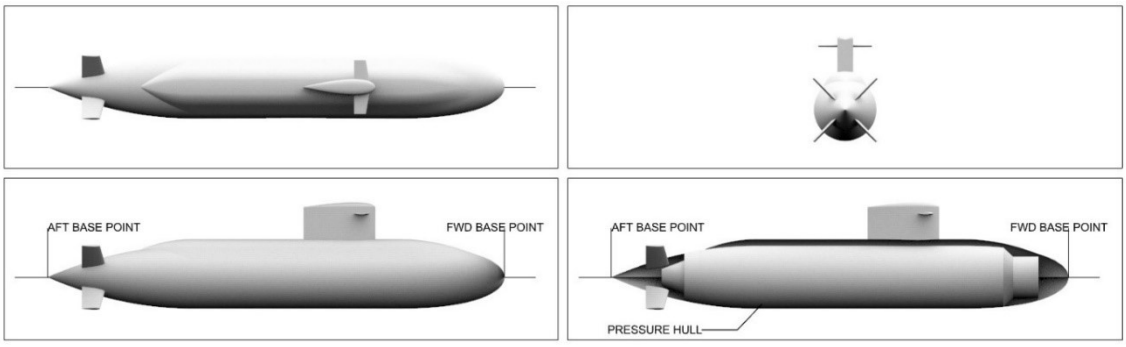

Figure 4.3 Views of Submarine

Tank plan and the perspective view of the tank arrangement made for the BB2 Joubert are given in the figure 4.4 and 4.5, respectively. Tank capacity table is presented in the table 4.5.

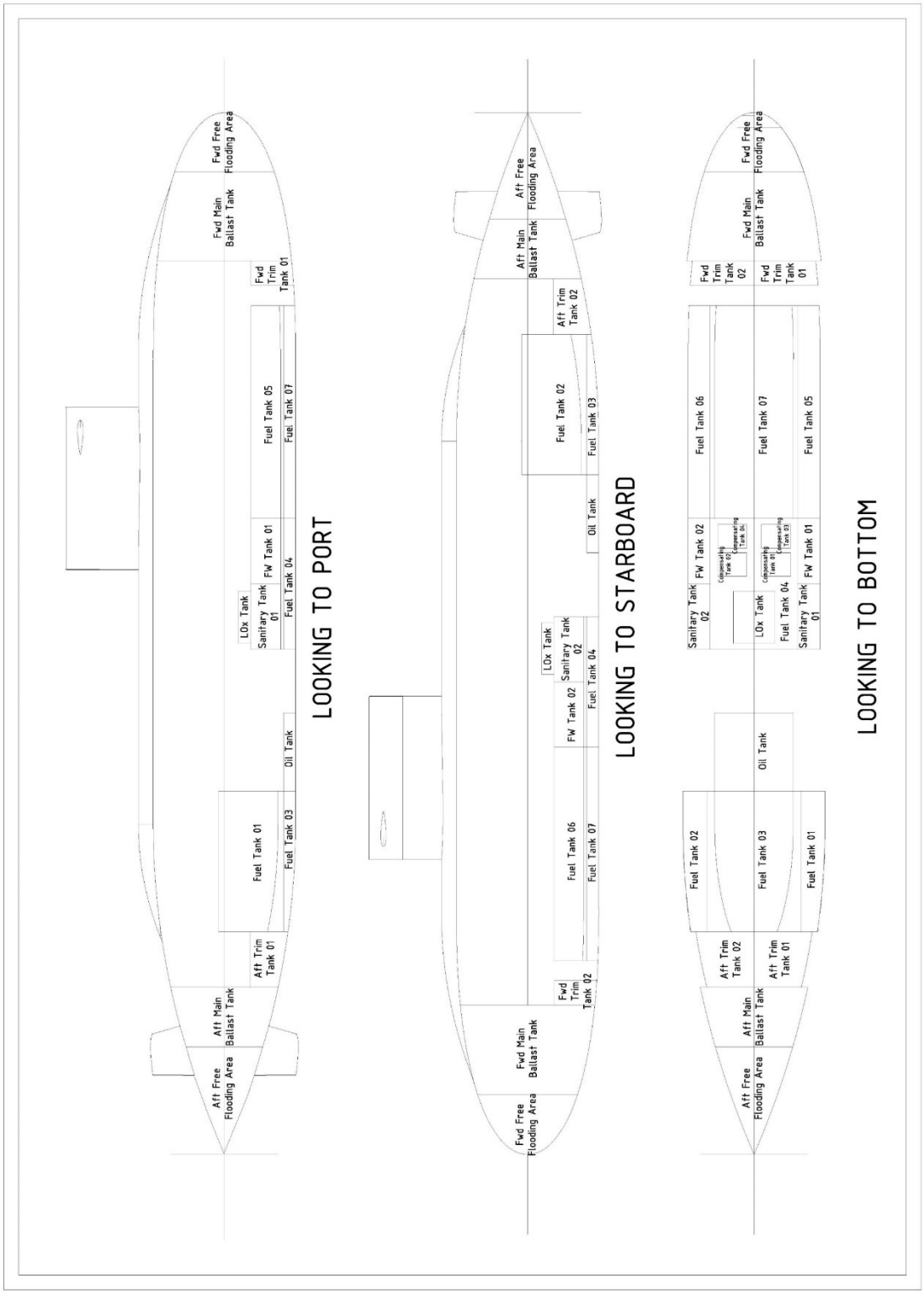

Figure 4.4 Tank Arrangement Plan

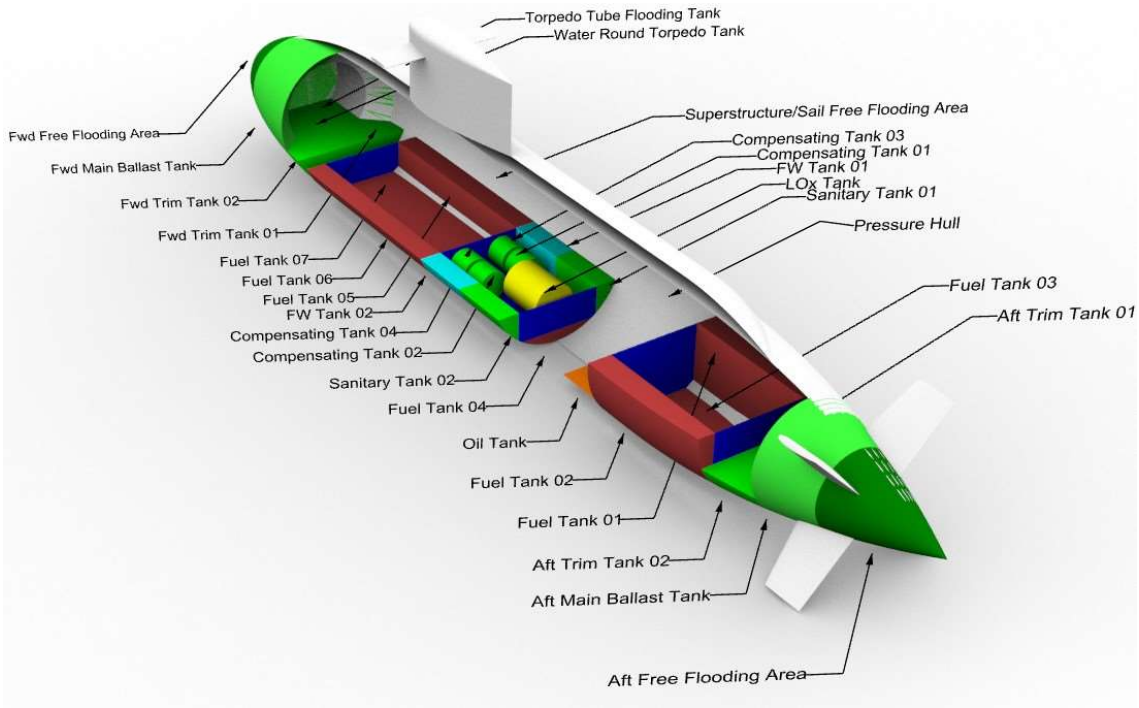

Figure 4.5 3D Tank Arrangement Plan

Table 4.5 Tank Capacities

Tank Capacities				
	Volume [m^3]	LCG [m]	TCG [m]	VCG [m]
Fuel Tank 01	40.366	20.076	-3.796	-1.119
Fuel Tank 02	40.366	20.076	3.796	-1.119
Fuel Tank 03	21.235	20.522	0	-4.289
Fuel Tank 04	25.343	38.4	0	-4.322
Fuel Tank 05	25.223	49.961	-3.495	-2.518
Fuel Tank 06	25.223	49.961	3.495	-2.518
Fuel Tank 07	41.124	49.946	0	-4.321
Fresh Water Tank 01	7.755	40.6	-3.497	-2.52
Fresh Water Tank 02	7.755	40.6	3.497	-2.52
Oil Tank	15.12	27.075	0	-4.322
Aft Main Ballast Tank	83.82	9.196	0	0
Aft Trim Tank 01	21.747	13.235	-1.426	-2.666
Aft Trim Tank 02	21.747	13.235	1.426	-2.666
Compensating Tank 01	4.778	39.7	-1.475	-2.775
Compensating Tank 02	4.778	39.7	1.475	-2.775
Compensating Tank 03	4.778	41.6	-1.475	-2.775
Compensating Tank 04	4.778	41.6	1.475	-2.775
Fwd Main Ballast Tank	120.794	63.392	0	0
Fwd Trim Tank 01	21.75	59.868	-1.581	-2.865
Fwd Trim Tank 02	21.75	59.868	1.581	-2.865
Torpedo Tube Flooding Tank	9.551	64.625	0	-2.351
Water Round Torpedo Tank	9.551	62.675	0	-2.351
Sanitary Tank 01	7.755	36.2	-3.497	-2.52
Sanitary Tank 02	7.755	36.2	3.497	-2.52
Lox Tank	21.551	36.15	0	-2.35

4.2 Intact Stability Analysis

This section presents the intact stability analysis and rule evaluations. A total of eight loading conditions were conducted. The examination of loading conditions focuses on the surfaced and submerged conditions. Loading conditions 1a, 1b, 2a, and 2b are specifically assessed in relation to the surfaced condition, whereas loading conditions 3a, 3b, 4a, and 4b are examined in the context of the submerged condition.

4.2.1 Surfaced Submarine

4.2.1.1 Loading Condition 1a

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

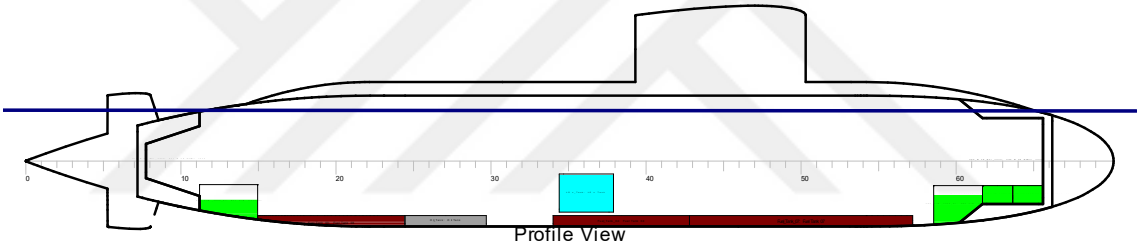

Figure 4.6 Profile View

Table 4.6 Densities

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1.000
	DIESEL FUEL	0.830
	LUB. OIL	0.900
	LOX	1.141

Table 4.7 Summary Table of Loading Condition 1a

Stability Calculations for Loading Condition 1A								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	15-24	DIESEL FUEL	98	0.83	32.2	20.077	3.794	-1.149
FUEL TANK 02	15-24	DIESEL FUEL	98	0.83	32.2	20.077	-3.794	-1.149
FUEL TANK 03	15-24	DIESEL FUEL	98	0.83	16.9	20.520	0.000	-4.295
FUEL TANK 04	34-43	DIESEL FUEL	98	0.83	20.2	38.391	0.000	-4.329
FUEL TANK 05	43-57	DIESEL FUEL	98	0.83	20.1	49.949	3.491	-2.532
FUEL TANK 06	43-57	DIESEL FUEL	98	0.83	20.1	49.949	-3.491	-2.532
FUEL TANK 07	43-57	DIESEL FUEL	98	0.83	32.8	49.921	0.000	-4.327
Total DIESEL FUEL					**174.5**	**34.732**	**0.000**	**-2.738**
FRESH WATER								
FRESH WATER TANK 01	38-43	FRESH WATER	98	1.00	7.4	40.599	3.492	-2.534
FRESH WATER TANK 02	38-43	FRESH WATER	98	1.00	7.4	40.599	-3.492	-2.534
Total FRESH WATER					**14.8**	**40.599**	**0.000**	**-2.534**
LUB, OIL								
OIL TANK	24-30	LUB, OIL	98	0.9	13.1	27.072	0.000	-4.329
Total LUB, OIL					**13.1**	**27.072**	**0.000**	**-4.329**
SEA WATER								
AFT MAIN BALLAST TANK	7-11	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	11-15	SEA WATER	37.5	1.025	8.2	13.366	1.088	-3.330
AFT TRIM TANK 02	11-15	SEA WATER	37.5	1.025	8.2	13.366	-1.088	-3.330
COMPENSATING TANK 01	39-40	SEA WATER	20	1.025	1.0	39.700	1.475	-3.458
COMPENSATING TANK 02	39-40	SEA WATER	20	1.025	1.0	39.700	-1.475	-3.458
COMPENSATING TANK 03	41-42	SEA WATER	20	1.025	1.0	41.600	1.475	-3.458
COMPENSATING TANK 04	41-42	SEA WATER	20	1.025	1.0	41.600	-1.475	-3.458
FWD MAIN BALLAST TANK	60-66	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	59-62	SEA WATER	62.5	1.025	13.7	59.790	1.413	-3.295
FWD TRIM TANK 02	59-62	SEA WATER	62.5	1.025	13.7	59.790	-1.413	-3.295
TORPEDO TUBE FLOODING TANK	64-66	SEA WATER	98	1.025	9.4	64.625	0.000	-2.362

Table 4.7 Summary Table of Loading Condition 1a (continued…)

WATER ROUND TORPEDO TANK	62-64	SEA WATER	98	1.025	9.4	62.675	0.000	-2.362
Total SEA WATER					**66.6**	**48.310**	**0.000**	**-3.049**
BILGE WATER / SLUDGE								
SANITARY TANK 01	34-38	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
SANITARY TANK 02	34-38	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
Total BILGE WATER / SLUDGE					**0.0**	**0.000**	**0.000**	**0.000**
LOx								
Lox TANK	34-38	LOX	98	1.141	23.6	36.150	0.000	-2.377
Total LOx					**23.6**	**36.150**	**0.000**	**-2.377**
LOADING CONDITION 1A FIXED WEIGHTS								
COMPLEMENT					3.8	37.561	0.000	-0.160
OFFICER EQUIPMENT					1.6	37.561	0.000	-0.160
P.O. EQUIPMENT					2.0	37.561	0.000	-0.160
RATING EQUIPMENT					0.8	37.561	0.000	-0.160
GARBAGE					0.0	0.000	0.000	0.000
PROVISIONS					20.0	37.561	0.000	-0.160
TORPEDO					0.0	0.000	0.000	0.000
SPECIAL PERSONNEL & OTHER MILITARY LOADS					0.0	0.000	0.000	0.000
DESIGN MARGIN					33.0	37.561	0.000	-0.160
CONSTRUCTION MARGIN					65.9	37.561	0.000	-0.160
MAINTENANCE MARGIN					33.0	37.561	0.000	-0.160
Loading Condition 1A Fixed Weights					**160.1**	**37.561**	**0.000**	**-0.160**
Lightweight					**3295.9**	**37.561**	**0.000**	**-0.160**
Deadweight					**452.4**	**37.770**	**0.000**	**-1.892**
Total Displacement					**3748.4**	**37.586**	**0.000**	**-0.369**
Buoyancy					**3748.3**	**37.586**	**0.000**	**-0.234**
Total Buoyancy					**3748.3**	**37.586**	**0.000**	**-0.234**

Table 4.8 Drafts at Equilibrium Angle

Drafts at equilibrium angle		
Draft at LCF	3.701	metres
Draft at AP	3.731	metres
Draft at FP	3.677	metres
Draft at midships	3.704	metres

Table 4.9 Hydrostatics at Equilibrium Angle

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim by the stern	0.053	metres
	0.04	degrees
KG	-0.369	metres
KB	-0.234	metres
FSC	0.011	metres
KGf	-0.358	metres
GMt	0.357	metres
BMt	0.233	metres
BMl	16.707	metres
Waterplane area	299.030	sq.metres
LCG	37.586	metres
LCB	37.586	metres
TCB	0.000	metres
LCF	38.572	metres
TCF	0.000	metres
TPC	3.065	tonnes/cm
MTC	8.998	tonnes-m/cm

Table 4.10 Summary Stability Table

Displacement [ton]	Δ	3748.4	
Length [m]	L_{DWL}	70.13	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	3.701	8.501
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.369	4.431
Longitudinal Center of Gravity [m]	LCG	37.586	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	0.181	
Wind Pressure [kN/m^2]	q_w	0.358	
Density of Air [t/m^3]	ρ_L	0.001225	
Wind Speed [m/s]	v_w	24.179	
Form Coefficient	c_f	0.600	
Projected Area Exposed to Wind Forces [m^2]	A_w	158.095	
Height of the Centroid of the Area Exposed to Wind [m] [from Reference Point] / [from Baseline]	A_{wz}	6.096	10.896
Height of the Centroid of the Area Exposed to Wind Above Half Draught [m] [from Baseline]	A_{wz}-0.5T	6.646	
Maximum Operational Speed of the Surfaced Submarine [knot] / [m/sn]	$v_0\uparrow$	12.000	6.173

Table 4.11 Righting – Heeling Lever Calculations

Heel Angle	Righting Lever	Heeling Lever				
[°]	hsw	k_F	k_D	k_W	$k_F + k_D + k_W$	$h_{SW} - (k_F+k_D+k_W)$
10	0.0641	0.002	0.002	0.006	0.010	0.054
20	0.1262	0.004	0.002	0.006	0.011	0.115
30	0.1845	0.006	0.002	0.005	0.013	0.172
45	0.2610	0.008	0.001	0.004	0.014	0.247

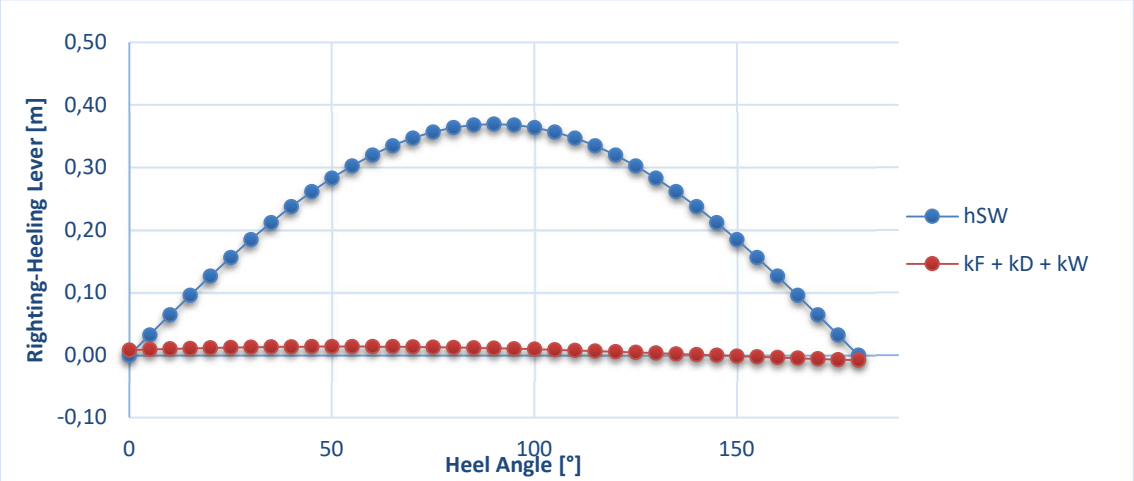

Figure 4.7 Righting – Heeling Lever / Heel Angle

Table 4.12 Criterion Assessment

#	Criterion	Actual Value	Critical Value	Result
1	The buoyancy reserve shall be at least 10% of the pressure tight volume of the submarine in surfaced condition.	12.2	10.0	+
2	Positive remaining lever h_{rem} at least 0.1 m in surfaced condition.	0.358	0.1	+
3	Minimum value for GM	0.357	0.220	+

This section focuses on stability analyses specifically related to loading case 1a, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Buoyancy reserve is 12.2% of the pressure tight volume of the submarine. Thus, the 10% limit value has been exceeded.
- Positive remaining lever h_{rem} is 0.358 m and is above the limit value of 0.1 m.
- The GM value is 0.357 m and is above the limit value of 0.22 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 1a.

4.2.1.2 Loading Condition 1b

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

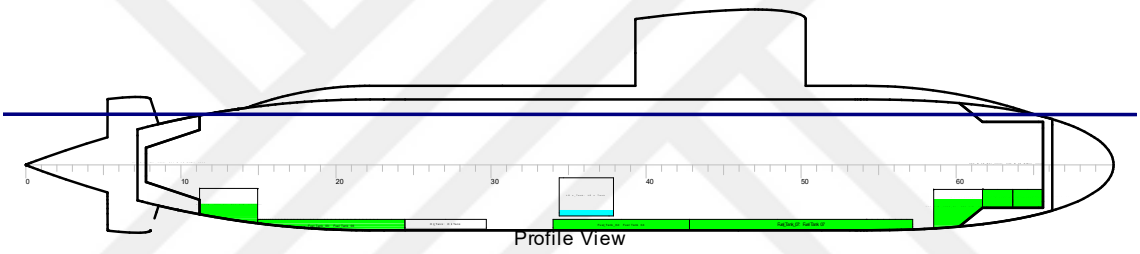

Figure 4.8 Profile View

Table 4.13 Densities

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	LUB, OIL	0.9
	BILGE WATER / SLUDGE	1.005
	LOX	1.141
	SEA WATER & DIESEL FUEL	1.005

Table 4.14 Summary Table of Loading Condition 1b

Stability Calculations for Loading Condition 1B								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	15-24	SEA WATER & DIESEL FUEL	98	1.005	39.0	20.078	3.794	-1.149
FUEL TANK 02	15-24	SEA WATER & DIESEL FUEL	98	1.005	39.0	20.078	-3.794	-1.149
FUEL TANK 03	15-24	SEA WATER & DIESEL FUEL	98	1.005	20.5	20.526	0.000	-4.295
FUEL TANK 04	34-43	SEA WATER & DIESEL FUEL	98	1.005	24.5	38.396	0.000	-4.329
FUEL TANK 05	43-57	SEA WATER & DIESEL FUEL	98	1.005	24.3	49.955	3.491	-2.532
FUEL TANK 06	43-57	SEA WATER & DIESEL FUEL	98	1.005	24.3	49.955	-3.491	-2.532
FUEL TANK 07	43-57	SEA WATER & DIESEL FUEL	98	1.005	39.7	49.934	0.000	-4.327
Total DIESEL FUEL					**211.3**	**34.737**	**0.000**	**-2.738**
FRESH WATER								
FRESH WATER TANK 01	38-43	FRESH WATER	10	1.00	0.8	40.598	3.155	-3.421
FRESH WATER TANK 02	38-43	FRESH WATER	10	1.00	0.8	40.598	-3.155	-3.421
Total FRESH WATER					**1.6**	**40.598**	**0.000**	**-3.421**
LUB, OIL								
OIL TANK	24-30	LUB, OIL	10	0.9	1.3	27.068	0.000	-4.698
Total LUB, OIL					**1.3**	**27.068**	**0.000**	**-4.698**
SEA WATER								
AFT MAIN BALLAST TANK	7-11	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	11-15	SEA WATER	37.5	1.025	8.2	13.366	1.088	-3.330
AFT TRIM TANK 02	11-15	SEA WATER	37.5	1.025	8.2	13.366	-1.088	-3.330
COMPENSATING TANK 01	39-40	SEA WATER	80	1.025	3.8	39.700	1.475	-2.946
COMPENSATING TANK 02	39-40	SEA WATER	80	1.025	3.8	39.700	-1.475	-2.946

Table 4.14 Summary Table of Loading Condition 1b (continued…)

COMPENSATING TANK 03	41-42	SEA WATER	80	1.025	3.8	41.600	1.475	-2.946
COMPENSATING TANK 04	41-42	SEA WATER	80	1.025	3.8	41.600	-1.475	-2.946
FWD MAIN BALLAST TANK	60-66	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	59-62	SEA WATER	62.5	1.025	13.7	59.790	1.413	-3.295
FWD TRIM TANK 02	59-62	SEA WATER	62.5	1.025	13.7	59.790	-1.413	-3.295
TORPEDO TUBE FLOODING TANK	64-66	SEA WATER	98	1.025	9.4	64.625	0.000	-2.362
WATER ROUND TORPEDO TANK	62-64	SEA WATER	98	1.025	9.4	62.675	0.000	-2.362
Total SEA WATER					**77.8**	**47.178**	**0.000**	**-3.008**
BILGE WATER / SLUDGE								
SANITARY TANK 01	34-38	BILGE WATER / SLUDGE	90	1.005	6.9	36.199	3.475	-2.593
SANITARY TANK 02	34-38	BILGE WATER / SLUDGE	90	1.005	6.9	36.199	-3.475	-2.593
Total BILGE WATER / SLUDGE					**13.8**	**36.199**	**0.000**	**-2.593**
LOx								
Lox TANK	34-38	LOX	10	1.141	2.4	36.149	0.000	-3.490
Total LOx					**2.4**	**36.149**	**0.000**	**-3.490**
LOADING CONDITION 1B FIXED WEIGHTS								
COMPLEMENT					3.8	37.561	0.000	-0.160
OFFICER EQUIPMENT					1.6	37.561	0.000	-0.160
P.O. EQUIPMENT					2.0	37.561	0.000	-0.160
RATING EQUIPMENT					0.1	37.561	0.000	-0.160
GARBAGE					3.0	37.561	0.000	-0.160
PROVISIONS					2.0	37.561	0.000	-0.160
TORPEDO					0.0	0.000	0.000	0.000
SPECIAL PERSONNEL & OTHER MILITARY LOADS					0.0	0.000	0.000	0.000
DESIGN MARGIN					33.0	37.561	0.000	-0.160
CONSTRUCTION MARGIN					65.9	37.561	0.000	-0.160
MAINTENANCE MARGIN					33.0	37.561	0.000	-0.160
Loading Condition 1B Fixed Weights					**144.4**	**37.561**	**0.000**	**-0.160**
Lightweight					**3295.9**	**37.561**	**0.000**	**-0.160**
Deadweight					**452.4**	**37.828**	**0.000**	**-1.970**
Total Displacement					**3748.4**	**37.593**	**0.000**	**-0.378**
Buoyancy					**3748.3**	**37.593**	**0.000**	**-0.234**
Total Buoyancy					**3748.3**	**37.593**	**0.000**	**-0.234**

Table 4.15 Drafts at Equilibrium Angle

Drafts at equilibrium angle		
Draft at LCF	3.701	metres
Draft at AP	3.715	metres
Draft at FP	3.690	metres
Draft at midships	3.703	metres

Table 4.16 Hydrostatics at Equilibrium Angle

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim by the stern	0.024	metres
	0.02	degrees
KG	-0.378	metres
KB	-0.234	metres
FSC	0.014	metres
KGf	-0.365	metres
GMt	0.364	metres
BMt	0.233	metres
BMl	16.714	metres
Waterplane area	299.070	sq.metres
LCG	37.593	metres
LCB	37.593	metres
TCB	0.000	metres
LCF	38.503	metres
TCF	0.000	metres
TPC	3.066	tonnes/cm
MTC	9.008	tonnes-m/cm

Table 4.17 Summary Stability Table

Displacement [ton]	Δ	3748.4	
Length [m]	L_{DWL}	70.13	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	3.701	8.501
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.378	4.422
Longitudinal Center of Gravity [m]	LCG	37.593	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	0.172	
Wind Pressure [kN/m^2]	q_w	0.358	
Density of Air [t/m^3]	ρ_L	0.001225	
Wind Speed [m/s]	v_w	24.179	
Form Coefficient	c_f	0.600	

Table 4.17 Summary Stability Table (continued…)

Projected Area Exposed to Wind Forces [m^2]	A_w	158.095	
Height of the Centroid of the Area Exposed to Wind [m] [from Reference Point] / [from Baseline]	A_{wz}	6.096	10.896
Height of the Centroid of the Area Exposed to Wind Above Half Draught [m] [from Baseline]	A_{wz}-0.5T	6.646	
Maximum Operational Speed of the Surfaced Submarine [knot] / [m/sn]	$v_0\uparrow$	12.000	6.173

Table 4.18 Righting – Heeling Lever Calculations

Heel Angle	**Righting Lever**	**Heeling Lever**				
[°]	hsw	k_F	k_D	k_W	$k_F + k_D + k_W$	h_{SW} - (k_F+k_D+k_W)
10	0.0657	0.002	0.002	0.006	0.010	0.055
20	0.1294	0.005	0.002	0.006	0.012	0.117
30	0.1892	0.007	0.002	0.005	0.014	0.175
45	0.2676	0.010	0.001	0.004	0.016	0.252

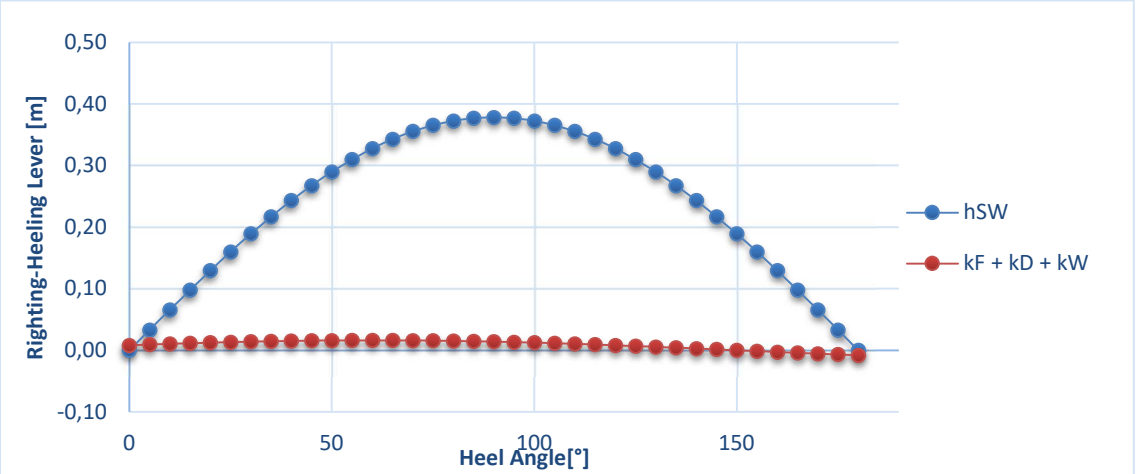

Figure 4.9 Righting – Heeling Lever / Heel Angle

Table 4.19 Criterion Assessment

#	Criterion	Actual Value	Critical Value	Result
1	The buoyancy reserve shall be at least 10% of the pressure tight volume of the submarine in surfaced condition.	12.2	10.0	+
2	Positive remaining lever h_{rem} at least 0.1 m in surfaced condition.	0.365	0.1	+
3	Minimum value for GM	0.364	0.220	+

This section focuses on stability analyses specifically related to loading case 1b, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Buoyancy reserve is 12.2% of the pressure tight volume of the submarine. Thus, the 10% limit value has been exceeded.
- Positive remaining lever h_{rem} is 0.365 m and is above the limit value of 0.1 m.
- The GM value is 0.364 m and is above the limit value of 0.22 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 1b.

4.2.1.3 Loading Condition 2a

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

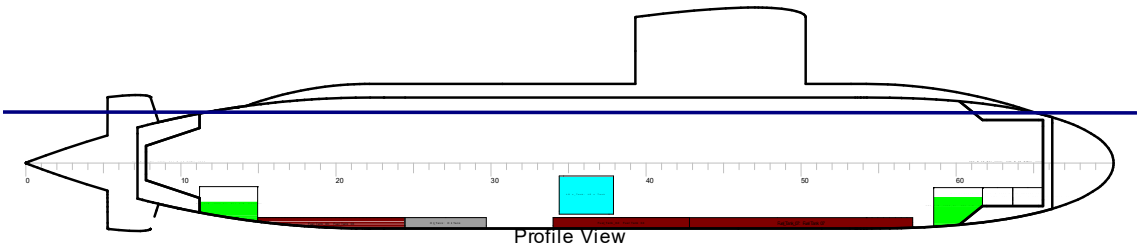

Figure 4.10 Profile View

Table 4.20 Densities

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	DIESEL FUEL	0.83
	LUB, OIL	0.9
	LOX	1.141

Table 4.21 Summary Table of Loading Condition 2a

Stability Calculations for Loading Condition 2A								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	15-24	DIESEL FUEL	98	0.83	32.2	20.077	3.794	-1.149
FUEL TANK 02	15-24	DIESEL FUEL	98	0.83	32.2	20.077	-3.794	-1.149
FUEL TANK 03	15-24	DIESEL FUEL	98	0.83	16.9	20.519	0.000	-4.295
FUEL TANK 04	34-43	DIESEL FUEL	98	0.83	20.2	38.390	0.000	-4.329
FUEL TANK 05	43-57	DIESEL FUEL	98	0.83	20.1	49.947	3.491	-2.532
FUEL TANK 06	43-57	DIESEL FUEL	98	0.83	20.1	49.947	-3.491	-2.532
FUEL TANK 07	43-57	DIESEL FUEL	98	0.83	32.8	49.918	0.000	-4.327
Total DIESEL FUEL					**174.5**	**34.731**	**0.000**	**-2.738**
FRESH WATER								
FRESH WATER TANK 01	38-43	FRESH WATER	98	1.00	7.4	40.599	3.492	-2.534
FRESH WATER TANK 02	38-43	FRESH WATER	98	1.00	7.4	40.599	-3.492	-2.534
Total FRESH WATER					**14.8**	**40.599**	**0.000**	**-2.534**
LUB, OIL								
OIL TANK	24-30	LUB, OIL	98	0.9	13.1	27.071	0.000	-4.329
Total LUB, OIL					**13.1**	**27.071**	**0.000**	**-4.329**
SEA WATER								
AFT MAIN BALLAST TANK	7-11	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	11-15	SEA WATER	37.5	1.025	8.2	13.365	1.088	-3.330
AFT TRIM TANK 02	11-15	SEA WATER	37.5	1.025	8.2	13.365	-1.088	-3.330
COMPENSATING TANK 01	39-40	SEA WATER	10	1.025	0.5	39.699	1.475	-3.569
COMPENSATING TANK 02	39-40	SEA WATER	10	1.025	0.5	39.699	-1.475	-3.569
COMPENSATING TANK 03	41-42	SEA WATER	10	1.025	0.5	41.599	1.475	-3.569
COMPENSATING TANK 04	41-42	SEA WATER	10	1.025	0.5	41.599	-1.475	-3.569
FWD MAIN BALLAST TANK	60-66	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	59-62	SEA WATER	62.5	1.025	13.7	59.790	1.413	-3.295
FWD TRIM TANK 02	59-62	SEA WATER	62.5	1.025	13.7	59.790	-1.413	-3.295

Table 4.21 Summary Table of Loading Condition 2a (continued…)

TORPEDO TUBE FLOODING TANK	64-66	SEA WATER	0	0	0.0	0.000	0.000	0.000
WATER ROUND TORPEDO TANK	62-64	SEA WATER	0	0	0.0	0.000	0.000	0.000
Total SEA WATER					**45.8**	**42.309**	**0.000**	**-3.319**
BILGE WATER / SLUDGE								
SANITARY TANK 01	34-38	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
SANITARY TANK 02	34-38	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
Total BILGE WATER / SLUDGE					**0.0**	**0.000**	**0.000**	**0.000**
LOx								
Lox TANK	34-38	LOX	98	1.141	23.6	36.150	0.000	-2.377
Total LOx					**23.6**	**36.150**	**0.000**	**-2.377**
LOADING CONDITION 2A FIXED WEIGHTS								
COMPLEMENT					3.8	37.561	0.000	-0.160
OFFICER EQUIPMENT					1.6	37.561	0.000	-0.160
P.O. EQUIPMENT					2.0	37.561	0.000	-0.160
RATING EQUIPMENT					0.8	37.561	0.000	-0.160
GARBAGE					0.0	0.000	0.000	0.000
PROVISIONS					20.0	37.561	0.000	-0.160
TORPEDO					18.8	63.650	0.000	-1.500
SPECIAL PERSONNEL & OTHER MILITARY LOADS					1.9	37.561	0.000	-0.160
DESIGN MARGIN					33.0	37.561	0.000	-0.160
CONSTRUCTION MARGIN					65.9	37.561	0.000	-0.160
MAINTENANCE MARGIN					33.0	37.561	0.000	-0.160
Loading Condition 2A Fixed Weights					**180.8**	**40.274**	**0.000**	**-0.299**
Lightweight					**3295.9**	**37.561**	**0.000**	**-0.160**
Deadweight					**452.4**	**37.756**	**0.000**	**-1.843**
Total Displacement					**3748.3**	**37.585**	**0.000**	**-0.363**
Buoyancy					**3748.3**	**37.585**	**0.000**	**-0.234**
Total Buoyancy					**3748.3**	**37.585**	**0.000**	**-0.234**

Table 4.22 Drafts at Equilibrium Angle

Drafts at equilibrium angle		
Draft at LCF	3.701	metres
Draft at AP	3.735	metres
Draft at FP	3.674	metres
Draft at midships	3.704	metres

Table 4.23 Hydrostatics at Equilibrium Angle

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim by the stern	0.060	metres
	0.05	degrees
KG	-0.363	metres
KB	-0.234	metres
FSC	0.011	metres
KGf	-0.353	metres
GMt	0.352	metres
BMt	0.233	metres
BMl	16.705	metres
Waterplane area	299.030	sq.metres
LCG	37.585	metres
LCB	37.585	metres
TCB	0.000	metres
LCF	38.589	metres
TCF	0.000	metres
TPC	3.065	tonnes/cm
MTC	8.994	tonnes-m/cm

Table 4.24 Summary Stability Table

Displacement [ton]	Δ	3748.3	
Length [m]	L_{DWL}	70.13	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	3.701	8.501
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.363	4.437
Longitudinal Center of Gravity [m]	LCG	37.585	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	0.187	
Wind Pressure [kN/m^2]	q_w	0.358	
Density of Air [t/m^3]	ρ_L	0.001225	
Wind Speed [m/s]	v_w	24.179	
Form Coefficient	c_f	0.600	

Table 4.24 Summary Stability Table (continued…)

Projected Area Exposed to Wind Forces [m^2]	A_w	158.095	
Height of the Centroid of the Area Exposed to Wind [m] [from Reference Point] / [from Baseline]	A_{wz}	6.096	10.896
Height of the Centroid of the Area Exposed to Wind Above Half Draught [m] [from Baseline]	A_{wz}-0.5T	6.646	
Maximum Operational Speed of the Surfaced Submarine [knot] / [m/sn]	$v_0\uparrow$	12.000	6.173

Table 4.25 Righting – Heeling Lever Calculations

Heel Angle	**Righting Lever**	**Heeling Lever**				
[°]	hsw	k_F	k_D	k_W	$k_F + k_D + k_W$	$h_{SW} - (k_F+k_D+k_W)$
10	0.0631	0.002	0.002	0.006	0.010	0.053
20	0.1242	0.004	0.002	0.006	0.011	0.113
30	0.1816	0.006	0.002	0.005	0.013	0.169
45	0.2568	0.008	0.001	0.004	0.014	0.243

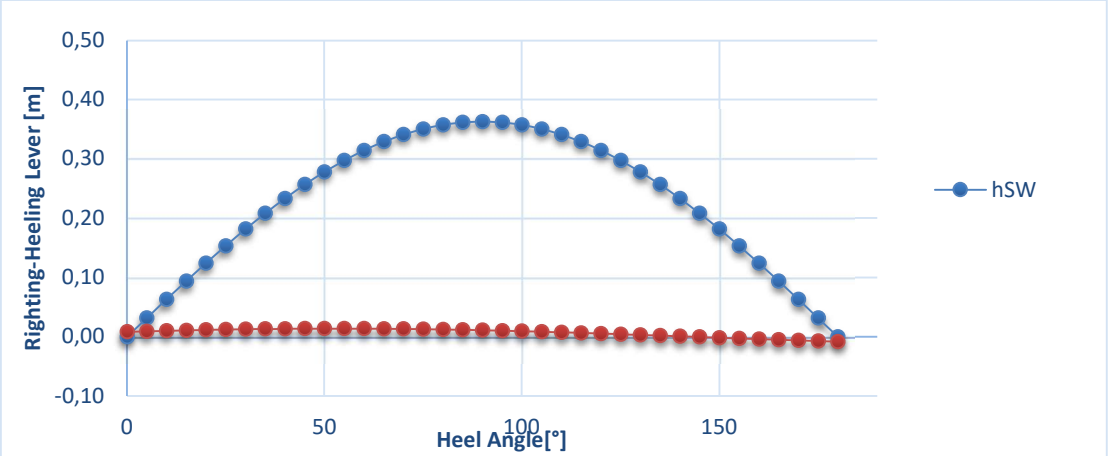

Figure 4.11 Righting – Heeling Lever / Heel Angle

Table 4.26 Criterion Assessment

#	Criterion	Actual Value	Critical Value	Result
1	The buoyancy reserve shall be at least 10% of the pressure tight volume of the submarine in surfaced condition.	12.2	10.0	+
2	Positive remaining lever h_{rem} at least 0.1 m in surfaced condition.	0.352	0.1	+
3	Minimum value for GM	0.352	0.220	+

This section focuses on stability analyses specifically related to loading case 2a, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Buoyancy reserve is 12.2% of the pressure tight volume of the submarine. Thus, the 10% limit value has been exceeded.
- Positive remaining lever h_{rem} is 0.352 m and is above the limit value of 0.1 m.
- The GM value is 0.352 m and is above the limit value of 0.22 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 2a.

4.2.1.4 Loading Condition 2b

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

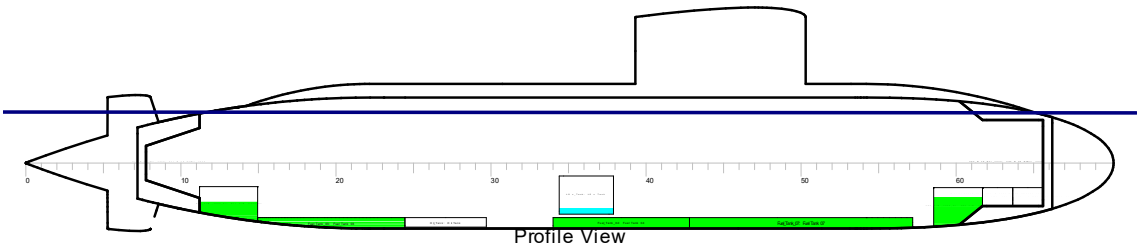

Figure 4.12 Profile View

Table 4.27 Densities

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	LUB, OIL	0.9
	BILGE WATER / SLUDGE	1.005
	LOX	1.141
	SEA WATER & DIESEL FUEL	1.005

Table 4.28 Summary Table of Loading Condition 2b

Stability Calculations for Loading Condition 2B								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	15-24	SEA WATER & DIESEL FUEL	98	1.01	39.0	20.078	3.794	-1.149
FUEL TANK 02	15-24	SEA WATER & DIESEL FUEL	98	1.01	39.0	20.078	-3.794	-1.149
FUEL TANK 03	15-24	SEA WATER & DIESEL FUEL	98	1.01	20.5	20.525	0.000	-4.295
FUEL TANK 04	34-43	SEA WATER & DIESEL FUEL	98	1.01	24.5	38.395	0.000	-4.329
FUEL TANK 05	43-57	SEA WATER & DIESEL FUEL	98	1.01	24.3	49.954	3.491	-2.532
FUEL TANK 06	43-57	SEA WATER & DIESEL FUEL	98	1.01	24.3	49.954	-3.491	-2.532
FUEL TANK 07	43-57	SEA WATER & DIESEL FUEL	98	1.01	39.7	49.931	0.000	-4.327
Total DIESEL FUEL					**211.3**	**34.737**	**0.000**	**-2.738**
FRESH WATER								
FRESH WATER TANK 01	38-43	FRESH WATER	10	1.00	0.8	40.598	3.155	-3.421
FRESH WATER TANK 02	38-43	FRESH WATER	10	1.00	0.8	40.598	-3.155	-3.421
Total FRESH WATER					**1.6**	**40.598**	**0.000**	**-3.421**
LUB, OIL								
OIL TANK	24-30	LUB, OIL	10	0.9	1.3	27.066	0.000	-4.698
Total LUB, OIL					**1.3**	**27.066**	**0.000**	**-4.698**
SEA WATER								
AFT MAIN BALLAST TANK	7-11	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	11-15	SEA WATER	37.5	1.025	8.2	13.366	1.088	-3.330
AFT TRIM TANK 02	11-15	SEA WATER	37.5	1.025	8.2	13.366	-1.088	-3.330
COMPENSATING TANK 01	39-40	SEA WATER	70	1.025	3.4	39.700	1.475	-3.026
COMPENSATING TANK 02	39-40	SEA WATER	70	1.025	3.4	39.700	-1.475	-3.026

Table 4.28 Summary Table of Loading Condition 2b (continued…)

COMPENSATING TANK 03	41-42	SEA WATER	70	1.025	3.4	41.600	1.475	-3.026
COMPENSATING TANK 04	41-42	SEA WATER	70	1.025	3.4	41.600	-1.475	-3.026
FWD MAIN BALLAST TANK	60-66	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	59-62	SEA WATER	62.5	1.025	13.7	59.790	1.413	-3.295
FWD TRIM TANK 02	59-62	SEA WATER	62.5	1.025	13.7	59.790	-1.413	-3.295
TORPEDO TUBE FLOODING TANK	64-66	SEA WATER	0	0	0.0	0.000	0.000	0.000
WATER ROUND TORPEDO TANK	62-64	SEA WATER	0	0	0.0	0.000	0.000	0.000
Total SEA WATER					**57.4**	**41.975**	**0.000**	**-3.242**
BILGE WATER / SLUDGE								
SANITARY TANK 01	34-38	BILGE WATER / SLUDGE	90	1.005	6.9	36.199	3.475	-2.593
SANITARY TANK 02	34-38	BILGE WATER / SLUDGE	90	1.005	6.9	36.199	-3.475	-2.593
Total BILGE WATER / SLUDGE					**13.8**	**36.199**	**0.000**	**-2.593**
LOx								
Lox TANK	34-38	LOX	10	1.141	2.4	36.149	0.000	-3.490
Total LOx					**2.4**	**36.149**	**0.000**	**-3.490**
LOADING CONDITION 2B FIXED WEIGHTS								
COMPLEMENT					3.8	37.561	0.000	-0.160
OFFICER EQUIPMENT					1.6	37.561	0.000	-0.160
P.O. EQUIPMENT					2.0	37.561	0.000	-0.160
RATING EQUIPMENT					0.1	37.561	0.000	-0.160
GARBAGE					3.0	37.561	0.000	-0.160
PROVISIONS					2.0	37.561	0.000	-0.160
TORPEDO					18.8	63.650	0.000	-1.500
SPECIAL PERSONNEL & OTHER MILITARY LOADS					1.9	37.561	0.000	-0.160
DESIGN MARGIN					33.0	37.561	0.000	-0.160
CONSTRUCTION MARGIN					65.9	37.561	0.000	-0.160
MAINTENANCE MARGIN					33.0	37.561	0.000	-0.160
Loading Condition 2B Fixed Weights					**165.1**	**40.532**	**0.000**	**-0.313**
Lightweight					**3295.9**	**37.561**	**0.000**	**-0.160**
Deadweight					**452.5**	**37.814**	**0.000**	**-1.925**
Total Displacement					**3748.4**	**37.592**	**0.000**	**-0.373**
Buoyancy					**3748.3**	**37.592**	**0.000**	**-0.234**
Total Buoyancy					**3748.3**	**37.592**	**0.000**	**-0.234**

Table 4.29 Drafts at Equilibrium Angle

Drafts at equilibrium angle		
Draft at LCF	3.701	metres
Draft at AP	3.719	metres
Draft at FP	3.687	metres
Draft at midships	3.703	metres

Table 4.30 Hydrostatics at Equilibrium Angle

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim by the stern	0.031	metres
	0.03	degrees
KG	-0.373	metres
KB	-0.234	metres
FSC	0.014	metres
KGf	-0.359	metres
GMt	0.358	metres
BMt	0.233	metres
BMl	16.711	metres
Waterplane area	299.050	sq.metres
LCG	37.592	metres
LCB	37.592	metres
TCB	0.000	metres
LCF	38.519	metres
TCF	0.000	metres
TPC	3.065	tonnes/cm
MTC	9.003	tonnes-m/cm

Table 4.31 Summary Stability Table

Displacement [ton]	Δ	3748.4	
Length [m]	L_{DWL}	70.13	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	3.701	8.501
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.373	4.427
Longitudinal Center of Gravity [m]	LCG	37.592	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	0.177	
Wind Pressure [kN/m^2]	q_w	0.358	
Density of Air [t/m^3]	ρ_L	0.001225	
Wind Speed [m/s]	v_w	24.179	

Table 4.31 Summary Stability Table (continued…)

Form Coefficient	c_f	0.600	
Projected Area Exposed to Wind Forces [m^2]	A_w	158.095	
Height of the Centroid of the Area Exposed to Wind [m] [from Reference Point] / [from Baseline]	A_{wz}	6.096	10.896
Height of the Centroid of the Area Exposed to Wind Above Half Draught [m] [from Baseline]	A_{wz}-0.5T	6.646	
Maximum Operational Speed of the Surfaced Submarine [knot] / [m/sn]	$v_0\uparrow$	12.00	6.173

Table 4.32 Righting – Heeling Lever Calculations

Heel Angle	**Righting Lever**	**Heeling Lever**				
[°]	h_{SW}	k_F	k_D	k_W	$k_F + k_D + k_W$	$h_{SW} - (k_F+k_D+k_W)$
10	0.0648	0.002	0.002	0.006	0.010	0.054
20	0.1276	0.005	0.002	0.006	0.012	0.115
30	0.1865	0.007	0.002	0.005	0.014	0.172
45	0.2638	0.010	0.001	0.004	0.016	0.248

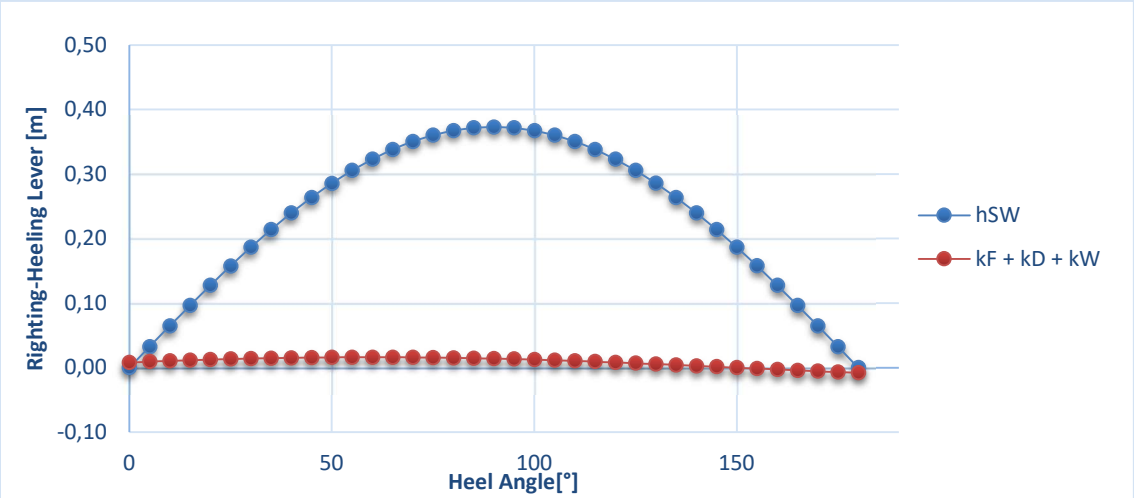

Figure 4.13 Righting – Heeling Lever / Heel Angle

Table 4.33 Criterion Assessment

#	Criterion	Actual Value	Critical Value	Result
1	The buoyancy reserve shall be at least 10% of the pressure tight volume of the submarine in surfaced condition.	12.2	10.0	+
2	Positive remaining lever h_{rem} at least 0.1 m in surfaced condition.	0.359	0.1	+
3	Minimum value for GM	0.358	0.220	+

This section focuses on stability analyses specifically related to loading case 2b, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Buoyancy reserve is 12.2% of the pressure tight volume of the submarine. Thus, the 10% limit value has been exceeded.
- Positive remaining lever h_{rem} is 0.359 m and is above the limit value of 0.1 m.
- The GM value is 0.358 m and is above the limit value of 0.22 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 2b.

4.2.2 Submerged Submarine

4.2.2.1 Loading Condition 3a

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

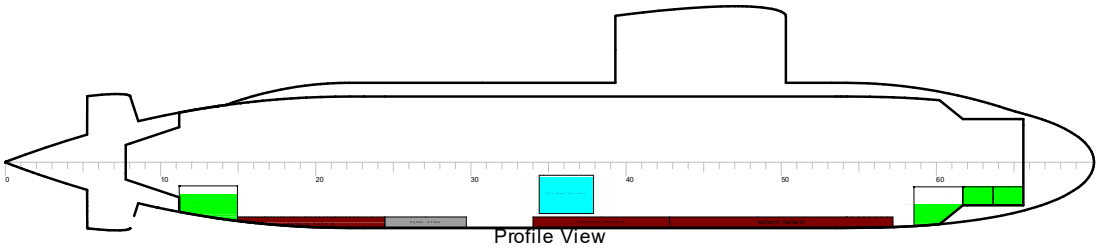

Figure 4.14 Profile View

Table 4.34 Densities

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	DIESEL FUEL	0.83
	LUB, OIL	0.9
	LOX	1.141

Vessel is submerged.

Table 4.35 Summary Table of Loading Condition 3a

Stability Calculations for Loading Condition 3A								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	15-24	DIESEL FUEL	98	0.83	32.2	20.079	3.794	-1.149
FUEL TANK 02	15-24	DIESEL FUEL	98	0.83	32.2	20.079	-3.794	-1.149
FUEL TANK 03	15-24	DIESEL FUEL	98	0.83	16.9	20.532	0.000	-4.295
FUEL TANK 04	34-43	DIESEL FUEL	98	0.83	20.2	38.400	0.000	-4.329
FUEL TANK 05	43-57	DIESEL FUEL	98	0.83	20.1	49.960	3.491	-2.532
FUEL TANK 06	43-57	DIESEL FUEL	98	0.83	20.1	49.960	-3.491	-2.532
FUEL TANK 07	43-57	DIESEL FUEL	98	0.83	32.8	49.946	0.000	-4.327
Total DIESEL FUEL					**174.5**	**34.743**	**0.000**	**-2.738**
FRESH WATER								
FRESH WATER TANK 01	38-43	FRESH WATER	98	1.00	7.4	40.600	3.492	-2.534
FRESH WATER TANK 02	38-43	FRESH WATER	98	1.00	7.4	40.600	-3.492	-2.534
Total FRESH WATER					**14.8**	**40.600**	**0.000**	**-2.534**
LUB, OIL								
OIL TANK	24-30	LUB, OIL	98	0.9	13.1	27.075	0.000	-4.329
Total LUB, OIL					**13.1**	**27.075**	**0.000**	**-4.329**
SEA WATER								
AFT MAIN BALLAST TANK	7-11	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	11-15	SEA WATER	62.5	1.025	13.7	13.287	1.256	-3.040
AFT TRIM TANK 02	11-15	SEA WATER	62.5	1.025	13.7	13.287	-1.256	-3.040
COMPENSATING TANK 01	39-40	SEA WATER	20	1.025	1.0	39.700	1.475	-3.458
COMPENSATING TANK 02	39-40	SEA WATER	20	1.025	1.0	39.700	-1.475	-3.458
COMPENSATING TANK 03	41-42	SEA WATER	20	1.025	1.0	41.600	1.475	-3.458
COMPENSATING TANK 04	41-42	SEA WATER	20	1.025	1.0	41.600	-1.475	-3.458
FWD MAIN BALLAST TANK	60-66	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	59-62	SEA WATER	37.5	1.025	8.2	59.685	1.253	-3.638
FWD TRIM TANK 02	59-62	SEA WATER	37.5	1.025	8.2	59.685	-1.253	-3.638

Table 4.35 Summary Table of Loading Condition 3a (continued…)

TORPEDO TUBE FLOODING TANK	64-66	SEA WATER	98	1.025	9.4	64.625	0.000	-2.362
WATER ROUND TORPEDO TANK	62-64	SEA WATER	98	1.025	9.4	62.675	0.000	-2.362
Total SEA WATER					**66.6**	**40.608**	**0.000**	**-3.020**
BILGE WATER / SLUDGE								
SANITARY TANK 01	34-38	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
SANITARY TANK 02	34-38	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
Total BILGE WATER / SLUDGE					**0.0**	**0.000**	**0.000**	**0.000**
LOx								
Lox TANK	34-38	LOX	98	1.141	23.6	36.150	0.000	-2.377
Total LOx					**23.6**	**36.150**	**0.000**	**-2.377**
LOADING CONDITION 3A FIXED WEIGHTS								
COMPLEMENT					3.8	37.561	0.000	-0.160
OFFICER EQUIPMENT					1.6	37.561	0.000	-0.160
P.O. EQUIPMENT					2.0	37.561	0.000	-0.160
RATING EQUIPMENT					0.8	37.561	0.000	-0.160
GARBAGE					0.0	0.000	0.000	0.000
PROVISIONS					20.0	37.561	0.000	-0.160
TORPEDO					0.0	0.000	0.000	0.000
SPECIAL PERSONNEL & OTHER MILITARY LOADS					0.0	0.000	0.000	0.000
DESIGN MARGIN					33.0	37.561	0.000	-0.160
CONSTRUCTION MARGIN					65.9	37.561	0.000	-0.160
MAINTENANCE MARGIN					33.0	37.561	0.000	-0.160
Loading Condition 3A Fixed Weights					**160.1**	**37.561**	**0.000**	**-0.160**
Lightweight					**3295.9**	**37.561**	**0.000**	**-0.160**
Deadweight					**452.5**	**36.633**	**0.000**	**-1.888**
Total Displacement					**3748.4**	**37.449**	**0.000**	**-0.369**
Buoyancy					**3748.4**	**37.449**	**0.000**	**0.000**
Total Buoyancy					**3748.4**	**37.449**	**0.000**	**0.000**

Table 4.36 Hydrostatics at Equilibrium Angle

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim	No trim	metres
KG	-0.369	metres
KB	0.000	metres
FSC	0.011	metres
KGf	-0.358	metres
GMt	0.358	metres
BMt	0.000	metres
BMl	0.000	metres
Waterplane area	0.000	sq.metres
LCG	37.449	metres
LCB	37.449	metres
TCB	0.000	metres
LCF	35.077	metres
TCF	0.000	metres
TPC	0.000	tonnes/cm
MTC	0.197	tonnes-m/cm

Table 4.37 Summary Stability Table

Displacement [ton]	Δ	3748.4	
Length [m]	L_{DWL}	70.13	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	3.701	8.501
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.369	4.431
Longitudinal Center of Gravity [m]	LCG	37.449	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	0.181	
Maximum Operational Speed of the Submerged Submarine [knot] / [m/sn]	$v_0\uparrow$	22.000	11.317

Table 4.38 Righting – Heeling Lever Calculations

Heel Angle	**Righting Lever**	**Heeling Lever**			
[°]	h_{SUB}	k_F	kD	$k_F + k_D$	$h_{SW} - (k_F+k_D)$
10	0.0640	0.002	0.007	0.009	0.055
20	0.1261	0.004	0.006	0.010	0.116
30	0.1843	0.006	0.006	0.011	0.173
45	0.2606	0.008	0.005	0.013	0.248

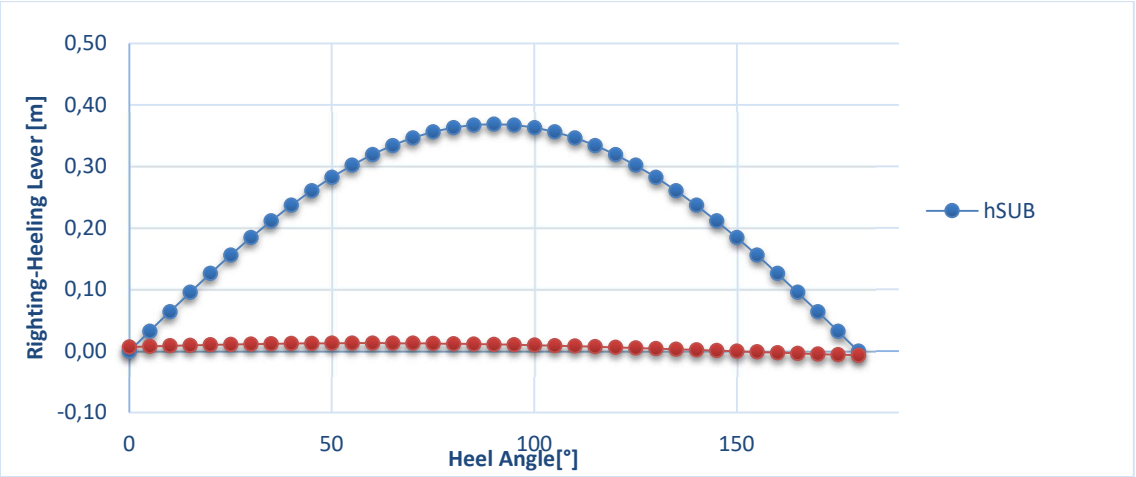

Figure 4.15 Righting – Heeling Lever / Heel Angle

Table 4.39 Criterion Assessment

#	Criterion	Actual Value	Critical Value	Result
1	Positive remaining lever h_{rem} at least 0.05 m in dived condition.	0.358	0.050	+
2	Minimum value for BG	0.369	0.350	+

This section focuses on stability analyses specifically related to loading case 3a, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Positive remaining lever h_{rem} is 0.358 m and is above the limit value of 0.05 m.
- The BG value is 0.369 m and is above the limit value of 0.35 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 3a.

4.2.2.2 Loading Condition 3b

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

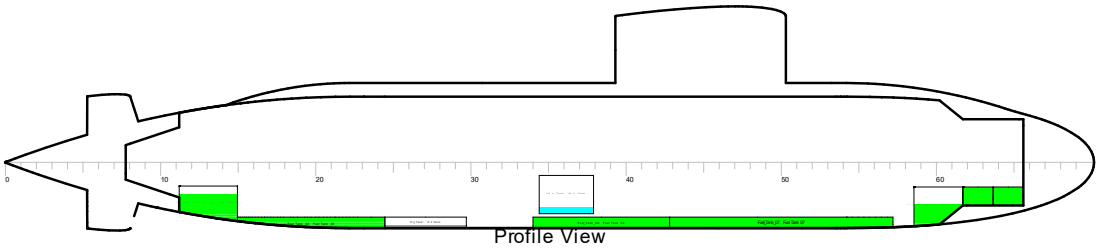

Figure 4.16 Profile View

Table 4.40 Densities

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	LUB, OIL	0.9
	BILGE WATER / SLUDGE	1.005
	LOX	1.141
	SEA WATER & DIESEL FUEL	1.005

Vessel is submerged.

Table 4.41 Summary Table of Loading Condition 3b

Stability Calculations for Loading Condition 3B								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	15-24	SEA WATER & DIESEL FUEL	98	1.01	39.0	20.079	3.794	-1.149
FUEL TANK 02	15-24	SEA WATER & DIESEL FUEL	98	1.01	39.0	20.079	-3.794	-1.149
FUEL TANK 03	15-24	SEA WATER & DIESEL FUEL	98	1.01	20.5	20.532	0.000	-4.295
FUEL TANK 04	34-43	SEA WATER & DIESEL FUEL	98	1.01	24.5	38.400	0.000	-4.329
FUEL TANK 05	43-57	SEA WATER & DIESEL FUEL	98	1.01	24.3	49.960	3.491	-2.532
FUEL TANK 06	43-57	SEA WATER & DIESEL FUEL	98	1.01	24.3	49.960	-3.491	-2.532
FUEL TANK 07	43-57	SEA WATER & DIESEL FUEL	98	1.01	39.7	49.946	0.000	-4.327
Total DIESEL FUEL					**211.3**	**34.743**	**0.000**	**-2.738**
FRESH WATER								
FRESH WATER TANK 01	38-43	FRESH WATER	10	1.00	0.8	40.600	3.155	-3.421
FRESH WATER TANK 02	38-43	FRESH WATER	10	1.00	0.8	40.600	-3.155	-3.421
Total FRESH WATER					**1.6**	**40.600**	**0.000**	**-3.421**
LUB, OIL								
OIL TANK	24-30	LUB, OIL	10	0.9	1.3	27.075	0.000	-4.698
Total LUB, OIL					**1.3**	**27.075**	**0.000**	**-4.698**
SEA WATER								
AFT MAIN BALLAST TANK	7-11	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	11-15	SEA WATER	64	1.025	14.0	13.284	1.264	-3.024
AFT TRIM TANK 02	11-15	SEA WATER	64	1.025	14.0	13.284	-1.264	-3.024
COMPENSATING TANK 01	39-40	SEA WATER	80	1.025	3.8	39.700	1.475	-2.946
COMPENSATING TANK 02	39-40	SEA WATER	80	1.025	3.8	39.700	-1.475	-2.946

Table 4.41 Summary Table of Loading Condition 3b (continued…)

COMPENSATING TANK 03	41-42	SEA WATER	80	1.025	3.8	41.600	1.475	-2.946
COMPENSATING TANK 04	41-42	SEA WATER	80	1.025	3.8	41.600	-1.475	-2.946
FWD MAIN BALLAST TANK	60-66	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	59-62	SEA WATER	36	1.025	7.9	59.676	1.242	-3.661
FWD TRIM TANK 02	59-62	SEA WATER	36	1.025	7.9	59.676	-1.242	-3.661
TORPEDO TUBE FLOODING TANK	64-66	SEA WATER	98	1.025	9.4	64.625	0.000	-2.362
WATER ROUND TORPEDO TANK	62-64	SEA WATER	98	1.025	9.4	62.675	0.000	-2.362
Total SEA WATER					**77.8**	**40.222**	**0.000**	**-2.978**
BILGE WATER / SLUDGE								
SANITARY TANK 01	34-38	BILGE WATER / SLUDGE	90	1.005	6.9	36.200	3.475	-2.593
SANITARY TANK 02	34-38	BILGE WATER / SLUDGE	90	1.005	6.9	36.200	-3.475	-2.593
Total BILGE WATER / SLUDGE					**13.8**	**36.200**	**0.000**	**-2.593**
LOx								
Lox TANK	34-38	LOX	10	1.141	2.4	36.150	0.000	-3.490
Total LOx					**2.4**	**36.150**	**0.000**	**-3.490**
LOADING CONDITION 3B FIXED WEIGHTS								
COMPLEMENT					3.8	37.561	0.000	-0.160
OFFICER EQUIPMENT					1.6	37.561	0.000	-0.160
P.O. EQUIPMENT					2.0	37.561	0.000	-0.160
RATING EQUIPMENT					0.1	37.561	0.000	-0.160
GARBAGE					3.0	37.561	0.000	-0.160
PROVISIONS					2.0	37.561	0.000	-0.160
TORPEDO					0.0	0.000	0.000	0.000
SPECIAL PERSONNEL & OTHER MILITARY LOADS					0.0	0.000	0.000	0.000
DESIGN MARGIN					33.0	37.561	0.000	-0.160
CONSTRUCTION MARGIN					65.9	37.561	0.000	-0.160
MAINTENANCE MARGIN					33.0	37.561	0.000	-0.160
Loading Condition 3B Fixed Weights					**144.4**	**37.561**	**0.000**	**-0.160**
Lightweight					**3295.9**	**37.561**	**0.000**	**-0.160**
Deadweight					**452.5**	**36.633**	**0.000**	**-1.965**
Total Displacement					**3748.4**	**37.449**	**0.000**	**-0.378**
Buoyancy					**3748.4**	**37.449**	**0.000**	**0.000**
Total Buoyancy					**3748.4**	**37.449**	**0.000**	**0.000**

Table 4.42 Hydrostatics at Equilibrium Angle

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim	No trim	metres
KG	-0.378	metres
KB	0.000	metres
FSC	0.014	metres
KGf	-0.364	metres
GMt	0.364	metres
BMt	0.000	metres
BMl	0.000	metres
Waterplane area	0.000	sq.metres
LCG	37.449	metres
LCB	37.449	metres
TCB	0.000	metres
LCF	35.077	metres
TCF	0.000	metres
TPC	0.000	tonnes/cm
MTC	0.202	tonnes-m/cm

Table 4.43 Summary Stability Table

Displacement [ton]	Δ	3748.4	
Length [m]	L_{DWL}	70.13	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	3.701	8.501
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.378	4.422
Longitudinal Center of Gravity [m]	LCG	37.449	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	0.172	
Maximum Operational Speed of the Submerged Submarine [knot] / [m/sn]	$v_0\uparrow$	22.000	11.317

Table 4.44 Righting – Heeling Lever Calculations

Heel Angle	**Righting Lever**	**Heeling Lever**			
[°]	h_{SUB}	k_F	kD	$k_F + k_D$	$h_{SW} - (k_F+k_D)$
10	0.0656	0.002	0.006	0.009	0.057
20	0.1292	0.005	0.006	0.011	0.118
30	0.1889	0.007	0.006	0.013	0.176
45	0.2672	0.010	0.005	0.014	0.253

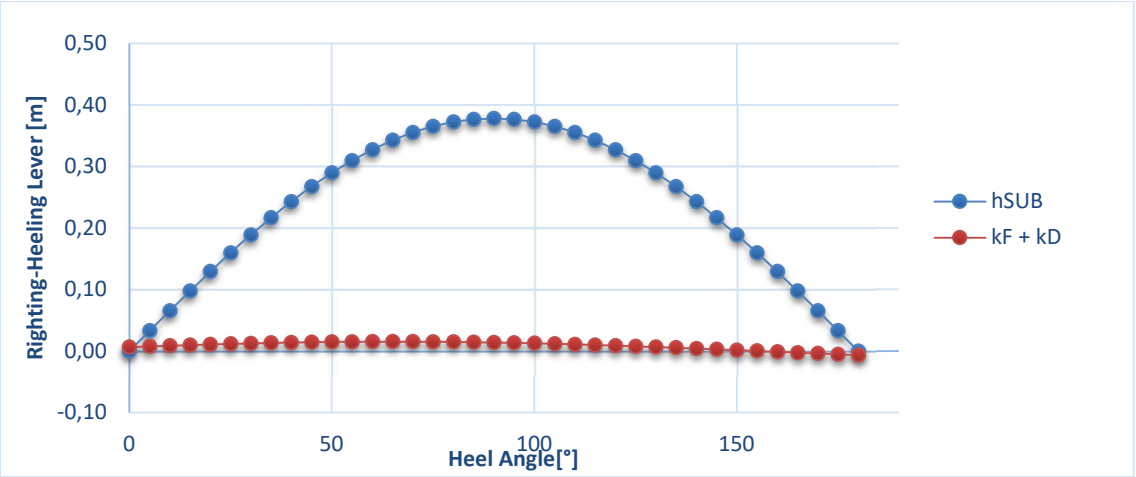

Figure 4.17 Righting – Heeling Lever / Heel Angle

Table 4.45 Criterion Assessment

#	Criterion	Actual Value	Critical Value	Result
1	Positive remaining lever h_{rem} at least 0.05 m in dived condition.	0.364	0.050	+
2	Minimum value for BG	0.378	0.350	+

This section focuses on stability analyses specifically related to loading case 3b, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Positive remaining lever h_{rem} is 0.364 m and is above the limit value of 0.05 m.
- The BG value is 0.378 m and is above the limit value of 0.35 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 3b.

4.2.2.3 Loading Condition 4a

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

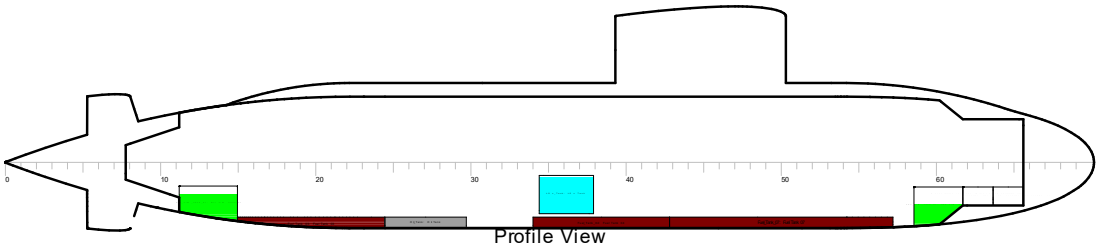

Figure 4.18 Profile View

Table 4.46 Densities

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	DIESEL FUEL	0.83
	LUB, OIL	0.9
	LOX	1.141

Vessel is submerged.

Table 4.47 Summary Table of Loading Condition 4a

Stability Calculations for Loading Condition 4A								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	15-24	DIESEL FUEL	98	0.83	32.2	20.079	3.794	-1.149
FUEL TANK 02	15-24	DIESEL FUEL	98	0.83	32.2	20.079	-3.794	-1.149
FUEL TANK 03	15-24	DIESEL FUEL	98	0.83	16.9	20.532	0.000	-4.295
FUEL TANK 04	34-43	DIESEL FUEL	98	0.83	20.2	38.400	0.000	-4.329
FUEL TANK 05	43-57	DIESEL FUEL	98	0.83	20.1	49.960	3.491	-2.532
FUEL TANK 06	43-57	DIESEL FUEL	98	0.83	20.1	49.960	-3.491	-2.532
FUEL TANK 07	43-57	DIESEL FUEL	98	0.83	32.8	49.946	0.000	-4.327
Total DIESEL FUEL					**174.5**	**34.743**	**0.000**	**-2.738**
FRESH WATER								
FRESH WATER TANK 01	38-43	FRESH WATER	98	1.00	7.4	40.600	3.492	-2.534
FRESH WATER TANK 02	38-43	FRESH WATER	98	1.00	7.4	40.600	-3.492	-2.534
Total FRESH WATER					**14.8**	**40.600**	**0.000**	**-2.534**
LUB, OIL								
OIL TANK	24-30	LUB, OIL	98	0.9	13.1	27.075	0.000	-4.329
Total LUB, OIL					**13.1**	**27.075**	**0.000**	**-4.329**
SEA WATER								
AFT MAIN BALLAST TANK	7-11	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	11-15	SEA WATER	62.5	1.025	13.7	13.287	1.256	-3.040
AFT TRIM TANK 02	11-15	SEA WATER	62.5	1.025	13.7	13.287	-1.256	-3.040
COMPENSATING TANK 01	39-40	SEA WATER	10	1.025	0.5	39.700	1.475	-3.569
COMPENSATING TANK 02	39-40	SEA WATER	10	1.025	0.5	39.700	-1.475	-3.569
COMPENSATING TANK 03	41-42	SEA WATER	10	1.025	0.5	41.600	1.475	-3.569
COMPENSATING TANK 04	41-42	SEA WATER	10	1.025	0.5	41.600	-1.475	-3.569
FWD MAIN BALLAST TANK	60-66	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	59-62	SEA WATER	37.5	1.025	8.2	59.685	1.253	-3.638

Table 4.47 Summary Table of Loading Condition 4a (continued…)

FWD TRIM TANK 02	59-62	SEA WATER	37.5	1.025	8.2	59.685	-1.253	-3.638
TORPEDO TUBE FLOODING TANK	64-66	SEA WATER	0	0	0.0	0.000	0.000	0.000
WATER ROUND TORPEDO TANK	62-64	SEA WATER	0	0	0.0	0.000	0.000	0.000
Total SEA WATER					**45.8**	**31.107**	**0.000**	**-3.277**
BILGE WATER / SLUDGE								
SANITARY TANK 01	34-38	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
SANITARY TANK 02	34-38	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
Total BILGE WATER / SLUDGE					**0.0**	**0.000**	**0.000**	**0.000**
LOx								
Lox TANK	34-38	LOX	98	1.141	23.6	36.150	0.000	-2.377
Total LOx					**23.6**	**36.150**	**0.000**	**-2.377**
LOADING CONDITION 4A FIXED WEIGHTS								
COMPLEMENT					3.8	37.561	0.000	-0.160
OFFICER EQUIPMENT					1.6	37.561	0.000	-0.160
P.O. EQUIPMENT					2.0	37.561	0.000	-0.160
RATING EQUIPMENT					0.8	37.561	0.000	-0.160
GARBAGE					0.0	0.000	0.000	0.000
PROVISIONS					20.0	37.561	0.000	-0.160
TORPEDO					18.8	63.650	0.000	-1.500
SPECIAL PERSONNEL & OTHER MILITARY LOADS					1.9	37.561	0.000	-0.160
DESIGN MARGIN					33.0	37.561	0.000	-0.160
CONSTRUCTION MARGIN					65.9	37.561	0.000	-0.160
MAINTENANCE MARGIN					33.0	37.561	0.000	-0.160
Loading Condition 4A Fixed Weights					**180.8**	**40.274**	**0.000**	**-0.299**
Lightweight					**3295.9**	**37.561**	**0.000**	**-0.160**
Deadweight					**452.5**	**36.633**	**0.000**	**-1.838**
Total Displacement					**3748.4**	**37.449**	**0.000**	**-0.363**
Buoyancy					**3748.4**	**37.449**	**0.000**	**0.000**
Total Buoyancy					**3748.4**	**37.449**	**0.000**	**0.000**

Table 4.48 Hydrostatics at Equilibrium Angle

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim	No trim	metres
KG	-0.363	metres
KB	0.000	metres
FSC	0.010	metres
KGf	-0.352	metres
GMt	0.352	metres
BMt	0.000	metres
BMl	0.000	metres
Waterplane area	0.000	sq.metres
LCG	37.449	metres
LCB	37.449	metres
TCB	0.000	metres
LCF	35.077	metres
TCF	0.000	metres
TPC	0.000	tonnes/cm
MTC	0.194	tonnes-m/cm

Table 4.49 Summary Stability Table

Displacement [ton]	Δ	3748.4	
Length [m]	L_{DWL}	70.13	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	3.701	8.501
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.363	4.437
Longitudinal Center of Gravity [m]	LCG	37.449	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	0.187	
Maximum Operational Speed of the Submerged Submarine [knot] / [m/sn]	$v_0\uparrow$	22.000	11.317

Table 4.50 Righting – Heeling Lever Calculations

Heel Angle	**Righting Lever**	**Heeling Lever**			
[°]	h_{SUB}	k_F	kD	$k_F + k_D$	$h_{SW} - (k_F+k_D)$
10	0.0630	0.002	0.007	0.009	0.054
20	0.1240	0.003	0.007	0.010	0.114
30	0.1813	0.005	0.006	0.011	0.170
45	0.2564	0.007	0.005	0.012	0.244

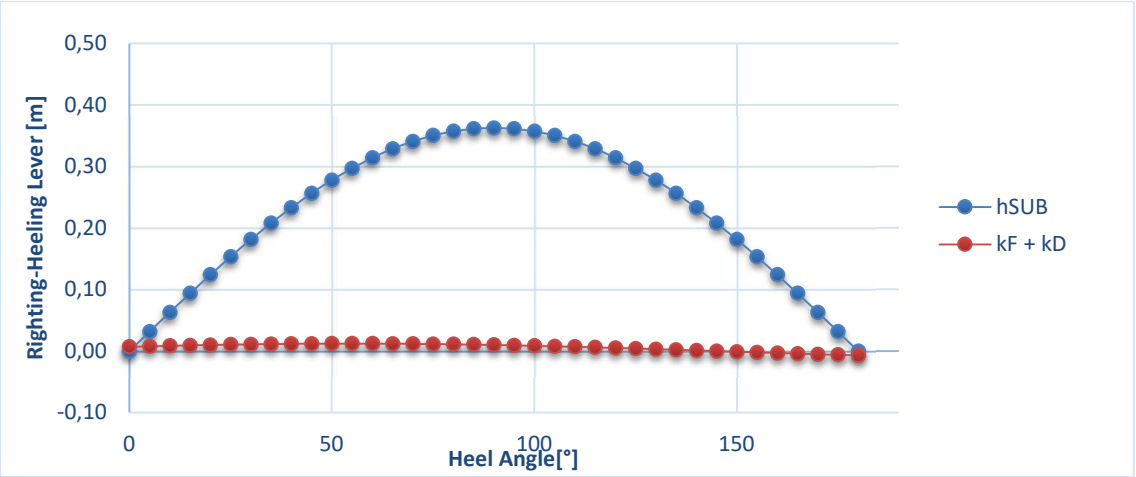

Figure 4.19 Righting – Heeling Lever / Heel Angle

Table 4.51 Criterion Assessment

#	Criterion	Actual Value	Critical Value	Result
1	Positive remaining lever h_{rem} at least 0.05 m in dived condition.	0.353	0.050	+
2	Minimum value for BG	0.363	0.350	+

This section focuses on stability analyses specifically related to loading case 4a, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Positive remaining lever h_{rem} is 0.353 m and is above the limit value of 0.05 m.
- The BG value is 0.363 m and is above the limit value of 0.35 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 4a.

4.2.2.4 Loading Condition 4b

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

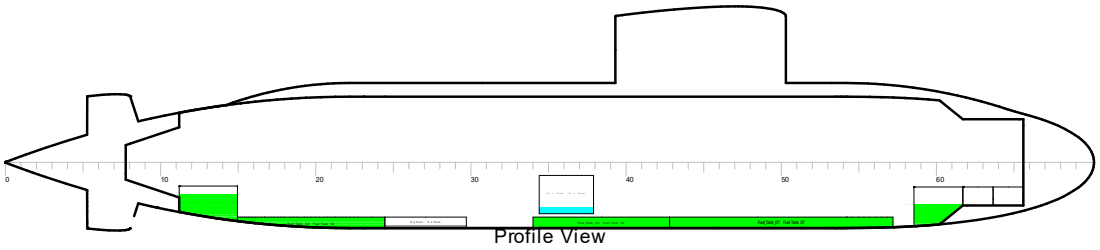

Figure 4.20 Profile View

Table 4.52 Densities

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	LUB, OIL	0.9
	BILGE WATER / SLUDGE	1.005
	LOX	1.141
	SEA WATER & DIESEL FUEL	1.005

Vessel is submerged.

Table 4.53 Summary Table of Loading Condition 4b

Stability Calculations for Loading Condition 4B								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	15-24	SEA WATER & DIESEL FUEL	98	1.01	39.0	20.079	3.794	-1.149
FUEL TANK 02	15-24	SEA WATER & DIESEL FUEL	98	1.01	39.0	20.079	-3.794	-1.149
FUEL TANK 03	15-24	SEA WATER & DIESEL FUEL	98	1.01	20.5	20.532	0.000	-4.295
FUEL TANK 04	34-43	SEA WATER & DIESEL FUEL	98	1.01	24.5	38.400	0.000	-4.329
FUEL TANK 05	43-57	SEA WATER & DIESEL FUEL	98	1.01	24.3	49.960	3.491	-2.532
FUEL TANK 06	43-57	SEA WATER & DIESEL FUEL	98	1.01	24.3	49.960	-3.491	-2.532
FUEL TANK 07	43-57	SEA WATER & DIESEL FUEL	98	1.01	39.7	49.946	0.000	-4.327
Total DIESEL FUEL					**211.3**	**34.743**	**0.000**	**-2.738**
FRESH WATER								
FRESH WATER TANK 01	38-43	FRESH WATER	10	1.00	0.8	40.600	3.155	-3.421
FRESH WATER TANK 02	38-43	FRESH WATER	10	1.00	0.8	40.600	-3.155	-3.421
Total FRESH WATER					**1.6**	**40.600**	**0.000**	**-3.421**
LUB, OIL								
OIL TANK	24-30	LUB, OIL	10	0.9	1.3	27.075	0.000	-4.698
Total LUB, OIL					**1.3**	**27.075**	**0.000**	**-4.698**
SEA WATER								
AFT MAIN BALLAST TANK	7-11	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	11-15	SEA WATER	64	1.025	14.0	13.284	1.264	-3.024
AFT TRIM TANK 02	11-15	SEA WATER	64	1.025	14.0	13.284	-1.264	-3.024
COMPENSATING TANK 01	39-40	SEA WATER	70	1.025	3.4	39.700	1.475	-3.026
COMPENSATING TANK 02	39-40	SEA WATER	70	1.025	3.4	39.700	-1.475	-3.026

Table 4.53 Summary Table of Loading Condition 4b (continued…)

COMPENSATING TANK 03	41-42	SEA WATER	70	1.025	3.4	41.600	1.475	-3.026
COMPENSATING TANK 04	41-42	SEA WATER	70	1.025	3.4	41.600	-1.475	-3.026
FWD MAIN BALLAST TANK	60-66	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	59-62	SEA WATER	36	1.025	7.9	59.676	1.242	-3.661
FWD TRIM TANK 02	59-62	SEA WATER	36	1.025	7.9	59.676	-1.242	-3.661
TORPEDO TUBE FLOODING TANK	64-66	SEA WATER	0	0	0.0	0.000	0.000	0.000
WATER ROUND TORPEDO TANK	62-64	SEA WATER	0	0	0.0	0.000	0.000	0.000
Total SEA WATER					**57.4**	**32.496**	**0.000**	**-3.200**
BILGE WATER / SLUDGE								
SANITARY TANK 01	34-38	BILGE WATER / SLUDGE	90	1.005	6.9	36.200	3.475	-2.593
SANITARY TANK 02	34-38	BILGE WATER / SLUDGE	90	1.005	6.9	36.200	-3.475	-2.593
Total BILGE WATER / SLUDGE					**13.8**	**36.200**	**0.000**	**-2.593**
LOx								
Lox TANK	34-38	LOX	10	1.141	2.4	36.150	0.000	-3.490
Total LOx					**2.4**	**36.150**	**0.000**	**-3.490**
LOADING CONDITION 4B FIXED WEIGHTS								
COMPLEMENT					3.8	37.561	0.000	-0.160
OFFICER EQUIPMENT					1.6	37.561	0.000	-0.160
P.O. EQUIPMENT					2.0	37.561	0.000	-0.160
RATING EQUIPMENT					0.1	37.561	0.000	-0.160
GARBAGE					3.0	37.561	0.000	-0.160
PROVISIONS					2.0	37.561	0.000	-0.160
TORPEDO					18.8	63.650	0.000	-1.500
SPECIAL PERSONNEL & OTHER MILITARY LOADS					1.9	37.561	0.000	-0.160
DESIGN MARGIN					33.0	37.561	0.000	-0.160
CONSTRUCTION MARGIN					65.9	37.561	0.000	-0.160
MAINTENANCE MARGIN					33.0	37.561	0.000	-0.160
Loading Condition 4B Fixed Weights					**165.1**	**40.532**	**0.000**	**-0.313**
Lightweight					**3295.9**	**37.561**	**0.000**	**-0.160**
Deadweight					**452.5**	**36.633**	**0.000**	**-1.919**
Total Displacement					**3748.4**	**37.449**	**0.000**	**-0.372**
Buoyancy					**3748.4**	**37.449**	**0.000**	**0.000**
Total Buoyancy					**3748.4**	**37.449**	**0.000**	**0.000**

Table 4.54 Hydrostatics at Equilibrium Angle

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim	No trim	metres
KG	-0.372	metres
KB	0.000	metres
FSC	0.014	metres
KGf	-0.358	metres
GMt	0.358	metres
BMt	0.000	metres
BMl	0.000	metres
Waterplane area	0.000	sq.metres
LCG	37.449	metres
LCB	37.449	metres
TCB	0.000	metres
LCF	35.077	metres
TCF	0.000	metres
TPC	0.000	tonnes/cm
MTC	0.199	tonnes-m/cm
Shell thickness	8.000	mm

Table 4.55 Summary Stability Table

Displacement [ton]	Δ	3748.4	
Length [m]	L_{DWL}	70.13	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	3.701	8.501
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.372	4.428
Longitudinal Center of Gravity [m]	LCG	37.449	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	0.178	
Maximum Operational Speed of the Submerged Submarine [knot] / [m/sn]	$v_0\uparrow$	22.000	11.317

Table 4.56 Righting – Heeling Lever Calculations

Heel Angle	**Righting Lever**	**Heeling Lever**			
[°]	h_{SUB}	k_F	kD	$k_F + k_D$	$h_{SW} - (k_F+k_D)$
10	0.0647	0.002	0.007	0.009	0.056
20	0.1274	0.005	0.006	0.011	0.116
30	0.1862	0.007	0.006	0.013	0.173
45	0.2633	0.010	0.005	0.015	0.249

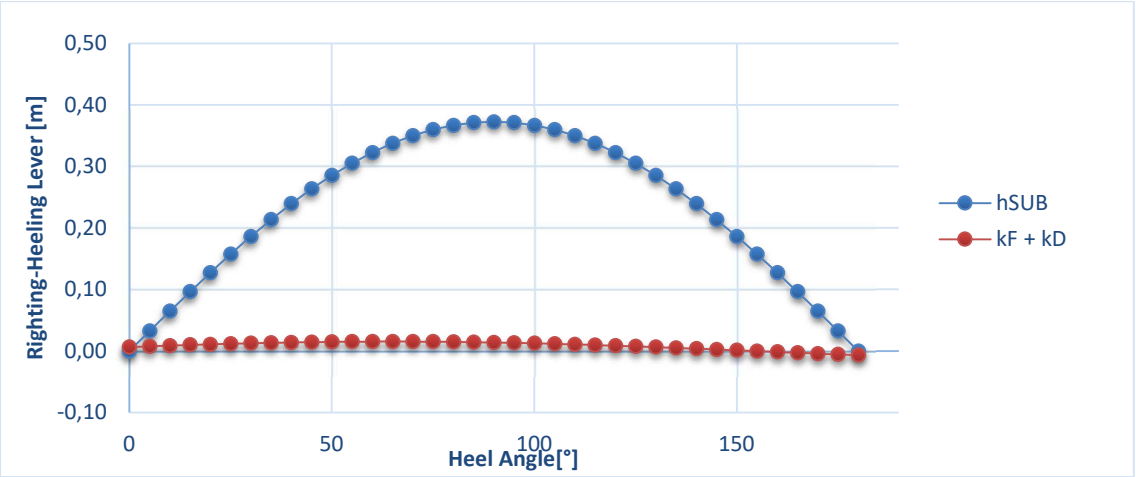

Figure 4.21 Righting – Heeling Lever / Heel Angle

Table 4.57 Criterion Assessment

#	Criterion	Actual Value	Critical Value	Result
1	Positive remaining lever h_{rem} at least 0.05 m in dived condition.	0.358	0.050	+
2	Minimum value for BG	0.372	0.350	+

This section focuses on stability analyses specifically related to loading case 4b, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Positive remaining lever h_{rem} is 0.358 m and is above the limit value of 0.05 m.
- The BG value is 0.372 m and is above the limit value of 0.35 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 4b.

4.2.3 Assessment of Compliance with the Rules

The following summary table compares the limit values with the values observed in the scenarios, in accordance with the rules.

Table 4.58 Criterion Assessment

SURFACED							
#	Criterion	Loading Condition				Critical Value	Result
		1A	1B	2A	2B		
		Actual Value					
1	The buoyancy reserve shall be at least 10% of the pressure tight volume of the submarine.	12.2	12.2	12.2	12.2	10.0	+
2	Positive remaining lever h_{rem} at least 0.1 m.	0.358	0.365	0.352	0.359	0.1	+
3	Minimum value for GM	0.357	0.364	0.352	0.358	0.220	+
SUBMERGED							
#	Criterion	Loading Condition				Critical Value	Result
		3A	3B	4A	4B		
		Actual Value					
1	Positive remaining lever h_{rem} at least 0.05 m.	0.358	0.364	0.353	0.358	0.050	+
2	Minimum value for BG	0.369	0.378	0.363	0.372	0.350	+

Table 4.58 demonstrates that intact stability requirements are fulfilled for all loading conditions.

4.3 Damaged Stability Analysis

This section presents the damaged stability analysis and rule evaluations. In damaged stability analysis, one important tank (e.g. a diving tank) within the exostructure must be fails because of damage according to DNV rules. For the damage scenarios, both the aft main ballast tank and the fore main ballast tank were separately subjected to damage across each loading condition. Subsequently, the criteria for damaged stability were evaluated within this framework.

4.3.1 Surfaced Submarine

The analysis of damaged stability in the surfaced condition focused on loading conditions 1a, 1b, 2a, and 2b. Within each loading condition, two distinct scenarios were considered based on whether the aft main ballast tank or the fore main ballast tank was damaged.

4.3.1.1 Loading Condition 1a

- **Aft Main Ballast Tank Damaged**

This section specifically addresses the scenario in which the aft main ballast tank is damaged within loading condition 1a. The calculations for damaged stability in this particular scenario are presented below.

The following tables provide essential information such as drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented.

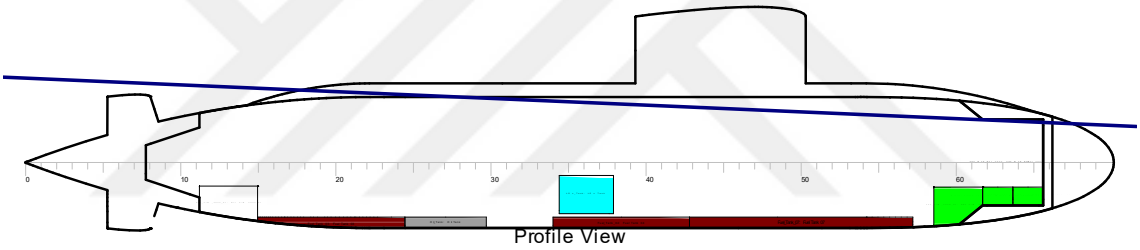

Figure 4.22 Profile View

Table 4.59 Densities

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1.000
	DIESEL FUEL	0.830
	LUB. OIL	0.900
	LOX	1.141

Table 4.60 Drafts at Equilibrium Angle

Drafts at equilibrium angle		
Draft at LCF	3.725	metres
Draft at AP	6.184	metres
Draft at FP	2.710	metres
Draft at midships	4.447	metres

Table 4.61 Hydrostatics at Equilibrium Angle

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim by the stern	3.473	metres
	2.84	degrees
KG	-0.364	metres
KB	-0.135	metres
Displacement	3747.5	tonnes
FSC	0.035	metres
KGf	-0.329	metres
GMt	0.329	metres
BMt	0.135	metres
BMl	4.973	metres
Waterplane area	190.620	sq.metres
LCG	37.780	metres
LCB	37.792	metres
TCB	0.000	metres
VCB	-0.135	metres
TCG	0.000	metres
LCF	49.668	metres
TCF	0.000	metres
TPC	1.954	tonnes/cm
MTC	2.779	tonnes-m/cm

Table 4.62 Righting – Heeling Lever Calculations

Heel Angle	**Righting Lever**	**Heeling Lever**				
[°]	hsw	k_F	k_D	k_W	$k_F + k_D + k_W$	$h_{SW} - (k_F+k_D+k_W)$
10	0.0613	0.006	0.002	0.006	0.014	0.047
20	0.1222	0.012	0.002	0.006	0.020	0.103
30	0.1795	0.018	0.002	0.005	0.024	0.155
45	0.2549	0.025	0.001	0.004	0.030	0.224

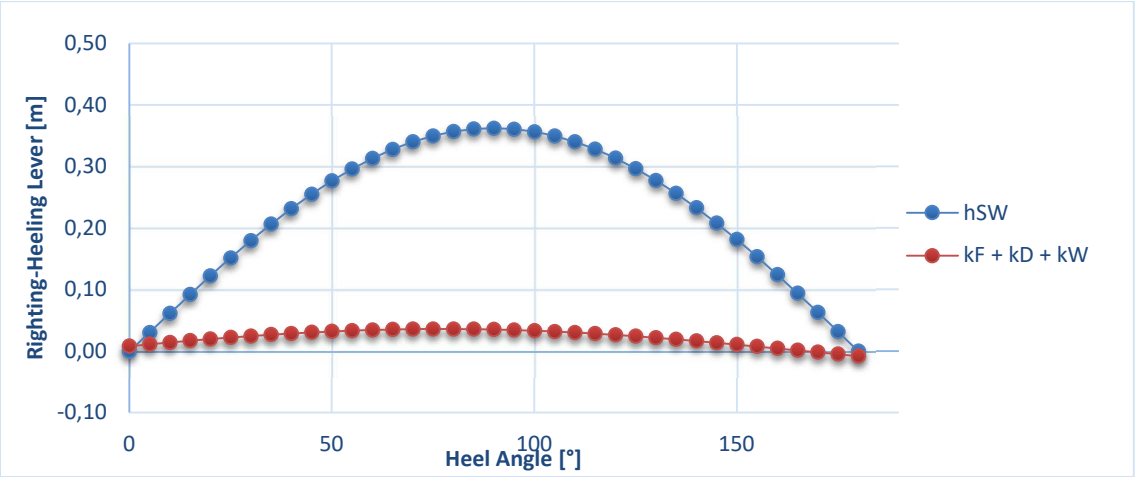

Figure 4.23 Righting – Heeling Lever / Heel Angle

Table 4.63 Criterion Assessment

#	Criterion	Actual Value	Critical Value	Result
1	The heel of the submarine shall not exceed φ = 22.5°	1.5	22.5	+
2	The trim forward and sternward shall remain below 10°.	2.84	10.0	+
3	Positive remaining lever h_{rem} at least 0.1 m in surfaced condition.	0.33	0.1	+

This section focuses on damaged stability analyses specifically related to loading case 1a, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- The heel of the submarine is 1.5° and is below the limit value of 22.5°.
- The trim of the submarine is 2.8° and is below the limit value of 10°.
- Positive remaining lever h_{rem} is 0.33 m and is above the limit value of 0.1 m.

Therefore, it can be concluded that the requirements of DNV damage stability requirements are satisfied for load case 1a.

- **Fore Main Ballast Tank Damaged**

This section specifically addresses the scenario in which the fore main ballast tank is damaged within loading condition 1a. The calculations for damaged stability in this particular scenario are presented below.

The following tables provide essential information such as drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented.

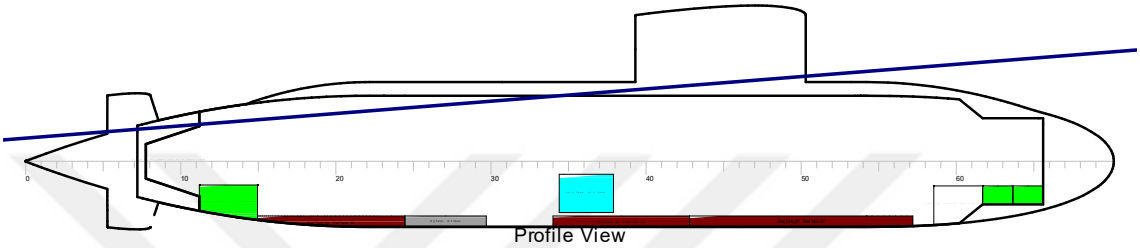

Figure 4.24 Profile View

Table 4.64 Densities

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1.000
	DIESEL FUEL	0.830
	LUB. OIL	0.900
	LOX	1.141

Table 4.65 Drafts at Equilibrium Angle

Drafts at equilibrium angle		
Draft at LCF	3.501	metres
Draft at AP	1.698	metres
Draft at FP	8.015	metres
Draft at midships	4.856	metres

Table 4.66 Hydrostatics at Equilibrium Angle

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim by the stern	6.318	metres
	5.16	degrees
KG	-0.361	metres
KB	-0.089	metres
Displacement	3747.5	tonnes
FSC	0.022	metres
KGf	-0.339	metres
GMt	0.339	metres
BMt	0.089	metres
BMl	1.693	metres
Waterplane area	133.380	sq.metres
LCG	37.258	metres
LCB	37.234	metres
TCB	0.000	metres
VCB	-0.089	metres
TCG	0.000	metres
LCF	20.029	metres
TCF	0.000	metres
TPC	1.367	tonnes/cm
MTC	1.050	tonnes-m/cm

Table 4.67 Righting – Heeling Lever Calculations

Heel Angle	**Righting Lever**	**Heeling Lever**				
[°]	h_{SW}	k_F	k_D	k_W	$k_F + k_D + k_W$	$h_{SW} - (k_F+k_D+k_W)$
10	0.0611	0.004	0.003	0.006	0.013	0.048
20	0.1216	0.008	0.003	0.006	0.017	0.105
30	0.1785	0.011	0.003	0.006	0.019	0.159
45	0.2533	0.016	0.002	0.005	0.022	0.231

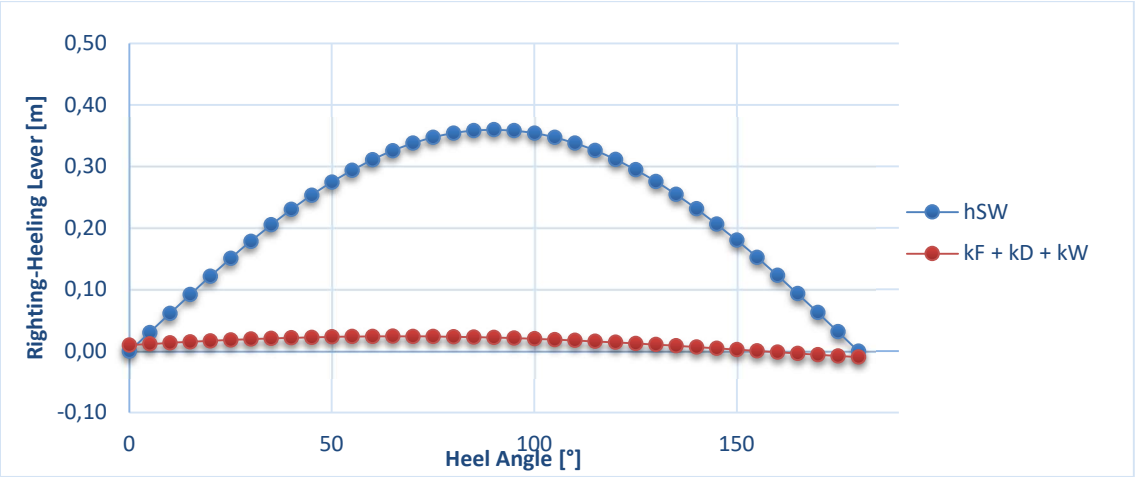

Figure 4.25 Righting – Heeling Lever / Heel Angle

Table 4.68 Criterion Assessment

#	Criterion	Actual Value	Critical Value	Result
1	The heel of the submarine shall not exceed φ = 22.5°	1.7	22.5	+
2	The trim forward and sternward shall remain below 10°.	5.16	10.0	+
3	Positive remaining lever h_{rem} at least 0.1 m in surfaced condition.	0.34	0.1	+

This section focuses on damaged stability analyses specifically related to loading case 1a, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- The heel of the submarine is 1.7° and is below the limit value of 22.5°.
- The trim of the submarine is 5.2° and is below the limit value of 10°.
- Positive remaining lever h_{rem} is 0.34 m and is above the limit value of 0.1 m.

Therefore, it can be concluded that the requirements of DNV damage stability requirements are satisfied for load case 1a.

4.3.1.2 Loading Condition 1b

- **Aft Main Ballast Tank Damaged**

This section specifically addresses the scenario in which the aft main ballast tank is damaged within loading condition 1b. The calculations for damaged stability in this particular scenario are presented below.

The following tables provide essential information such as drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented.

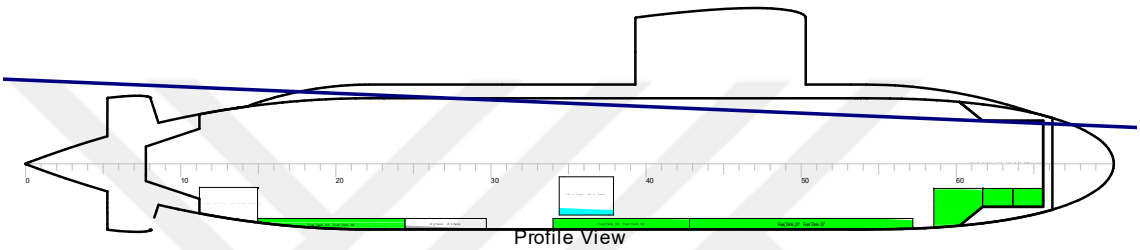

Figure 4.26 Profile View

Table 4.69 Densities

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	LUB, OIL	0.9
	BILGE WATER / SLUDGE	1.005
	LOX	1.141
	SEA WATER & DIESEL FUEL	1.005

Table 4.70 Drafts at Equilibrium Angle

Drafts at equilibrium angle		
Draft at LCF	3.735	metres
Draft at AP	6.129	metres
Draft at FP	2.733	metres
Draft at midships	4.431	metres

Table 4.71 Hydrostatics at Equilibrium Angle

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim by the stern	3.396	metres
	2.77	degrees
KG	-0.373	metres
KB	-0.135	metres
Displacement	3747.5	tonnes
FSC	0.037	metres
KGf	-0.336	metres
GMt	0.336	metres
BMt	0.135	metres
BMl	5.144	metres
Waterplane area	192.290	sq.metres
LCG	37.786	metres
LCB	37.797	metres
TCB	0.000	metres
VCB	-0.135	metres
TCG	0.000	metres
LCF	49.460	metres
TCF	0.000	metres
TPC	1.971	tonnes/cm
MTC	2.875	tonnes-m/cm

Table 4.72 Righting – Heeling Lever Calculations

Heel Angle	**Righting Lever**	**Heeling Lever**				
[°]	h_{SW}	k_F	k_D	k_W	$k_F + k_D + k_W$	$h_{SW} - (k_F+k_D+k_W)$
10	0.0624	0.006	0.002	0.006	0.014	0.048
20	0.1245	0.013	0.002	0.006	0.020	0.104
30	0.1831	0.019	0.002	0.005	0.025	0.158
45	0.2602	0.026	0.001	0.004	0.032	0.228

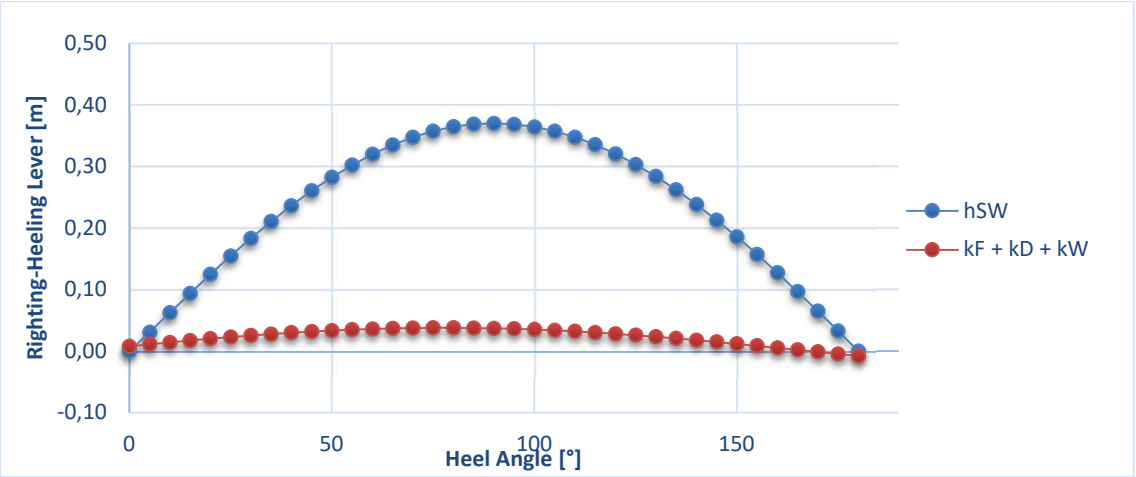

Figure 4.27 Righting – Heeling Lever / Heel Angle

Table 4.73 Criterion Assessment

#	Criterion	Actual Value	Critical Value	Result
1	The heel of the submarine shall not exceed φ = 22.5°	1.4	22.5	+
2	The trim forward and sternward shall remain below 10°.	2.77	10.0	+
3	Positive remaining lever h_{rem} at least 0.1 m in surfaced condition.	0.33	0.1	+

This section focuses on damaged stability analyses specifically related to loading case 1b, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- The heel of the submarine is 1.4° and is below the limit value of 22.5°.
- The trim of the submarine is 2.8° and is below the limit value of 10°.
- Positive remaining lever h_{rem} is 0.33 m and is above the limit value of 0.1 m.

Therefore, it can be concluded that the requirements of DNV damage stability requirements are satisfied for load case 1b.

- **Fore Main Ballast Tank Damaged**

This section specifically addresses the scenario in which the fore main ballast tank is damaged within loading condition 1b. The calculations for damaged stability in this particular scenario are presented below.

The following tables provide essential information such as drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented.

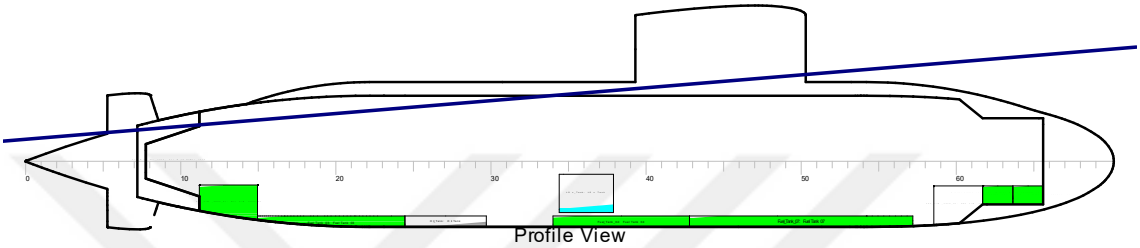

Figure 4.28 Profile View

Table 4.74 Densities

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	LUB, OIL	0.9
	BILGE WATER / SLUDGE	1.005
	LOX	1.141
	SEA WATER & DIESEL FUEL	1.005

Table 4.75 Drafts at Equilibrium Angle

Drafts at equilibrium angle		
Draft at LCF	3.473	metres
Draft at AP	1.615	metres
Draft at FP	8.223	metres
Draft at midships	4.919	metres

Table 4.76 Hydrostatics at Equilibrium Angle

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim by the stern	6.608	metres
	5.40	degrees
KG	-0.371	metres
KB	-0.088	metres
Displacement	3747.5	tonnes
FSC	0.023	metres
KGf	-0.347	metres
GMt	0.348	metres
BMt	0.089	metres
BMl	1.600	metres
Waterplane area	131.340	sq.metres
LCG	37.267	metres
LCB	37.240	metres
TCB	0.000	metres
VCB	-0.088	metres
TCG	0.000	metres
LCF	19.719	metres
TCF	0.000	metres
TPC	1.346	tonnes/cm
MTC	1.006	tonnes-m/cm

Table 4.77 Righting – Heeling Lever Calculations

Heel Angle	**Righting Lever**	**Heeling Lever**				
[°]	h_{SW}	k_F	k_D	k_W	$k_F + k_D + k_W$	$h_{SW} - (k_F+k_D+k_W)$
10	0.0623	0.004	0.003	0.006	0.014	0.049
20	0.1239	0.008	0.003	0.006	0.017	0.107
30	0.1821	0.012	0.003	0.006	0.020	0.162
45	0.2587	0.016	0.002	0.005	0.023	0.235

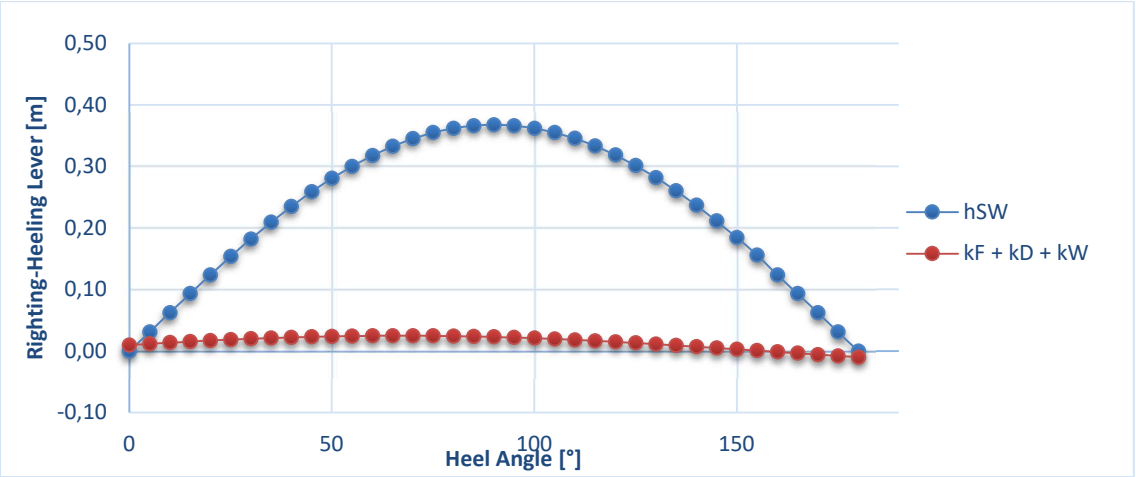

Figure 4.29 Righting – Heeling Lever / Heel Angle

Table 4.78 Criterion Assessment

#	Criterion	Actual Value	Critical Value	Result
1	The heel of the submarine shall not exceed φ = 22.5°	1.7	22.5	+
2	The trim forward and sternward shall remain below 10°.	5.40	10.0	+
3	Positive remaining lever h_{rem} at least 0.1 m in surfaced condition.	0.34	0.1	+

This section focuses on damaged stability analyses specifically related to loading case 1b, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- The heel of the submarine is 1.7° and is below the limit value of 22.5°.
- The trim of the submarine is 5.4° and is below the limit value of 10°.
- Positive remaining lever h_{rem} is 0.34 m and is above the limit value of 0.1 m.

Therefore, it can be concluded that the requirements of DNV damage stability requirements are satisfied for load case 1b.

4.3.1.3 Loading Condition 2a

- **Aft Main Ballast Tank Damaged**

This section specifically addresses the scenario in which the aft main ballast tank is damaged within loading condition 2a. The calculations for damaged stability in this particular scenario are presented below.

The following tables provide essential information such as drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented.

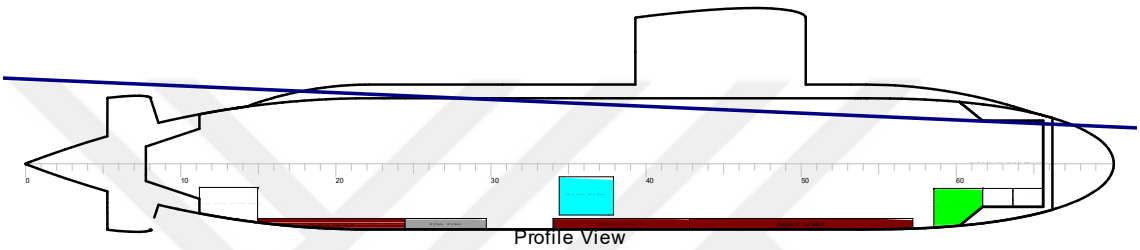

Figure 4.30 Profile View

Table 4.79 Densities

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1.000
	DIESEL FUEL	0.830
	LUB. OIL	0.900
	LOX	1.141

Table 4.80 Drafts at Equilibrium Angle

Drafts at equilibrium angle		
Draft at LCF	3.721	metres
Draft at AP	6.201	metres
Draft at FP	2.703	metres
Draft at midships	4.452	metres

Table 4.81 Hydrostatics at Equilibrium Angle

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim by the stern	3.498	metres
	2.86	degrees
KG	-0.358	metres
KB	-0.135	metres
Displacement	3747.5	tonnes
FSC	0.027	metres
KGf	-0.331	metres
GMt	0.330	metres
BMt	0.135	metres
BMl	4.921	metres
Waterplane area	190.100	sq.metres
LCG	37.779	metres
LCB	37.790	metres
TCB	0.000	metres
VCB	-0.135	metres
TCG	0.000	metres
LCF	49.734	metres
TCF	0.000	metres
TPC	1.949	tonnes/cm
MTC	2.748	tonnes-m/cm

Table 4.82 Righting – Heeling Lever Calculations

Heel Angle	**Righting Lever**	**Heeling Lever**				
[°]	h_{SW}	k_F	k_D	k_W	$k_F + k_D + k_W$	$h_{SW} - (k_F+k_D+k_W)$
10	0.0605	0.005	0.002	0.006	0.013	0.048
20	0.1205	0.009	0.002	0.006	0.017	0.104
30	0.1769	0.014	0.002	0.005	0.021	0.156
45	0.2510	0.019	0.001	0.004	0.025	0.226

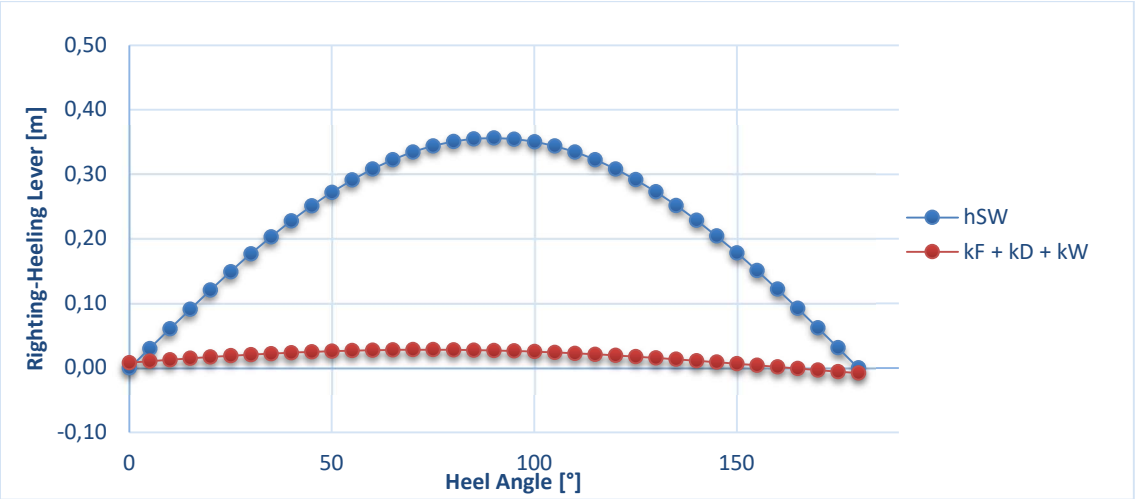

Figure 4.31 Righting – Heeling Lever / Heel Angle

Table 4.83 Criterion Assessment

#	Criterion	Actual Value	Critical Value	Result
1	The heel of the submarine shall not exceed φ = 22.5°	1.5	22.5	+
2	The trim forward and sternward shall remain below 10°.	2.86	10.0	+
3	Positive remaining lever h_{rem} at least 0.1 m in surfaced condition.	0.33	0.1	+

This section focuses on damaged stability analyses specifically related to loading case 2a, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- The heel of the submarine is 1.5° and is below the limit value of 22.5°.
- The trim of the submarine is 2.9° and is below the limit value of 10°.
- Positive remaining lever h_{rem} is 0.33 m and is above the limit value of 0.1 m.

Therefore, it can be concluded that the requirements of DNV damage stability requirements are satisfied for load case 2a.

- **Fore Main Ballast Tank Damaged**

This section specifically addresses the scenario in which the fore main ballast tank is damaged within loading condition 2a. The calculations for damaged stability in this particular scenario are presented below.

The following tables provide essential information such as drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented.

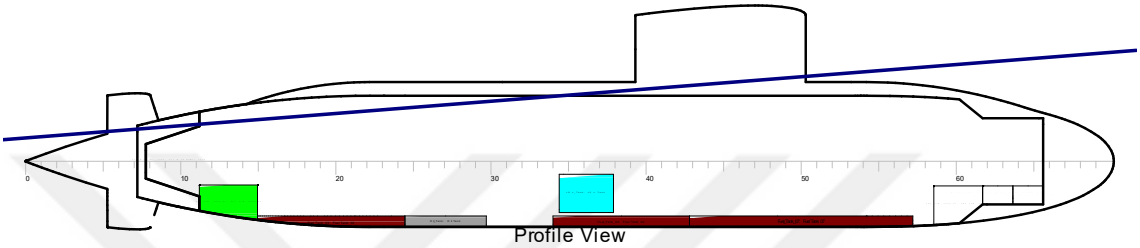

Figure 4.32 Profile View

Table 4.84 Densities

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1.000
	DIESEL FUEL	0.830
	LUB. OIL	0.900
	LOX	1.141

Table 4.85 Drafts at Equilibrium Angle

Drafts at equilibrium angle		
Draft at LCF	3.506	metres
Draft at AP	1.71	metres
Draft at FP	7.986	metres
Draft at midships	4.848	metres

Table 4.86 Hydrostatics at Equilibrium Angle

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim by the stern	6.276	metres
	5.13	degrees
KG	-0.355	metres
KB	-0.089	metres
Displacement	3747.5	tonnes
FSC	0.016	metres
KGf	-0.339	metres
GMt	0.339	metres
BMt	0.089	metres
BMl	1.705	metres
Waterplane area	133.640	sq.metres
LCG	37.256	metres
LCB	37.232	metres
TCB	0.000	metres
VCB	-0.089	metres
TCG	0.000	metres
LCF	20.074	metres
TCF	0.000	metres
TPC	1.370	tonnes/cm
MTC	1.053	tonnes-m/cm

Table 4.87 Righting – Heeling Lever Calculations

Heel Angle	**Righting Lever**	**Heeling Lever**				
[°]	h_{SW}	k_F	k_D	k_W	$k_F + k_D + k_W$	$h_{SW} - (k_F+k_D+k_W)$
10	0.0603	0.003	0.003	0.006	0.012	0.048
20	0.1199	0.005	0.003	0.006	0.015	0.105
30	0.1759	0.008	0.003	0.006	0.016	0.159
45	0.2495	0.011	0.002	0.005	0.018	0.231

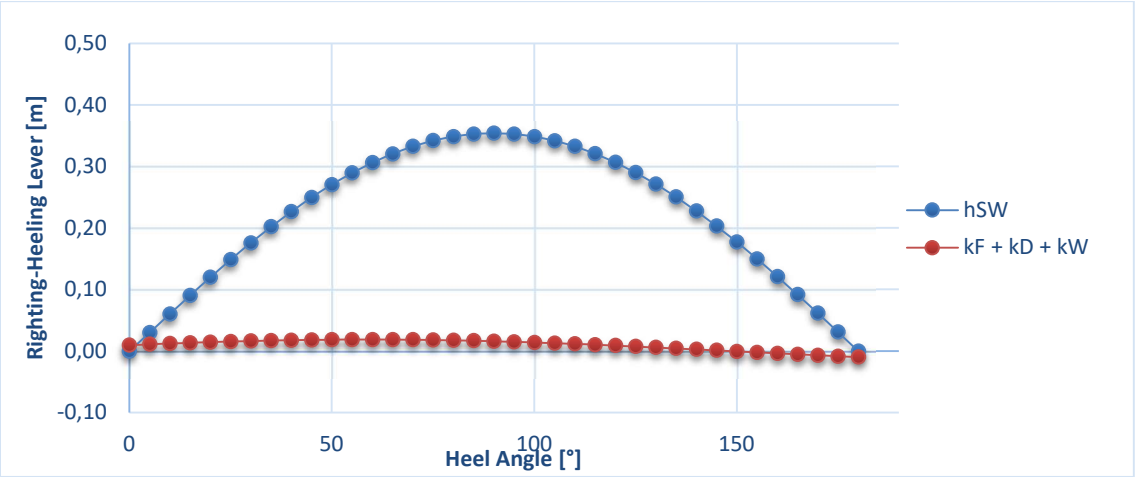

Figure 4.33 Righting – Heeling Lever / Heel Angle

Table 4.88 Criterion Assessment

#	Criterion	Actual Value	Critical Value	Result
1	The heel of the submarine shall not exceed φ = 22.5°	1.7	22.5	+
2	The trim forward and sternward shall remain below 10°.	5.13	10.0	+
3	Positive remaining lever h_{rem} at least 0.1 m in surfaced condition.	0.34	0.1	+

This section focuses on damaged stability analyses specifically related to loading case 2a, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn;

- The heel of the submarine is 1.7° and is below the limit value of 22.5°.
- The trim of the submarine is 5.1° and is below the limit value of 10°.
- Positive remaining lever h_{rem} is 0.34 m and is above the limit value of 0.1 m.

Therefore, it can be concluded that the requirements of DNV damage stability requirements are satisfied for load case 2a.

4.3.1.4 Loading Condition 2b

- **Aft Main Ballast Tank Damaged**

This section specifically addresses the scenario in which the aft main ballast tank is damaged within loading condition 2b. The calculations for damaged stability in this particular scenario are presented below.

The following tables provide essential information such as drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented.

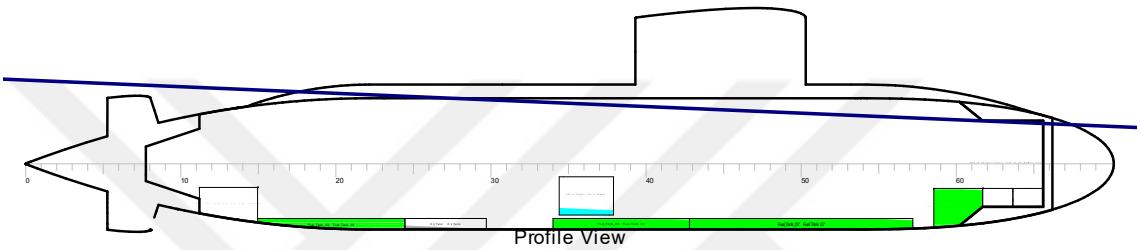

Figure 4.34 Profile View

Table 4.89 Densities

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	LUB, OIL	0.9
	BILGE WATER / SLUDGE	1.005
	LOX	1.141
	SEA WATER & DIESEL FUEL	1.005

Table 4.90 Drafts at Equilibrium Angle

Drafts at equilibrium angle		
Draft at LCF	3.732	metres
Draft at AP	6.146	metres
Draft at FP	2.726	metres
Draft at midships	4.436	metres

Table 4.91 Hydrostatics at Equilibrium Angle

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim by the stern	3.420	metres
	2.79	degrees
KG	-0.367	metres
KB	-0.135	metres
Displacement	3747.5	tonnes
FSC	0.029	metres
KGf	-0.338	metres
GMt	0.338	metres
BMt	0.135	metres
BMl	5.090	metres
Waterplane area	191.770	sq.metres
LCG	37.784	metres
LCB	37.796	metres
TCB	0.000	metres
VCB	-0.135	metres
TCG	0.000	metres
LCF	49.525	metres
TCF	0.000	metres
TPC	1.966	tonnes/cm
MTC	2.843	tonnes-m/cm

Table 4.92 Righting – Heeling Lever Calculations

Heel Angle	**Righting Lever**	**Heeling Lever**				
[°]	h_{SW}	k_F	k_D	k_W	$k_F + k_D + k_W$	$h_{SW} - (k_F+k_D+k_W)$
10	0.0616	0.005	0.002	0.006	0.013	0.049
20	0.1227	0.010	0.002	0.006	0.017	0.105
30	0.1804	0.015	0.002	0.005	0.021	0.159
45	0.2564	0.021	0.001	0.004	0.026	0.230

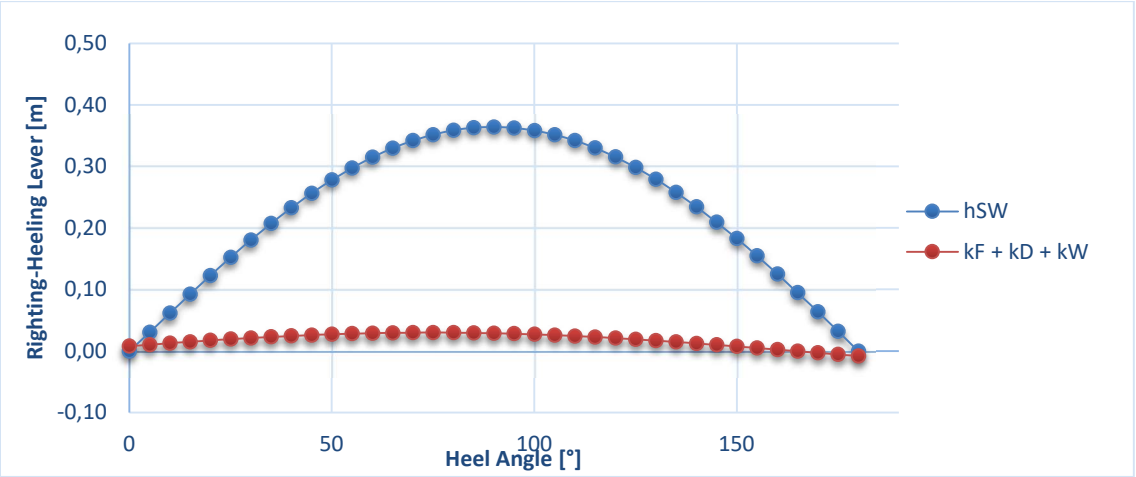

Figure 4.35 Righting – Heeling Lever / Heel Angle

Table 4.93 Criterion Assessment

#	Criterion	Actual Value	Critical Value	Result
1	The heel of the submarine shall not exceed φ = 22.5°	1.4	22.5	+
2	The trim forward and sternward shall remain below 10°.	2.79	10.0	+
3	Positive remaining lever h_{rem} at least 0.1 m in surfaced condition.	0.34	0.1	+

This section focuses on damaged stability analyses specifically related to loading case 2b, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn;

- The heel of the submarine is 1.4° and is below the limit value of 22.5°.
- The trim of the submarine is 2.8° and is below the limit value of 10°.
- Positive remaining lever h_{rem} is 0.34 m and is above the limit value of 0.1 m.

Therefore, it can be concluded that the requirements of DNV damage stability requirements are satisfied for load case 2b.

- **Fore Main Ballast Tank Damaged**

This section specifically addresses the scenario in which the fore main ballast tank is damaged within loading condition 2b. The calculations for damaged stability in this particular scenario are presented below.

The following tables provide essential information such as drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented.

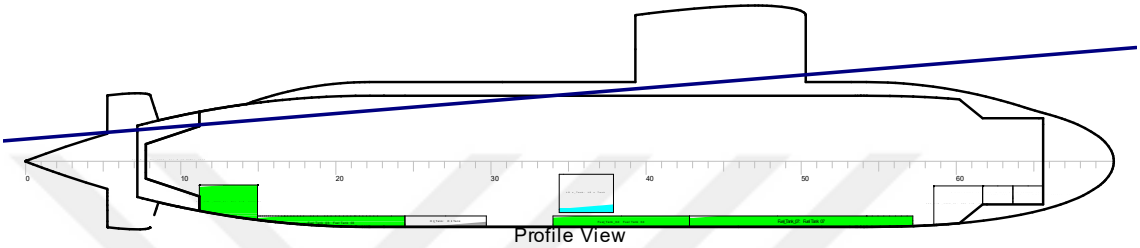

Figure 4.36 Profile View

Table 4.94 Densities

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	LUB, OIL	0.9
	BILGE WATER / SLUDGE	1.005
	LOX	1.141
	SEA WATER & DIESEL FUEL	1.005

Table 4.95 Drafts at Equilibrium Angle

Drafts at equilibrium angle		
Draft at LCF	3.477	metres
Draft at AP	1.628	metres
Draft at FP	8.192	metres
Draft at midships	4.910	metres

Table 4.96 Hydrostatics at Equilibrium Angle

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim by the stern	6.565	metres
	5.36	degrees
KG	-0.365	metres
KB	-0.089	metres
Displacement	3747.5	tonnes
FSC	0.018	metres
KGf	-0.347	metres
GMt	0.347	metres
BMt	0.089	metres
BMl	1.614	metres
Waterplane area	131.640	sq.metres
LCG	37.265	metres
LCB	37.239	metres
TCB	0.000	metres
VCB	-0.089	metres
TCG	0.000	metres
LCF	19.763	metres
TCF	0.000	metres
TPC	1.349	tonnes/cm
MTC	1.010	tonnes-m/cm

Table 4.97 Righting – Heeling Lever Calculations

Heel Angle	**Righting Lever**	**Heeling Lever**				
[°]	h_{SW}	k_F	k_D	k_W	$k_F + k_D + k_W$	$h_{SW} - (k_F+k_D+k_W)$
10	0.0615	0.003	0.003	0.006	0.013	0.049
20	0.1222	0.006	0.003	0.006	0.015	0.107
30	0.1795	0.009	0.003	0.006	0.018	0.162
45	0.2549	0.013	0.002	0.005	0.020	0.235

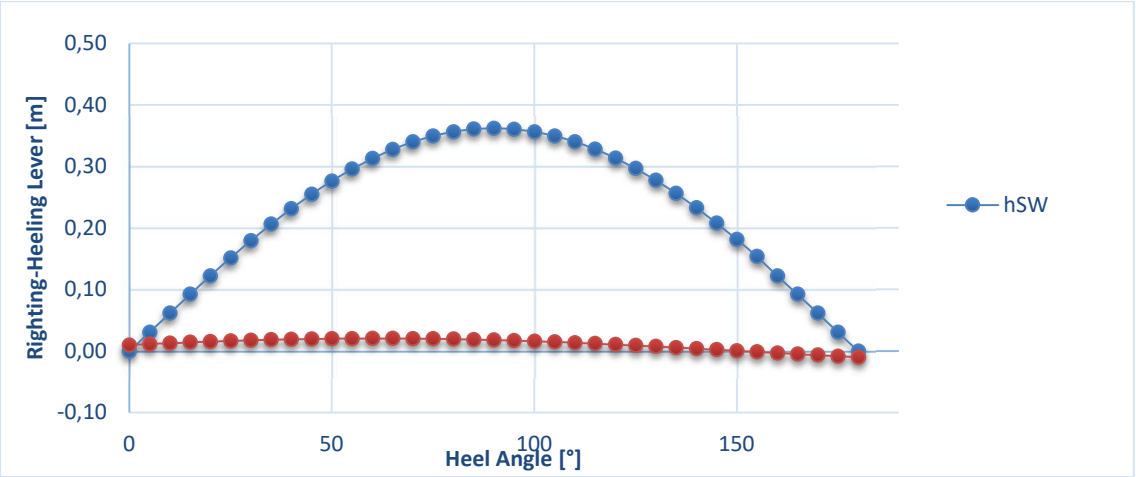

Figure 4.37 Righting – Heeling Lever / Heel Angle

Table 4.98 Criterion Assessment

#	Criterion	Actual Value	Critical Value	Result
1	The heel of the submarine shall not exceed φ = 22.5°	1.7	22.5	+
2	The trim forward and sternward shall remain below 10°.	5.4	10.0	+
3	Positive remaining lever h_{rem} at least 0.1 m in surfaced condition.	0.34	0.1	+

This section focuses on damaged stability analyses specifically related to loading case 2b, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn;

- The heel of the submarine is 1.7° and is below the limit value of 22.5°.
- The trim of the submarine is 5.4° and is below the limit value of 10°.
- Positive remaining lever h_{rem} is 0.34 m and is above the limit value of 0.1 m.

Therefore, it can be concluded that the requirements of DNV damage stability requirements are satisfied for load case 2b.

4.3.2 Submerged Submarine

In the damaged stability calculations when the submarine is surfaced, each loading condition was divided into two scenarios as the aft main ballast tank damaged or the fore main ballast tank damaged. Calculations were made in such a way that whichever tank was damaged, it would no longer be a buoyant element.

When it came to the submerged situation, since these tanks were diving tanks, even though the tanks were not damaged, they were no longer be a buoyant element. Thus, the scenarios that will occur when one of the main ballast tanks is damaged in the submerged situation corresponds to the scenarios examined in intact stability. For this reason, the class rules could be examined without need for extra scenarios. The criteria for damaged stability in the submerged state are as follows.

- The submarine has still to be able to surface in a safe way.
- The centre of weight has still to be below the centre of buoyancy.

According to the first rule, if one of the main ballast tanks is damaged, the submarine must be able to return to the surface safely. For example, if it is assumed that the aft main ballast tank is damaged, the submarine should discharge seawater from the fore main ballast tank into the sea, and the weight-buoyancy balance should not prevent the submarine from returning to the surface. Since the submarine has neutral buoyancy in submerged condition when the main ballast tanks are full, emptying a main ballast tank will allow the submarine to rise to the surface in terms of weight-buoyancy balance.

In the second rule, the center of gravity must still be below the center of buoyancy in damaged condition when the submarine is submerged. In terms of examining this rule, it will be sufficient to examine the results in intact stability since the center of gravity-center of buoyancy in the damaged stability calculations will not change. Accordingly, the relationship between the center of gravity and the center of buoyancy is given as follows according to their heights from the baseline.

Table 4.99 Center of Gravity-Buoyancy

Scenario	Center of Gravity from Baseline [m]	Center of Buoyancy from Baseline [m]
3a	4.431	4.8
3b	4.422	4.8
4a	4.437	4.8
4b	4.428	4.8

As can be seen from the table, the center of gravity will continue to remain below the center of buoyancy.

Thus, damaged stability requirements in the submerged state are met.

5
SCALED MODELS

The BB2 Joubert Submarine has a length of 70.13 m and a depth of 10.6 m. In order to examine the stability rules for submarines which have different lengths, the model was scaled with 30 m, 48 m and 100 m lengths, and compliance with the rules was evaluated for scaled models.

In this section, intact stability analyzes and rule evaluations are given for scaled submarine models described above. Eight loading conditions were examined in intact stability analyzes for each scaled submarine model. Loading condition 1a, 1b, 2a, 2b is for surfaced condition, while loading condition 3a, 3b, 4a, 4b is for submerged condition.

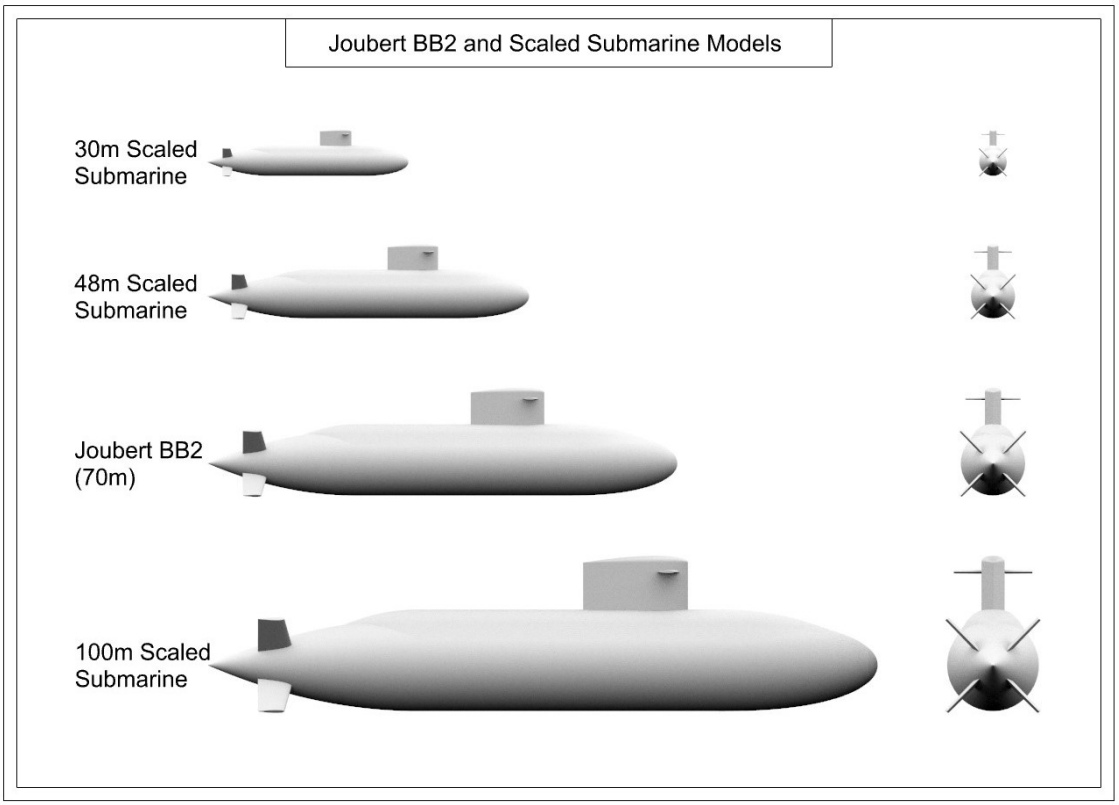

Figure 5.1 BB2 Joubert Submarine and Scaled Submarine Models

5.1 30m

5.1.1 Surfaced Submarine (30m)

5.1.1.1 Loading Condition 1a (30m)

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

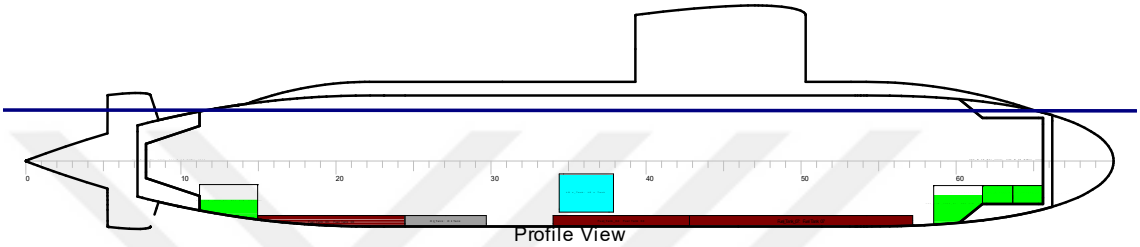

Figure 5.2 Profile View (30m)

Table 5.1 Densities (30m)

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1.000
	DIESEL FUEL	0.830
	LUB. OIL	0.900
	LOX	1.141

Table 5.2 Summary Table of Loading Condition 1a (30m)

Stability Calculations for Loading Condition 1A								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	6-10	DIESEL FUEL	98	0.83	2.5	8.589	1.623	-0.492
FUEL TANK 02	6-10	DIESEL FUEL	98	0.83	2.5	8.589	-1.623	-0.492
FUEL TANK 03	6-10	DIESEL FUEL	98	0.83	1.3	8.783	0.000	-1.837
FUEL TANK 04	15-18	DIESEL FUEL	98	0.83	1.6	16.427	0.000	-1.852
FUEL TANK 05	18-24	DIESEL FUEL	98	0.83	1.6	21.372	1.493	-1.083
FUEL TANK 06	18-24	DIESEL FUEL	98	0.83	1.6	21.372	-1.493	-1.083
FUEL TANK 07	18-24	DIESEL FUEL	98	0.83	2.6	21.365	0.000	-1.851
Total DIESEL FUEL					**13.7**	**14.862**	**0.000**	**-1.171**
FRESH WATER								
FRESH WATER TANK 01	16-18	FRESH WATER	98	1.00	0.6	17.368	1.494	-1.084
FRESH WATER TANK 02	16-18	FRESH WATER	98	1.00	0.6	17.368	-1.494	-1.084
Total FRESH WATER					**1.2**	**17.368**	**0.000**	**-1.084**
LUB, OIL								
OIL TANK	10-13	LUB, OIL	98	0.9	1.0	11.582	0.000	-1.852
Total LUB, OIL					**1.0**	**11.582**	**0.000**	**-1.852**
SEA WATER								
AFT MAIN BALLAST TANK	3-5	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	5-6	SEA WATER	37.5	1.025	0.6	5.718	0.465	-1.425
AFT TRIM TANK 02	5-6	SEA WATER	37.5	1.025	0.6	5.718	-0.465	-1.425
COMPENSATING TANK 01	17-17	SEA WATER	20	1.025	0.1	16.983	0.631	-1.479
COMPENSATING TANK 02	17-17	SEA WATER	20	1.025	0.1	16.983	-0.631	-1.479
COMPENSATING TANK 03	17-18	SEA WATER	20	1.025	0.1	17.795	0.631	-1.479
COMPENSATING TANK 04	17-18	SEA WATER	20	1.025	0.1	17.795	-0.631	-1.479
FWD MAIN BALLAST TANK	26-28	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	25-26	SEA WATER	62.5	1.025	1.1	25.577	0.604	-1.409
FWD TRIM TANK 02	25-26	SEA WATER	62.5	1.025	1.1	25.577	-0.604	-1.409

Table 5.2 Summary Table of Loading Condition 1a (30m) (continued…)

TORPEDO TUBE FLOODING TANK	27-28	SEA WATER	98	1.025	0.7	27.645	0.000	-1.011
WATER ROUND TORPEDO TANK	26-27	SEA WATER	98	1.025	0.7	26.811	0.000	-1.011
Total SEA WATER					**5.2**	**20.666**	**0.000**	**-1.304**
BILGE WATER / SLUDGE								
SANITARY TANK 01	15-16	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
SANITARY TANK 02	15-16	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
Total BILGE WATER / SLUDGE					**0.0**	**0.000**	**0.000**	**0.000**
LOx								
Lox TANK	15-16	LOX	98	1.141	1.8	15.464	0.000	-1.017
Total LOx					**1.8**	**15.464**	**0.000**	**-1.017**
LOADING CONDITION 1A FIXED WEIGHTS								
COMPLEMENT					0.3	16.067	0.000	-0.160
OFFICER EQUIPMENT					0.1	16.067	0.000	-0.160
P.O. EQUIPMENT					0.2	16.067	0.000	-0.160
RATING EQUIPMENT					0.1	16.067	0.000	-0.160
GARBAGE					0.0	0.000	0.000	0.000
PROVISIONS					1.6	16.067	0.000	-0.160
TORPEDO					0.0	0.000	0.000	0.000
SPECIAL PERSONNEL & OTHER MILITARY LOADS					0.0	0.000	0.000	0.000
DESIGN MARGIN					2.6	16.067	0.000	-0.160
CONSTRUCTION MARGIN					5.2	16.067	0.000	-0.160
MAINTENANCE MARGIN					2.6	16.067	0.000	-0.160
Loading Condition 1A Fixed Weights					**12.7**	**16.067**	**0.000**	**-0.160**
Lightweight					**259.3**	**16.067**	**0.000**	**-0.160**
Deadweight					**35.5**	**16.158**	**0.000**	**-0.840**
Total Displacement					**294.8**	**16.078**	**0.000**	**-0.242**
Buoyancy					**294.8**	**16.078**	**0.000**	**-0.101**
Total Buoyancy					**294.8**	**16.078**	**0.000**	**-0.101**

Table 5.3 Drafts at Equilibrium Angle (30m)

Drafts at equilibrium angle		
Draft at LCF	1.579	metres
Draft at AP	1.592	metres
Draft at FP	1.569	metres
Draft at midships	1.581	metres

Table 5.4 Hydrostatics at Equilibrium Angle (30m)

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim by the stern	0.024	metres
	0.02	degrees
KG	-0.242	metres
KB	-0.101	metres
FSC	0.005	metres
KGf	-0.237	metres
GMt	0.237	metres
BMt	0.100	metres
BMl	7.178	metres
Waterplane area	55.090	sq.metres
LCG	16.078	metres
LCB	16.078	metres
TCB	0.000	metres
LCF	16.502	metres
TCF	0.000	metres
TPC	0.565	tonnes/cm
MTC	0.719	tonnes-m/cm

Table 5.5 Summary Stability Table (30m)

Displacement [ton]	Δ	294.8	
Length [m]	L_{DWL}	30.00	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	1.579	*3.632*
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.242	*1.811*
Longitudinal Center of Gravity [m]	LCG	16.078	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	-0.005	
Wind Pressure [kN/m^2]	q_w	0.358	
Density of Air [t/m^3]	ρ_L	0.001225	
Wind Speed [m/s]	v_w	24.179	
Form Coefficient	c_f	0.600	

Table 5.5 Summary Stability Table (30m) (continued…)

Projected Area Exposed to Wind Forces [m^2]	A_w	28.999	
Height of the Centroid of the Area Exposed to Wind [m] [from Reference Point] / [from Baseline]	A_{wz}	2.605	4.658
Height of the Centroid of the Area Exposed to Wind Above Half Draught [m] [from Baseline]	A_{wz}-0.5T	2.842	
Maximum Operational Speed of the Surfaced Submarine [knot] / [m/sn]	$v_0\uparrow$	12.000	6.173

Table 5.6 Righting – Heeling Lever Calculations (30m)

Heel Angle	**Righting Lever**	**Heeling Lever**				
[°]	hsw	k_F	k_D	k_W	$k_F + k_D + k_W$	h_{SW} - (k_F+k_D+k_W)
10	0.0412	0.001	0.000	0.006	0.007	0.034
20	0.0810	0.002	0.000	0.006	0.007	0.074
30	0.1184	0.003	0.000	0.005	0.008	0.111
45	0.1677	0.004	0.000	0.004	0.008	0.160

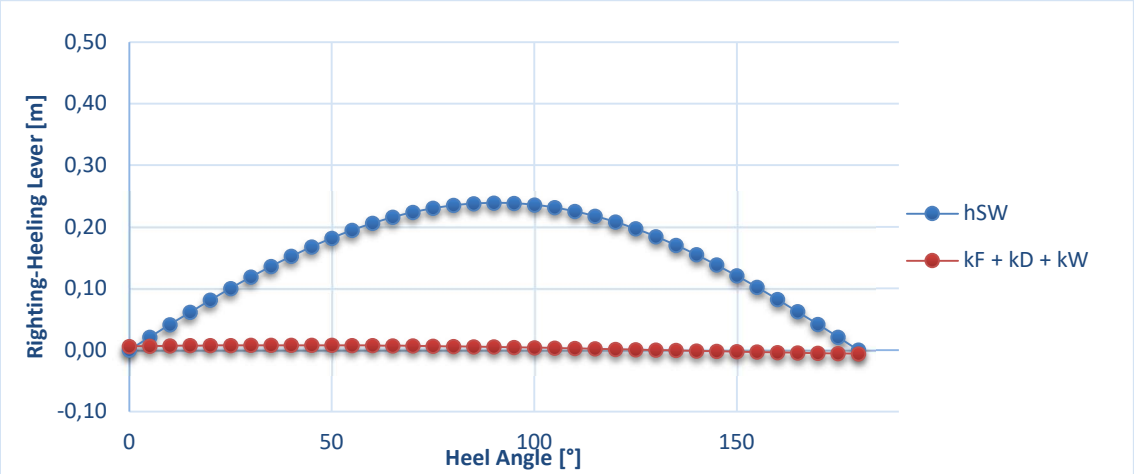

Figure 5.3 Righting – Heeling Lever / Heel Angle (30m)

Table 5.7 Criterion Assessment (30m)

#	Criterion	Actual Value	Critical Value	Result
1	The buoyancy reserve shall be at least 10% of the pressure tight volume of the submarine in surfaced condition.	12.3	10.0	+
2	Positive remaining lever h_{rem} at least 0.1 m in surfaced condition.	0.234	0.1	+
3	Minimum value for GM	0.237	0.150	+

This section focuses on stability analyses specifically related to loading case 1a, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Buoyancy reserve is 12.3% of the pressure tight volume of the submarine. Thus, the 10% limit value has been exceeded.
- Positive remaining lever h_{rem} is 0.234 m and is above the limit value of 0.1 m.
- The GM value is 0.237 m and is above the limit value of 0.15 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 1a.

5.1.1.2 Loading Condition 1b (30m)

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

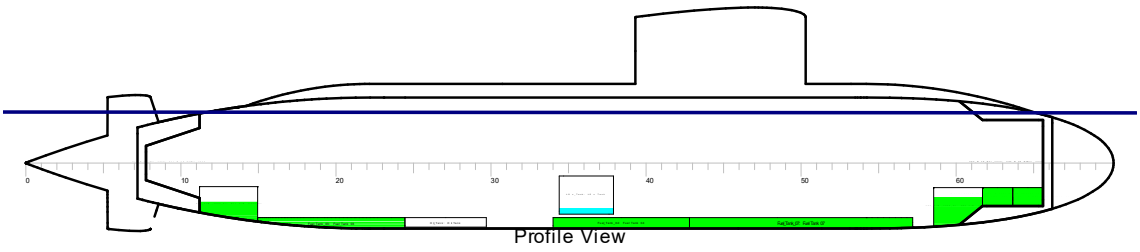

Figure 5.4 Profile View (30m)

Table 5.8 Densities (30m)

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	LUB, OIL	0.9
	BILGE WATER / SLUDGE	1.005
	LOX	1.141
	SEA WATER & DIESEL FUEL	1.005

Table 5.9 Summary Table of Loading Condition 1b (30m)

Stability Calculations for Loading Condition 1B								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	6-10	SEA WATER & DIESEL FUEL	98	1.005	3.1	8.589	1.623	-0.492
FUEL TANK 02	6-10	SEA WATER & DIESEL FUEL	98	1.005	3.1	8.589	-1.623	-0.492
FUEL TANK 03	6-10	SEA WATER & DIESEL FUEL	98	1.005	1.6	8.783	0.000	-1.837
FUEL TANK 04	15-18	SEA WATER & DIESEL FUEL	98	1.005	1.9	16.427	0.000	-1.852
FUEL TANK 05	18-24	SEA WATER & DIESEL FUEL	98	1.005	1.9	21.372	1.493	-1.083
FUEL TANK 06	18-24	SEA WATER & DIESEL FUEL	98	1.005	1.9	21.372	-1.493	-1.083
FUEL TANK 07	18-24	SEA WATER & DIESEL FUEL	98	1.005	3.1	21.365	0.000	-1.851
Total DIESEL FUEL					**16.6**	**14.862**	**0.000**	**-1.171**
FRESH WATER								
FRESH WATER TANK 01	16-18	FRESH WATER	10	1.00	0.1	17.367	1.350	-1.463
FRESH WATER TANK 02	16-18	FRESH WATER	10	1.00	0.1	17.367	-1.350	-1.463
Total FRESH WATER					**0.2**	**17.367**	**0.000**	**-1.463**
LUB, OIL								
OIL TANK	10-13	LUB, OIL	10	0.9	0.1	11.579	0.000	-2.010
Total LUB, OIL					**0.1**	**11.579**	**0.000**	**-2.010**
SEA WATER								
AFT MAIN BALLAST TANK	3-5	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	5-6	SEA WATER	37.5	1.025	0.6	5.718	0.465	-1.425
AFT TRIM TANK 02	5-6	SEA WATER	37.5	1.025	0.6	5.718	-0.465	-1.425
COMPENSATING TANK 01	17-17	SEA WATER	80	1.025	0.3	16.983	0.631	-1.260
COMPENSATING TANK 02	17-17	SEA WATER	80	1.025	0.3	16.983	-0.631	-1.260

Table 5.9 Summary Table of Loading Condition 1b (30m) (continued…)

COMPENSATING TANK 03	17-18	SEA WATER	80	1.025	0.3	17.795	0.631	-1.260
COMPENSATING TANK 04	17-18	SEA WATER	80	1.025	0.3	17.795	-0.631	-1.260
FWD MAIN BALLAST TANK	26-28	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	25-26	SEA WATER	62.5	1.025	1.1	25.577	0.604	-1.409
FWD TRIM TANK 02	25-26	SEA WATER	62.5	1.025	1.1	25.577	-0.604	-1.409
TORPEDO TUBE FLOODING TANK	27-28	SEA WATER	98	1.025	0.7	27.645	0.000	-1.011
WATER ROUND TORPEDO TANK	26-27	SEA WATER	98	1.025	0.7	26.811	0.000	-1.011
Total SEA WATER					**6.0**	**20.181**	**0.000**	**-1.287**
BILGE WATER / SLUDGE								
SANITARY TANK 01	15-16	BILGE WATER / SLUDGE	90	1.005	0.5	15.485	1.487	-1.109
SANITARY TANK 02	15-16	BILGE WATER / SLUDGE	90	1.005	0.5	15.485	-1.487	-1.109
Total BILGE WATER/SLUDGE					**1.0**	**15.485**	**0.000**	**-1.109**
LOx								
Lox TANK	15-16	LOX	10	1.141	0.2	15.464	0.000	-1.493
Total LOx					**0.2**	**15.464**	**0.000**	**-1.493**
LOADING CONDITION 1B FIXED WEIGHTS								
COMPLEMENT					0.3	16.067	0.000	-0.160
OFFICER EQUIPMENT					0.1	16.067	0.000	-0.160
P.O. EQUIPMENT					0.2	16.067	0.000	-0.160
RATING EQUIPMENT					0.0	16.067	0.000	-0.160
GARBAGE					0.2	16.067	0.000	-0.160
PROVISIONS					0.2	16.067	0.000	-0.160
TORPEDO					0.0	0.000	0.000	0.000
SPECIAL PERSONNEL & OTHER MILITARY LOADS					0.0	0.000	0.000	0.000
DESIGN MARGIN					2.6	16.067	0.000	-0.160
CONSTRUCTION MARGIN					5.2	16.067	0.000	-0.160
MAINTENANCE MARGIN					2.6	16.067	0.000	-0.160
Loading Condition 1B Fixed Weights					**11.4**	**16.067**	**0.000**	**-0.160**
Lightweight					**259.3**	**16.067**	**0.000**	**-0.160**
Deadweight					**35.5**	**16.182**	**0.000**	**-0.870**
Total Displacement					**294.8**	**16.081**	**0.000**	**-0.246**
Buoyancy					**294.8**	**16.081**	**0.000**	**-0.101**
Total Buoyancy					**294.8**	**16.081**	**0.000**	**-0.101**

Table 5.10 Drafts at Equilibrium Angle (30m)

Drafts at equilibrium angle		
Draft at LCF	1.580	metres
Draft at AP	1.586	metres
Draft at FP	1.574	metres
Draft at midships	1.580	metres

Table 5.11 Hydrostatics at Equilibrium Angle (30m)

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim by the stern	0.012	metres
	0.01	degrees
KG	-0.246	metres
KB	-0.101	metres
FSC	0.006	metres
KGf	-0.239	metres
GMt	0.239	metres
BMt	0.100	metres
BMl	7.181	metres
Waterplane area	55.100	sq.metres
LCG	16.081	metres
LCB	16.081	metres
TCB	0.000	metres
LCF	16.474	metres
TCF	0.000	metres
TPC	0.565	tonnes/cm
MTC	0.720	tonnes-m/cm

Table 5.12 Summary Stability Table (30m)

Form Coefficient	Δ	294.8	
Length [m]	L_{DWL}	30.00	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	1.580	3.633
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.246	1.807
Longitudinal Center of Gravity [m]	LCG	16.081	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	-0.010	
Wind Pressure [kN/m^2]	q_w	0.358	
Density of Air [t/m^3]	ρ_L	0.001225	
Wind Speed [m/s]	v_w	24.179	
Form Coefficient	c_f	0.600	

Table 5.12 Summary Stability Table (30m) (continued…)

Projected Area Exposed to Wind Forces [m^2]	A_w	28.999	
Height of the Centroid of the Area Exposed to Wind [m] [from Reference Point] / [from Baseline]	A_{wz}	2.605	4.658
Height of the Centroid of the Area Exposed to Wind Above Half Draught [m] [from Baseline]	A_{wz}-0.5T	2.842	
Maximum Operational Speed of the Surfaced Submarine [knot] / [m/sn]	$v_0\uparrow$	12.000	6.173

Table 5.13 Righting – Heeling Lever Calculations (30m)

Heel Angle	**Righting Lever**	**Heeling Lever**				
[°]	hsw	k_F	k_D	k_W	$k_F + k_D + k_W$	$h_{SW} - (k_F+k_D+k_W)$
10	0.0416	0.001	0.000	0.006	0.007	0.035
20	0.0818	0.002	0.000	0.006	0.008	0.074
30	0.1197	0.003	0.000	0.005	0.008	0.112
45	0.1696	0.004	0.000	0.004	0.008	0.161

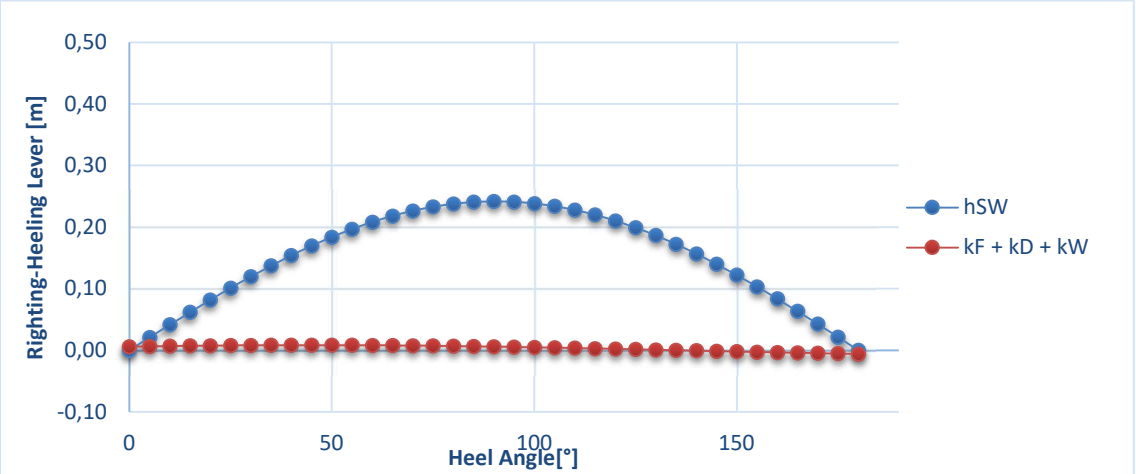

Figure 5.5 Righting – Heeling Lever / Heel Angle (30m)

Table 5.14 Criterion Assessment (30m)

#	Criterion	Actual Value	Critical Value	Result
1	The buoyancy reserve shall be at least 10% of the pressure tight volume of the submarine in surfaced condition.	12.3	10.0	+
2	Positive remaining lever h_{rem} at least 0.1 m in surfaced condition.	0.236	0.1	+
3	Minimum value for GM	0.239	0.150	+

This section focuses on stability analyses specifically related to loading case 1b, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Buoyancy reserve is 12.3% of the pressure tight volume of the submarine. Thus, the 10% limit value has been exceeded.
- Positive remaining lever h_{rem} is 0.236 m and is above the limit value of 0.1 m.
- The GM value is 0.239 m and is above the limit value of 0.15 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 1b.

5.1.1.3 Loading Condition 2a (30m)

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

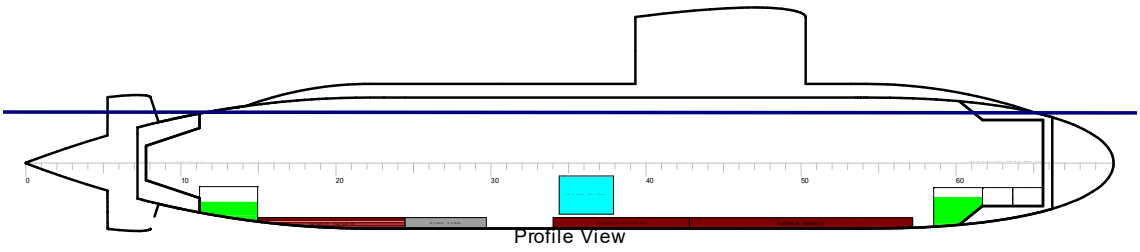

Figure 5.6 Profile View (30m)

Table 5.15 Densities (30m)

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	DIESEL FUEL	0.83
	LUB, OIL	0.9
	LOX	1.141

Table 5.16 Summary Table of Loading Condition 2a (30m)

Stability Calculations for Loading Condition 2A								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	6-10	DIESEL FUEL	98	0.83	2.5	8.589	1.623	-0.492
FUEL TANK 02	6-10	DIESEL FUEL	98	0.83	2.5	8.589	-1.623	-0.492
FUEL TANK 03	6-10	DIESEL FUEL	98	0.83	1.3	8.783	0.000	-1.837
FUEL TANK 04	15-18	DIESEL FUEL	98	0.83	1.6	16.427	0.000	-1.852
FUEL TANK 05	18-24	DIESEL FUEL	98	0.83	1.6	21.372	1.493	-1.083
FUEL TANK 06	18-24	DIESEL FUEL	98	0.83	1.6	21.372	-1.493	-1.083
FUEL TANK 07	18-24	DIESEL FUEL	98	0.83	2.6	21.365	0.000	-1.851
Total DIESEL FUEL					**13.7**	**14.862**	**0.000**	**-1.171**
FRESH WATER								
FRESH WATER TANK 01	16-18	FRESH WATER	98	1.00	0.6	17.368	1.494	-1.084
FRESH WATER TANK 02	16-18	FRESH WATER	98	1.00	0.6	17.368	-1.494	-1.084
Total FRESH WATER					**1.2**	**17.368**	**0.000**	**-1.084**
LUB, OIL								
OIL TANK	10-13	LUB, OIL	98	0.9	1.0	11.582	0.000	-1.852
Total LUB, OIL					**1.0**	**11.582**	**0.000**	**-1.852**
SEA WATER								
AFT MAIN BALLAST TANK	3-5	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	5-6	SEA WATER	37.5	1.025	0.6	5.717	0.465	-1.425
AFT TRIM TANK 02	5-6	SEA WATER	37.5	1.025	0.6	5.717	-0.465	-1.425
COMPENSATING TANK 01	17-17	SEA WATER	10	1.025	0.0	16.982	0.631	-1.527
COMPENSATING TANK 02	17-17	SEA WATER	10	1.025	0.0	16.982	-0.631	-1.527
COMPENSATING TANK 03	17-18	SEA WATER	10	1.025	0.0	17.795	0.631	-1.527
COMPENSATING TANK 04	17-18	SEA WATER	10	1.025	0.0	17.795	-0.631	-1.527
FWD MAIN BALLAST TANK	26-28	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	25-26	SEA WATER	62.5	1.025	1.1	25.577	0.604	-1.409
FWD TRIM TANK 02	25-26	SEA WATER	62.5	1.025	1.1	25.577	-0.604	-1.409
TORPEDO TUBE FLOODING TANK	27-28	SEA WATER	0	0	0.0	0.000	0.000	0.000
WATER ROUND TORPEDO TANK	26-27	SEA WATER	0	0	0.0	0.000	0.000	0.000

Table 5.16 Summary Table of Loading Condition 2a (30m) (continued…)

Total SEA WATER					**3.4**	**18.099**	**0.000**	**-1.420**
BILGE WATER / SLUDGE								
SANITARY TANK 01	15-16	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
SANITARY TANK 02	15-16	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
Total BILGE WATER / SLUDGE					**0.0**	**0.000**	**0.000**	**0.000**
LOx								
Lox TANK	15-16	LOX	98	1.141	1.8	15.464	0.000	-1.017
Total LOx					**1.8**	**15.464**	**0.000**	**-1.017**
LOADING CONDITION 2A FIXED WEIGHTS								
COMPLEMENT					0.3	16.067	0.000	-0.160
OFFICER EQUIPMENT					0.1	16.067	0.000	-0.160
P.O. EQUIPMENT					0.2	16.067	0.000	-0.160
RATING EQUIPMENT					0.1	16.067	0.000	-0.160
GARBAGE					0.0	0.000	0.000	0.000
PROVISIONS					1.6	16.067	0.000	-0.160
TORPEDO					1.5	27.228	0.000	-1.500
SPECIAL PERSONNEL & OTHER MILITARY LOADS					0.2	16.067	0.000	-0.160
DESIGN MARGIN					2.6	16.067	0.000	-0.160
CONSTRUCTION MARGIN					5.2	16.067	0.000	-0.160
MAINTENANCE MARGIN					2.6	16.067	0.000	-0.160
Loading Condition 2A Fixed Weights					**14.4**	**17.230**	**0.000**	**-0.300**
Lightweight					**259.3**	**16.067**	**0.000**	**-0.160**
Deadweight					**35.5**	**16.153**	**0.000**	**-0.855**
Total Displacement					**294.8**	**16.077**	**0.000**	**-0.244**
Buoyancy					**294.8**	**16.077**	**0.000**	**-0.101**
Total Buoyancy					**294.8**	**16.077**	**0.000**	**-0.101**

Table 5.17 Drafts at Equilibrium Angle (30m)

Drafts at equilibrium angle		
Draft at LCF	1.580	metres
Draft at AP	1.594	metres
Draft at FP	1.568	metres
Draft at midships	1.581	metres

Table 5.18 Hydrostatics at Equilibrium Angle (30m)

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim by the stern	0.026	metres
	0.02	degrees
KG	-0.244	metres
KB	-0.101	metres
FSC	0.004	metres
KGf	-0.239	metres
GMt	0.239	metres
BMt	0.100	metres
BMl	7.177	metres
Waterplane area	55.090	sq.metres
LCG	16.077	metres
LCB	16.077	metres
TCB	0.000	metres
LCF	16.508	metres
TCF	0.000	metres
TPC	0.565	tonnes/cm
MTC	0.719	tonnes-m/cm

Table 5.19 Summary Stability Table (30m)

Displacement [ton]	Δ	294.8	
Length [m]	L_{DWL}	30.00	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	1.580	3.633
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.244	1.809
Longitudinal Center of Gravity [m]	LCG	16.077	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	-0.008	
Wind Pressure [kN/m^2]	q_w	0.358	
Density of Air [t/m^3]	ρ_L	0.001225	
Wind Speed [m/s]	v_w	24.179	
Form Coefficient	c_f	0.600	
Projected Area Exposed to Wind Forces [m^2]	A_w	28.999	
Height of the Centroid of the Area Exposed to Wind [m] [from Reference Point] / [from Baseline]	A_{wz}	2.605	4.658
Height of the Centroid of the Area Exposed to Wind Above Half Draught [m] [from Baseline]	A_{wz}-0.5T	2.842	
Maximum Operational Speed of the Surfaced Submarine [knot] / [m/sn]	$v_0\uparrow$	12.000	6.173

Table 5.20 Righting – Heeling Lever Calculations (30m)

Heel Angle	Righting Lever	Heeling Lever				
[°]	h_{SW}	k_F	k_D	k_W	$k_F + k_D + k_W$	$h_{SW} - (k_F+k_D+k_W)$
10	0.0415	0.001	0.000	0.006	0.007	0.035
20	0.0817	0.001	0.000	0.006	0.007	0.075
30	0.1194	0.002	0.000	0.005	0.007	0.112
45	0.1691	0.003	0.000	0.004	0.007	0.162

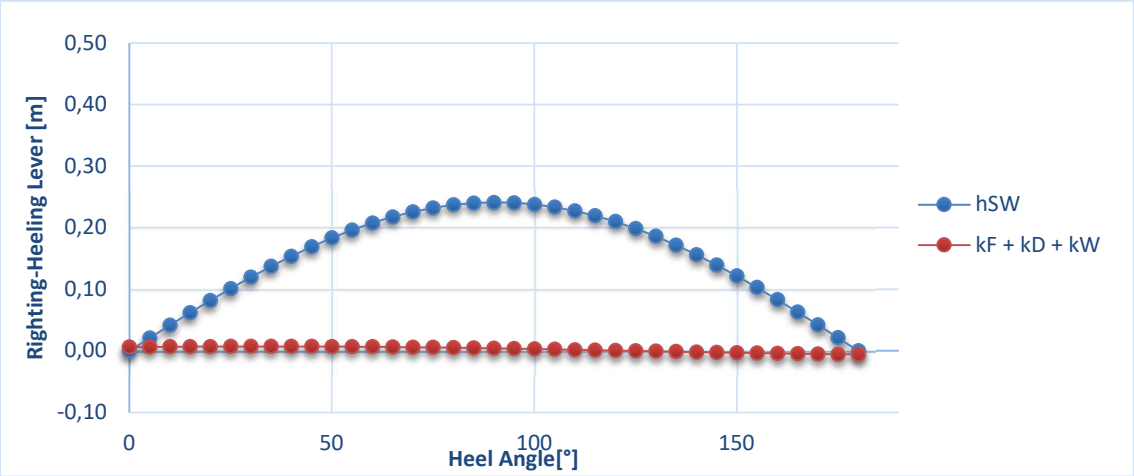

Figure 5.7 Righting – Heeling Lever / Heel Angle (30m)

Table 5.21 Criterion Assessment (30m)

#	Criterion	Actual Value	Critical Value	Result
1	The buoyancy reserve shall be at least 10% of the pressure tight volume of the submarine in surfaced condition.	12.3	10.0	+
2	Positive remaining lever h_{rem} at least 0.1 m in surfaced condition.	0.237	0.1	+
3	Minimum value for GM	0.239	0.150	+

This section focuses on stability analyses specifically related to loading case 2a, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Buoyancy reserve is 12.3% of the pressure tight volume of the submarine. Thus, the 10% limit value has been exceeded.
- Positive remaining lever h_{rem} is 0.237 m and is above the limit value of 0.1 m.
- The GM value is 0.239 m and is above the limit value of 0.15 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 2a.

5.1.1.4 Loading Condition 2b (30m)

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

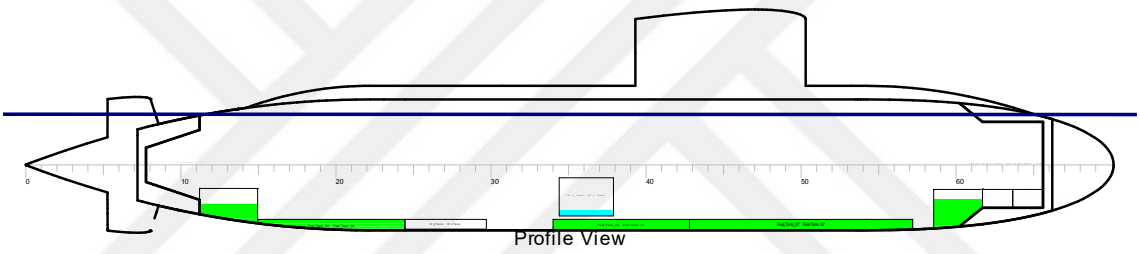

Figure 5.8 Profile View (30m)

Table 5.22 Densities (30m)

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	LUB, OIL	0.9
	BILGE WATER / SLUDGE	1.005
	LOX	1.141
	SEA WATER & DIESEL FUEL	1.005

Table 5.23 Summary Table of Loading Condition 2b (30m)

Stability Calculations for Loading Condition 2B								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	6-10	SEA WATER & DIESEL FUEL	98	1.01	3.1	8.589	1.623	-0.492
FUEL TANK 02	6-10	SEA WATER & DIESEL FUEL	98	1.01	3.1	8.589	-1.623	-0.492
FUEL TANK 03	6-10	SEA WATER & DIESEL FUEL	98	1.01	1.6	8.783	0.000	-1.837
FUEL TANK 04	15-18	SEA WATER & DIESEL FUEL	98	1.01	1.9	16.427	0.000	-1.852
FUEL TANK 05	18-24	SEA WATER & DIESEL FUEL	98	1.01	1.9	21.372	1.493	-1.083
FUEL TANK 06	18-24	SEA WATER & DIESEL FUEL	98	1.01	1.9	21.372	-1.493	-1.083
FUEL TANK 07	18-24	SEA WATER & DIESEL FUEL	98	1.01	3.1	21.365	0.000	-1.851
Total DIESEL FUEL					**16.6**	**14.862**	**0.000**	**-1.171**
FRESH WATER								
FRESH WATER TANK 01	16-18	FRESH WATER	10	1.00	0.1	17.367	1.350	-1.463
FRESH WATER TANK 02	16-18	FRESH WATER	10	1.00	0.1	17.367	-1.350	-1.463
Total FRESH WATER					**0.2**	**17.367**	**0.000**	**-1.463**
LUB, OIL								
OIL TANK	10-13	LUB, OIL	10	0.9	0.1	11.578	0.000	-2.010
Total LUB, OIL					**0.1**	**11.578**	**0.000**	**-2.010**
SEA WATER								
AFT MAIN BALLAST TANK	3-5	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	5-6	SEA WATER	37.5	1.025	0.6	5.718	0.465	-1.425
AFT TRIM TANK 02	5-6	SEA WATER	37.5	1.025	0.6	5.718	-0.465	-1.425
COMPENSATING TANK 01	17-17	SEA WATER	70	1.025	0.3	16.983	0.631	-1.295
COMPENSATING TANK 02	17-17	SEA WATER	70	1.025	0.3	16.983	-0.631	-1.295

Table 5.23 Summary Table of Loading Condition 2b (30m) (continued…)

COMPENSATING TANK 03	17-18	SEA WATER	70	1.025	0.3	17.795	0.631	-1.295
COMPENSATING TANK 04	17-18	SEA WATER	70	1.025	0.3	17.795	-0.631	-1.295
FWD MAIN BALLAST TANK	26-28	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	25-26	SEA WATER	62.5	1.025	1.1	25.577	0.604	-1.409
FWD TRIM TANK 02	25-26	SEA WATER	62.5	1.025	1.1	25.577	-0.604	-1.409
TORPEDO TUBE FLOODING TANK	27-28	SEA WATER	0	0	0.0	0.000	0.000	0.000
WATER ROUND TORPEDO TANK	26-27	SEA WATER	0	0	0.0	0.000	0.000	0.000
Total SEA WATER					**4.6**	**17.956**	**0.000**	**-1.387**
BILGE WATER / SLUDGE								
SANITARY TANK 01	15-16	BILGE WATER / SLUDGE	90	1.005	0.5	15.485	1.487	-1.109
SANITARY TANK 02	15-16	BILGE WATER / SLUDGE	90	1.005	0.5	15.485	-1.487	-1.109
Total BILGE WATER / SLUDGE					**1.0**	**15.485**	**0.000**	**-1.109**
LOx								
Lox TANK	15-16	LOX	10	1.141	0.2	15.463	0.000	-1.493
Total LOx					**0.2**	**15.463**	**0.000**	**-1.493**
LOADING CONDITION 2B FIXED WEIGHTS								
COMPLEMENT					0.3	16.067	0.000	-0.160
OFFICER EQUIPMENT					0.1	16.067	0.000	-0.160
P.O. EQUIPMENT					0.2	16.067	0.000	-0.160
RATING EQUIPMENT					0.0	16.067	0.000	-0.160
GARBAGE					0.2	16.067	0.000	-0.160
PROVISIONS					0.2	16.067	0.000	-0.160
TORPEDO					1.5	27.228	0.000	-1.500
SPECIAL PERSONNEL & OTHER MILITARY LOADS					0.2	16.067	0.000	-0.160
DESIGN MARGIN					2.6	16.067	0.000	-0.160
CONSTRUCTION MARGIN					5.2	16.067	0.000	-0.160
MAINTENANCE MARGIN					2.6	16.067	0.000	-0.160
Loading Condition 2B Fixed Weights					**13.1**	**17.345**	**0.000**	**-0.313**
Lightweight					**259.3**	**16.067**	**0.000**	**-0.160**
Deadweight					**35.5**	**16.177**	**0.000**	**-0.887**
Total Displacement					**294.8**	**16.080**	**0.000**	**-0.248**
Buoyancy					**294.8**	**16.080**	**0.000**	**-0.101**
Total Buoyancy					**294.8**	**16.080**	**0.000**	**-0.101**

Table 5.24 Drafts at Equilibrium Angle (30m)

Drafts at equilibrium angle		
Draft at LCF	1.580	metres
Draft at AP	1.588	metres
Draft at FP	1.573	metres
Draft at midships	1.580	metres

Table 5.25 Hydrostatics at Equilibrium Angle (30m)

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim by the stern	0.015	metres
	0.01	degrees
KG	-0.248	metres
KB	-0.101	metres
FSC	0.006	metres
KGf	-0.242	metres
GMt	0.241	metres
BMt	0.100	metres
BMl	7.180	metres
Waterplane area	55.100	sq.metres
LCG	16.080	metres
LCB	16.080	metres
TCB	0.000	metres
LCF	16.480	metres
TCF	0.000	metres
TPC	0.565	tonnes/cm
MTC	0.720	tonnes-m/cm

Table 5.26 Summary Stability Table (30m)

Displacement [ton]	Δ	294.8	
Length [m]	L_{DWL}	30.00	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	1.580	3.633
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.248	1.805
Longitudinal Center of Gravity [m]	LCG	16.080	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	-0.012	
Wind Pressure [kN/m^2]	q_w	0.358	
Density of Air [t/m^3]	ρ_L	0.001225	
Wind Speed [m/s]	v_w	24.179	
Form Coefficient	c_f	0.600	

Table 5.26 Summary Stability Table (30m) (continued…)

Projected Area Exposed to Wind Forces [m^2]	A_w	28.999	
Height of the Centroid of the Area Exposed to Wind [m] [from Reference Point] / [from Baseline]	A_{wz}	2.605	4.658
Height of the Centroid of the Area Exposed to Wind Above Half Draught [m] [from Baseline]	A_{wz}-0.5T	2.842	
Maximum Operational Speed of the Surfaced Submarine [knot] / [m/sn]	$v_0\uparrow$	12.000	6.173

Table 5.27 Righting – Heeling Lever Calculations (30m)

Heel Angle	**Righting Lever**	**Heeling Lever**				
[°]	h_{SW}	k_F	k_D	k_W	$k_F + k_D + k_W$	$h_{SW} - (k_F+k_D+k_W)$
10	0.0419	0.001	0.000	0.006	0.007	0.035
20	0.0825	0.002	0.000	0.006	0.008	0.075
30	0.1207	0.003	0.000	0.005	0.008	0.113
45	0.1710	0.004	0.000	0.004	0.008	0.163

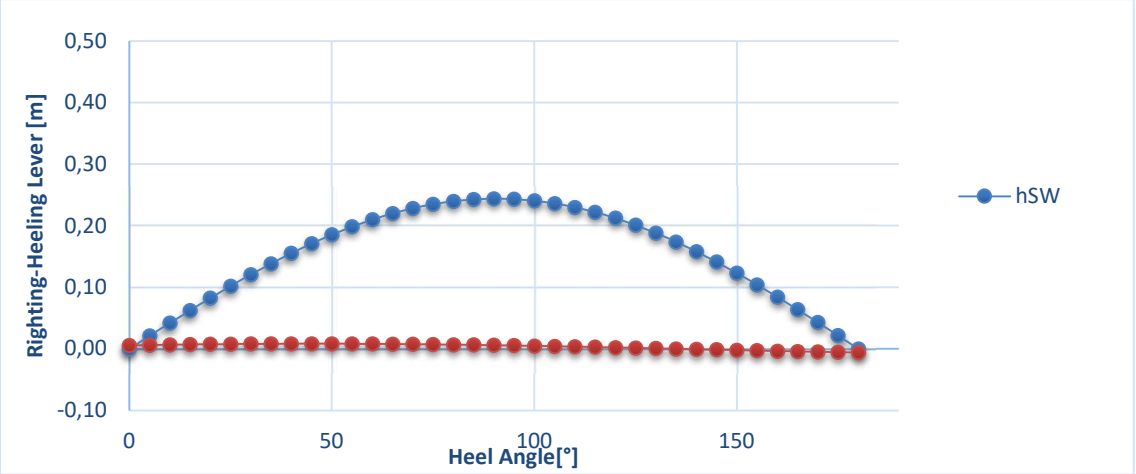

Figure 5.9 Righting – Heeling Lever / Heel Angle (30m)

Table 5.28 Criterion Assessment (30m)

#	Criterion	Actual Value	Critical Value	Result
1	The buoyancy reserve shall be at least 10% of the pressure tight volume of the submarine in surfaced condition.	12.3	10.0	+
2	Positive remaining lever h_{rem} at least 0.1 m in surfaced condition.	0.238	0.1	+
3	Minimum value for GM	0.241	0.150	+

This section focuses on stability analyses specifically related to loading case 2b, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Buoyancy reserve is 12.3% of the pressure tight volume of the submarine. Thus, the 10% limit value has been exceeded.
- Positive remaining lever h_{rem} is 0.238 m and is above the limit value of 0.1 m.
- The GM value is 0.241 m and is above the limit value of 0.15 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 2b.

5.1.2 Submerged Submarine (30m)

5.1.2.1 Loading Condition 3a (30m)

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

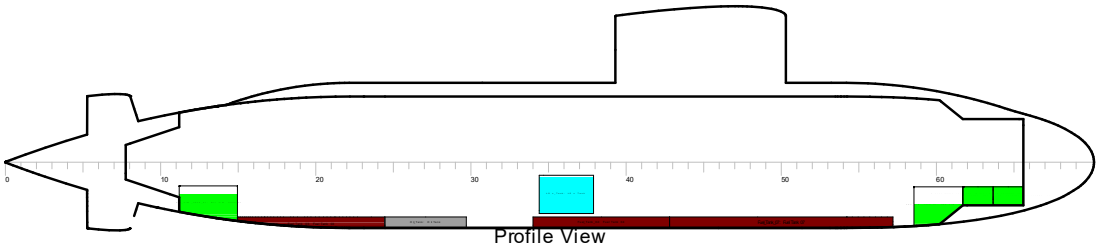

Figure 5.10 Profile View (30m)

Table 5.29 Densities (30m)

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	DIESEL FUEL	0.83
	LUB, OIL	0.9
	LOX	1.141

Table 5.30 Summary Table of Loading Condition 3a (30m)

Stability Calculations for Loading Condition 3A								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	6-10	DIESEL FUEL	98	0.83	2.5	8.589	1.623	-0.492
FUEL TANK 02	6-10	DIESEL FUEL	98	0.83	2.5	8.589	-1.623	-0.492
FUEL TANK 03	6-10	DIESEL FUEL	98	0.83	1.3	8.783	0.000	-1.837
FUEL TANK 04	15-18	DIESEL FUEL	98	0.83	1.6	16.427	0.000	-1.852
FUEL TANK 05	18-24	DIESEL FUEL	98	0.83	1.6	21.372	1.493	-1.083
FUEL TANK 06	18-24	DIESEL FUEL	98	0.83	1.6	21.372	-1.493	-1.083
FUEL TANK 07	18-24	DIESEL FUEL	98	0.83	2.6	21.365	0.000	-1.851
Total DIESEL FUEL					**13.7**	**14.862**	**0.000**	**-1.171**
FRESH WATER								
FRESH WATER TANK 01	16-18	FRESH WATER	98	1.00	0.6	17.368	1.494	-1.084
FRESH WATER TANK 02	16-18	FRESH WATER	98	1.00	0.6	17.368	-1.494	-1.084
Total FRESH WATER					**1.2**	**17.368**	**0.000**	**-1.084**
LUB, OIL								
OIL TANK	10-13	LUB, OIL	98	0.9	1.0	11.582	0.000	-1.852
Total LUB, OIL					**1.0**	**11.582**	**0.000**	**-1.852**
SEA WATER								
AFT MAIN BALLAST TANK	3-5	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	5-6	SEA WATER	62.5	1.025	1.1	5.684	0.537	-1.301
AFT TRIM TANK 02	5-6	SEA WATER	62.5	1.025	1.1	5.684	-0.537	-1.301
COMPENSATING TANK 01	17-17	SEA WATER	20	1.025	0.1	16.983	0.631	-1.479
COMPENSATING TANK 02	17-17	SEA WATER	20	1.025	0.1	16.983	-0.631	-1.479
COMPENSATING TANK 03	17-18	SEA WATER	20	1.025	0.1	17.796	0.631	-1.479
COMPENSATING TANK 04	17-18	SEA WATER	20	1.025	0.1	17.796	-0.631	-1.479
FWD MAIN BALLAST TANK	26-28	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	25-26	SEA WATER	37.5	1.025	0.6	25.532	0.536	-1.556
FWD TRIM TANK 02	25-26	SEA WATER	37.5	1.025	0.6	25.532	-0.536	-1.556

Table 5.30 Summary Table of Loading Condition 3a (30m) (continued…)

TORPEDO TUBE FLOODING TANK	27-28	SEA WATER	98	1.025	0.7	27.645	0.000	-1.011
WATER ROUND TORPEDO TANK	26-27	SEA WATER	98	1.025	0.7	26.811	0.000	-1.011
Total SEA WATER					**5.2**	**17.370**	**0.000**	**-1.292**
BILGE WATER / SLUDGE								
SANITARY TANK 01	15-16	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
SANITARY TANK 02	15-16	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
Total BILGE WATER / SLUDGE					**0.0**	**0.000**	**0.000**	**0.000**
LOx								
Lox TANK	15-16	LOX	98	1.141	1.8	15.464	0.000	-1.017
Total LOx					**1.8**	**15.464**	**0.000**	**-1.017**
LOADING CONDITION 3A FIXED WEIGHTS								
COMPLEMENT					0.3	16.067	0.000	-0.160
OFFICER EQUIPMENT					0.1	16.067	0.000	-0.160
P.O. EQUIPMENT					0.2	16.067	0.000	-0.160
RATING EQUIPMENT					0.1	16.067	0.000	-0.160
GARBAGE					0.0	0.000	0.000	0.000
PROVISIONS					1.6	16.067	0.000	-0.160
TORPEDO					0.0	0.000	0.000	0.000
SPECIAL PERSONNEL & OTHER MILITARY LOADS					0.0	0.000	0.000	0.000
DESIGN MARGIN					2.6	16.067	0.000	-0.160
CONSTRUCTION MARGIN					5.2	16.067	0.000	-0.160
MAINTENANCE MARGIN					2.6	16.067	0.000	-0.160
Loading Condition 3A Fixed Weights					**12.7**	**16.067**	**0.000**	**-0.160**
Lightweight					**259.3**	**16.067**	**0.000**	**-0.160**
Deadweight					**35.6**	**15.676**	**0.000**	**-0.837**
Total Displacement					**294.9**	**16.020**	**0.000**	**-0.242**
Buoyancy					**294.9**	**16.020**	**0.000**	**0.000**
Total Buoyancy					**294.9**	**16.020**	**0.000**	**0.000**

Table 5.31 Hydrostatics at Equilibrium Angle (30m)

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim	No trim	metres
KG	-0.242	metres
KB	0.000	metres
FSC	0.005	metres
KGf	-0.237	metres
GMt	0.237	metres
BMt	0.000	metres
BMl	0.000	metres
Waterplane area	0.000	sq.metres
LCG	16.020	metres
LCB	16.020	metres
TCB	0.000	metres
LCF	35.077	metres
TCF	0.000	metres
TPC	0.000	tonnes/cm
MTC	0.024	tonnes-m/cm

Table 5.32 Summary Stability Table (30m)

Displacement [ton]	Δ	294.9	
Length [m]	L_{DWL}	30.00	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	1.580	3.633
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.242	1.811
Longitudinal Center of Gravity [m]	LCG	16.020	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	-0.006	
Maximum Operational Speed of the Submerged Submarine [knot] / [m/sn]	$v_0\uparrow$	22.000	11.317

Table 5.33 Righting – Heeling Lever Calculations (30m)

Heel Angle	**Righting Lever**	**Heeling Lever**			
[°]	h_{SUB}	k_F	kD	$k_F + k_D$	$h_{SW} - (k_F+k_D)$
10	0.0412	0.001	0.000	0.000	0.041
20	0.0810	0.002	0.000	0.001	0.080
30	0.1183	0.003	0.000	0.002	0.116
45	0.1676	0.004	0.000	0.003	0.164

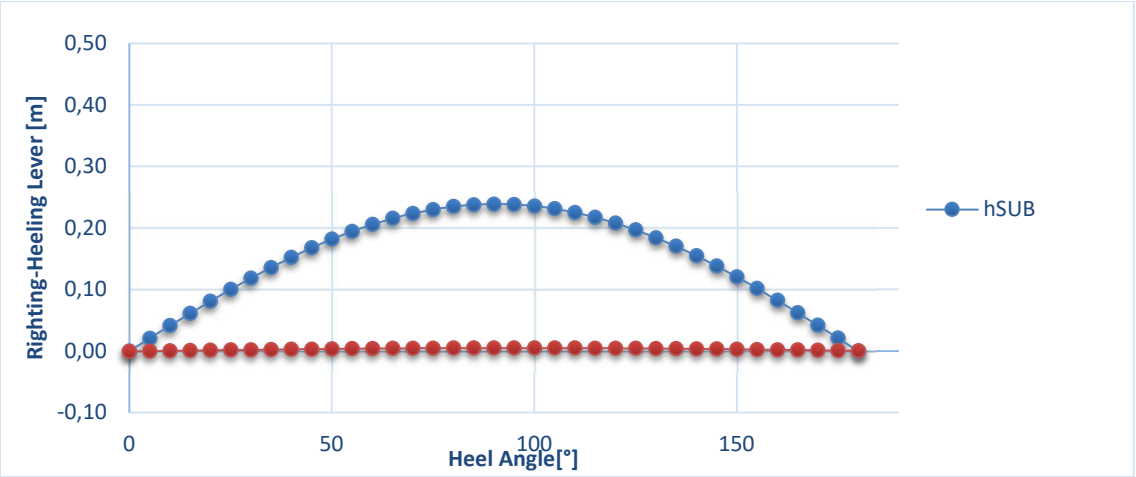

Figure 5.11 Righting – Heeling Lever / Heel Angle (30m)

Table 5.34 Criterion Assessment (30m)

#	Criterion	Actual Value	Critical Value	Result
1	Positive remaining lever h_{rem} at least 0.05 m in dived condition.	0.234	0.050	+
2	Minimum value for BG	0.242	0.220	+

This section focuses on stability analyses specifically related to loading case 3a, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn

- Positive remaining lever h_{rem} is 0.234 m and is above the limit value of 0.05 m.
- The BG value is 0.242 m and is above the limit value of 0.22 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 3a.

5.1.2.2 Loading Condition 3b (30m)

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below

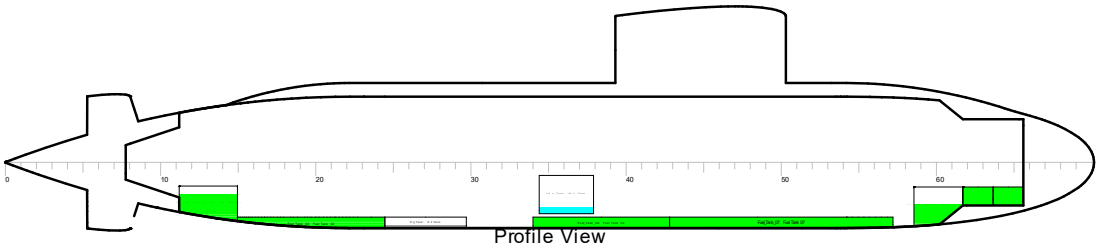

Figure 5.12 Profile View (30m)

Table 5.35 Densities (30m)

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	LUB, OIL	0.9
	BILGE WATER / SLUDGE	1.005
	LOX	1.141
	SEA WATER & DIESEL FUEL	1.005

Vessel is submerged.

Table 5.36 Summary Table of Loading Condition 3b (30m)

Stability Calculations for Loading Condition 3B								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	6-10	SEA WATER & DIESEL FUEL	98	1.01	3.1	8.589	1.623	-0.492
FUEL TANK 02	6-10	SEA WATER & DIESEL FUEL	98	1.01	3.1	8.589	-1.623	-0.492
FUEL TANK 03	6-10	SEA WATER & DIESEL FUEL	98	1.01	1.6	8.783	0.000	-1.837
FUEL TANK 04	15-18	SEA WATER & DIESEL FUEL	98	1.01	1.9	16.427	0.000	-1.852
FUEL TANK 05	18-24	SEA WATER & DIESEL FUEL	98	1.01	1.9	21.372	1.493	-1.083
FUEL TANK 06	18-24	SEA WATER & DIESEL FUEL	98	1.01	1.9	21.372	-1.493	-1.083
FUEL TANK 07	18-24	SEA WATER & DIESEL FUEL	98	1.01	3.1	21.365	0.000	-1.851
Total DIESEL FUEL					**16.6**	**14.862**	**0.000**	**-1.171**
FRESH WATER								
FRESH WATER TANK 01	16-18	FRESH WATER	10	1.00	0.1	17.368	1.350	-1.463
FRESH WATER TANK 02	16-18	FRESH WATER	10	1.00	0.1	17.368	-1.350	-1.463
Total FRESH WATER					**0.2**	**17.368**	**0.000**	**-1.463**
LUB, OIL								
OIL TANK	10-13	LUB, OIL	10	0.9	0.1	11.582	0.000	-2.010
Total LUB, OIL					**0.1**	**11.582**	**0.000**	**-2.010**
SEA WATER								
AFT MAIN BALLAST TANK	3-5	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	5-6	SEA WATER	64	1.025	1.1	5.683	0.541	-1.294
AFT TRIM TANK 02	5-6	SEA WATER	64	1.025	1.1	5.683	-0.541	-1.294
COMPENSATING TANK 01	17-17	SEA WATER	80	1.025	0.3	16.983	0.631	-1.260
COMPENSATING TANK 02	17-17	SEA WATER	80	1.025	0.3	16.983	-0.631	-1.260

Table 5.36 Summary Table of Loading Condition 3b (30m) (continued…)

COMPENSATING TANK 03	17-18	SEA WATER	80	1.025	0.3	17.796	0.631	-1.260
COMPENSATING TANK 04	17-18	SEA WATER	80	1.025	0.3	17.796	-0.631	-1.260
FWD MAIN BALLAST TANK	26-28	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	25-26	SEA WATER	36	1.025	0.6	25.528	0.531	-1.566
FWD TRIM TANK 02	25-26	SEA WATER	36	1.025	0.6	25.528	-0.531	-1.566
TORPEDO TUBE FLOODING TANK	27-28	SEA WATER	98	1.025	0.7	27.645	0.000	-1.011
WATER ROUND TORPEDO TANK	26-27	SEA WATER	98	1.025	0.7	26.811	0.000	-1.011
Total SEA WATER					**6.0**	**17.206**	**0.000**	**-1.274**
BILGE WATER / SLUDGE								
SANITARY TANK 01	15-16	BILGE WATER / SLUDGE	90	1.005	0.5	15.486	1.487	-1.109
SANITARY TANK 02	15-16	BILGE WATER / SLUDGE	90	1.005	0.5	15.486	-1.487	-1.109
Total BILGE WATER / SLUDGE					**1.0**	**15.486**	**0.000**	**-1.109**
LOx								
Lox TANK	15-16	LOX	10	1.141	0.2	15.464	0.000	-1.493
Total LOx					**0.2**	**15.464**	**0.000**	**-1.493**
LOADING CONDITION 3B FIXED WEIGHTS								
COMPLEMENT					0.3	16.067	0.000	-0.160
OFFICER EQUIPMENT					0.1	16.067	0.000	-0.160
P.O. EQUIPMENT					0.2	16.067	0.000	-0.160
RATING EQUIPMENT					0.0	16.067	0.000	-0.160
GARBAGE					0.2	16.067	0.000	-0.160
PROVISIONS					0.2	16.067	0.000	-0.160
TORPEDO					0.0	0.000	0.000	0.000
SPECIAL PERSONNEL & OTHER MILITARY LOADS					0.0	0.000	0.000	0.000
DESIGN MARGIN					2.6	16.067	0.000	-0.160
CONSTRUCTION MARGIN					5.2	16.067	0.000	-0.160
MAINTENANCE MARGIN					2.6	16.067	0.000	-0.160
Loading Condition 3B Fixed Weights					**11.4**	**16.067**	**0.000**	**-0.160**
Lightweight					**259.3**	**16.067**	**0.000**	**-0.160**
Deadweight					**35.6**	**15.676**	**0.000**	**-0.867**
Total Displacement					**294.9**	**16.020**	**0.000**	**-0.245**
Buoyancy					**294.9**	**16.020**	**0.000**	**0.000**
Total Buoyancy					**294.9**	**16.020**	**0.000**	**0.000**

Table 5.37 Hydrostatics at Equilibrium Angle (30m)

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim	No trim	metres
KG	-0.245	metres
KB	0.000	metres
FSC	0.006	metres
KGf	-0.239	metres
GMt	0.239	metres
BMt	0.000	metres
BMl	0.000	metres
Waterplane area	0.000	sq.metres
LCG	16.020	metres
LCB	16.020	metres
TCB	0.000	metres
LCF	35.077	metres
TCF	0.000	metres
TPC	0.000	tonnes/cm
MTC	0.024	tonnes-m/cm

Table 5.38 Summary Stability Table (30m)

Displacement [ton]	Δ	294.9	
Length [m]	L_{DWL}	30.00	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	1.580	3.633
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.245	1.808
Longitudinal Center of Gravity [m]	LCG	16.020	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	-0.009	
Maximum Operational Speed of the Submerged Submarine [knot] / [m/sn]	$v_0\uparrow$	22.000	11.317

Table 5.39 Righting – Heeling Lever Calculations (30m)

Heel Angle	**Righting Lever**	**Heeling Lever**			
[°]	h_{SUB}	k_F	kD	$k_F + k_D$	$h_{SW} - (k_F+k_D)$
10	0.0416	0.001	-0.001	0.000	0.041
20	0.0818	0.002	-0.001	0.001	0.080
30	0.1196	0.003	-0.001	0.002	0.117
45	0.1696	0.004	-0.001	0.004	0.166

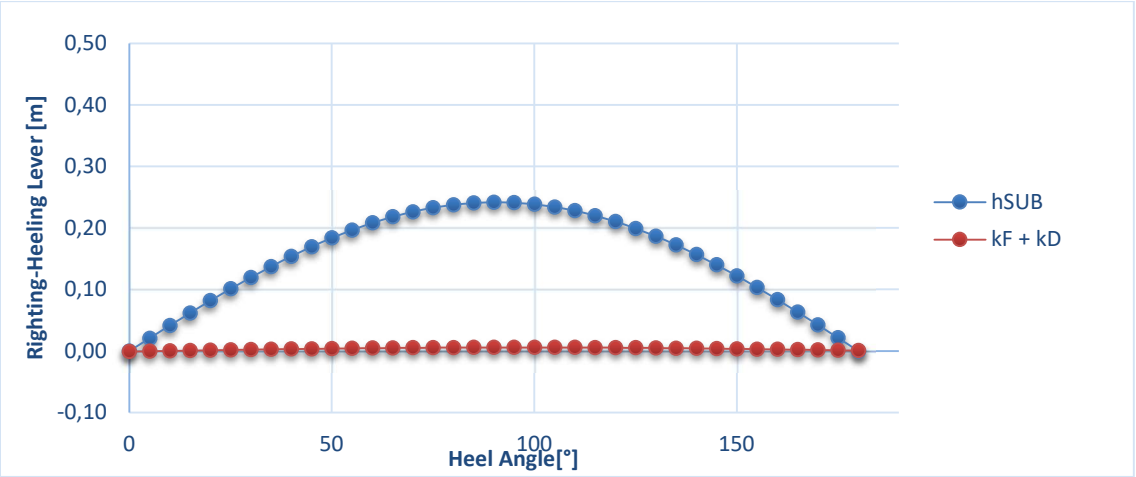

Figure 5.13 Righting – Heeling Lever / Heel Angle (30m)

Table 5.40 Criterion Assessment (30m)

#	Criterion	Actual Value	Critical Value	Result
1	Positive remaining lever h_{rem} at least 0.05 m in dived condition.	0.236	0.050	+
2	Minimum value for BG	0.245	0.220	+

This section focuses on stability analyses specifically related to loading case 3b, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Positive remaining lever h_{rem} is 0.236 m and is above the limit value of 0.05 m.
- The BG value is 0.245 m and is above the limit value of 0.22 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 3b.

5.1.2.3 Loading Condition 4a (30m)

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below

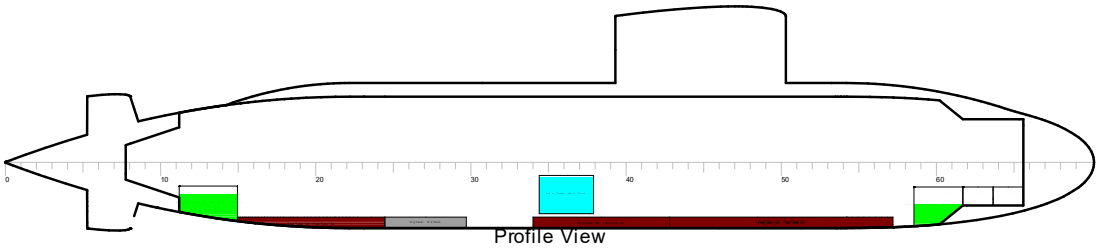

Figure 5.14 Profile View (30m)

Table 5.41 Densities (30m)

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	DIESEL FUEL	0.83
	LUB, OIL	0.9
	LOX	1.141

Table 5.42 Summary Table of Loading Condition 4a (30m)

Stability Calculations for Loading Condition 4A								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	6-10	DIESEL FUEL	98	0.83	2.5	8.589	1.623	-0.492
FUEL TANK 02	6-10	DIESEL FUEL	98	0.83	2.5	8.589	-1.623	-0.492
FUEL TANK 03	6-10	DIESEL FUEL	98	0.83	1.3	8.783	0.000	-1.837
FUEL TANK 04	15-18	DIESEL FUEL	98	0.83	1.6	16.427	0.000	-1.852
FUEL TANK 05	18-24	DIESEL FUEL	98	0.83	1.6	21.372	1.493	-1.083
FUEL TANK 06	18-24	DIESEL FUEL	98	0.83	1.6	21.372	-1.493	-1.083
FUEL TANK 07	18-24	DIESEL FUEL	98	0.83	2.6	21.365	0.000	-1.851
Total DIESEL FUEL					**13.7**	**14.862**	**0.000**	**-1.171**
FRESH WATER								
FRESH WATER TANK 01	16-18	FRESH WATER	98	1.00	0.6	17.368	1.494	-1.084
FRESH WATER TANK 02	16-18	FRESH WATER	98	1.00	0.6	17.368	-1.494	-1.084
Total FRESH WATER					**1.2**	**17.368**	**0.000**	**-1.084**
LUB, OIL								
OIL TANK	10-13	LUB, OIL	98	0.9	1.0	11.582	0.000	-1.852
Total LUB, OIL					**1.0**	**11.582**	**0.000**	**-1.852**
SEA WATER								
AFT MAIN BALLAST TANK	3-5	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	5-6	SEA WATER	62.5	1.025	1.1	5.684	0.537	-1.301
AFT TRIM TANK 02	5-6	SEA WATER	62.5	1.025	1.1	5.684	-0.537	-1.301
COMPENSATING TANK 01	17-17	SEA WATER	10	1.025	0.0	16.983	0.631	-1.527
COMPENSATING TANK 02	17-17	SEA WATER	10	1.025	0.0	16.983	-0.631	-1.527
COMPENSATING TANK 03	17-18	SEA WATER	10	1.025	0.0	17.796	0.631	-1.527
COMPENSATING TANK 04	17-18	SEA WATER	10	1.025	0.0	17.796	-0.631	-1.527
FWD MAIN BALLAST TANK	26-28	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	25-26	SEA WATER	37.5	1.025	0.6	25.532	0.536	-1.556

Table 5.42 Summary Table of Loading Condition 4a (30m) (continued…)

FWD TRIM TANK 02	25-26	SEA WATER	37.5	1.025	0.6	25.532	-0.536	-1.556
TORPEDO TUBE FLOODING TANK	27-28	SEA WATER	0	0	0.0	0.000	0.000	0.000
WATER ROUND TORPEDO TANK	26-27	SEA WATER	0	0	0.0	0.000	0.000	0.000
Total SEA WATER					**3.4**	**13.306**	**0.000**	**-1.402**
BILGE WATER / SLUDGE								
SANITARY TANK 01	15-16	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
SANITARY TANK 02	15-16	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
Total BILGE WATER / SLUDGE					**0.0**	**0.000**	**0.000**	**0.000**
LOx								
Lox TANK	15-16	LOX	98	1.141	1.8	15.464	0.000	-1.017
Total LOx					**1.8**	**15.464**	**0.000**	**-1.017**
LOADING CONDITION 4A FIXED WEIGHTS								
COMPLEMENT					0.3	16.067	0.000	-0.160
OFFICER EQUIPMENT					0.1	16.067	0.000	-0.160
P.O. EQUIPMENT					0.2	16.067	0.000	-0.160
RATING EQUIPMENT					0.1	16.067	0.000	-0.160
GARBAGE					0.0	0.000	0.000	0.000
PROVISIONS					1.6	16.067	0.000	-0.160
TORPEDO					1.5	27.228	0.000	-1.500
SPECIAL PERSONNEL & OTHER MILITARY LOADS					0.2	16.067	0.000	-0.160
DESIGN MARGIN					2.6	16.067	0.000	-0.160
CONSTRUCTION MARGIN					5.2	16.067	0.000	-0.160
MAINTENANCE MARGIN					2.6	16.067	0.000	-0.160
Loading Condition 4A Fixed Weights					**14.4**	**17.230**	**0.000**	**-0.300**
Lightweight					**259.3**	**16.067**	**0.000**	**-0.160**
Deadweight					**35.6**	**15.676**	**0.000**	**-0.852**
Total Displacement					**294.9**	**16.020**	**0.000**	**-0.243**
Buoyancy					**294.9**	**16.020**	**0.000**	**0.000**
Total Buoyancy					**294.9**	**16.020**	**0.000**	**0.000**

Table 5.43 Hydrostatics at Equilibrium Angle (30m)

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim	No trim	metres
KG	-0.243	metres
KB	0.000	metres
FSC	0.004	metres
KGf	-0.239	metres
GMt	0.239	metres
BMt	0.000	metres
BMl	0.000	metres
Waterplane area	0.000	sq.metres
LCG	16.020	metres
LCB	16.020	metres
TCB	0.000	metres
LCF	35.077	metres
TCF	0.000	metres
TPC	0.000	tonnes/cm
MTC	0.024	tonnes-m/cm

Table 5.44 Summary Stability Table (30m)

Displacement [ton]	Δ	294.9	
Length [m]	L_{DWL}	30.00	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	1.580	3.633
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.243	1.810
Longitudinal Center of Gravity [m]	LCG	16.020	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	-0.006	
Maximum Operational Speed of the Submerged Submarine [knot] / [m/sn]	$v_0\uparrow$	22.000	11.317

Table 5.45 Righting – Heeling Lever Calculations (30m)

Heel Angle	**Righting Lever**	**Heeling Lever**			
[°]	h_{SUB}	k_F	kD	$k_F + k_D$	$h_{SW} - (k_F+k_D)$
10	0.0415	0.001	-0.001	0.000	0.041
20	0.0816	0.001	-0.001	0.001	0.081
30	0.1193	0.002	0.000	0.002	0.118
45	0.1689	0.003	0.000	0.002	0.166

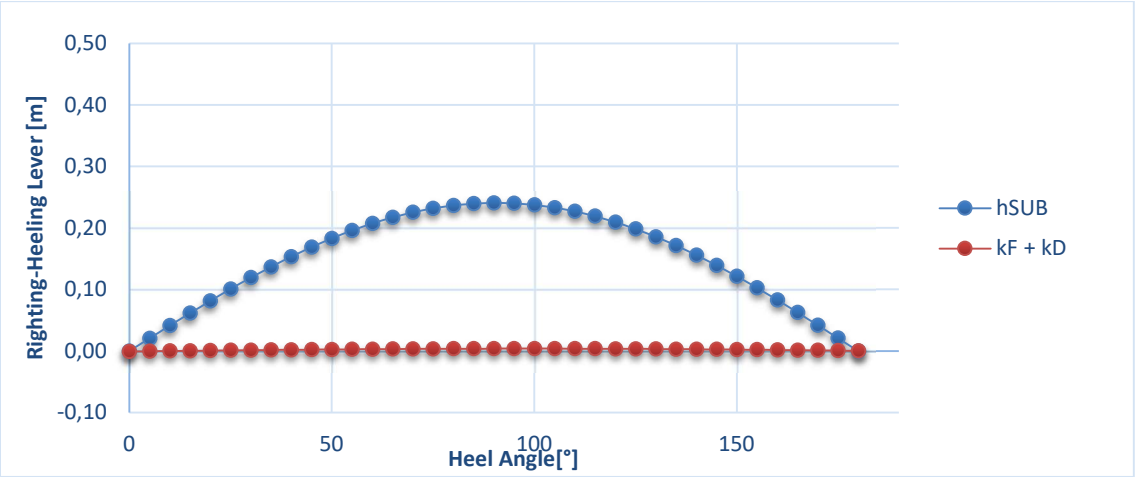

Figure 5.15 Righting – Heeling Lever / Heel Angle (30m)

Table 5.46 Criterion Assessment (30m)

#	Criterion	Actual Value	Critical Value	Result
1	Positive remaining lever h_{rem} at least 0.05 m in dived condition.	0.237	0.050	+
2	Minimum value for BG	0.243	0.220	+

This section focuses on stability analyses specifically related to loading case 4a, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Positive remaining lever h_{rem} is 0.237 m and is above the limit value of 0.05 m.
- The BG value is 0.243 m and is above the limit value of 0.22 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 4a.

5.1.2.4 Loading Condition 4b (30m)

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

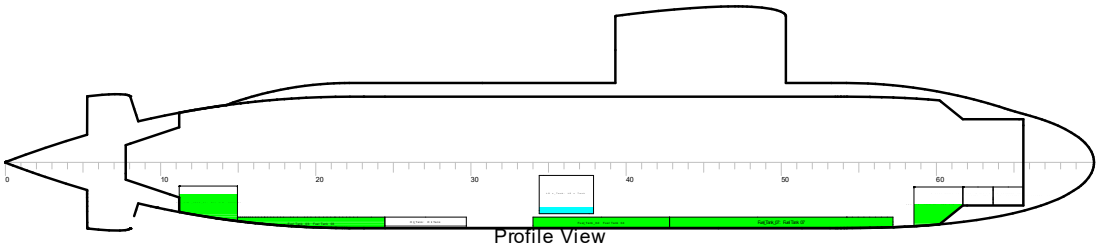

Figure 5.16 Profile View (30m)

Table 5.47 Densities (30m)

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	LUB, OIL	0.9
	BILGE WATER / SLUDGE	1.005
	LOX	1.141
	SEA WATER & DIESEL FUEL	1.005

Vessel is submerged.

Table 5.48 Summary Table of Loading Condition 4b (30m)

Stability Calculations for Loading Condition 4B								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	6-10	SEA WATER & DIESEL FUEL	98	1.01	3.1	8.589	1.623	-0.492
FUEL TANK 02	6-10	SEA WATER & DIESEL FUEL	98	1.01	3.1	8.589	-1.623	-0.492
FUEL TANK 03	6-10	SEA WATER & DIESEL FUEL	98	1.01	1.6	8.783	0.000	-1.837
FUEL TANK 04	15-18	SEA WATER & DIESEL FUEL	98	1.01	1.9	16.427	0.000	-1.852
FUEL TANK 05	18-24	SEA WATER & DIESEL FUEL	98	1.01	1.9	21.372	1.493	-1.083
FUEL TANK 06	18-24	SEA WATER & DIESEL FUEL	98	1.01	1.9	21.372	-1.493	-1.083
FUEL TANK 07	18-24	SEA WATER & DIESEL FUEL	98	1.01	3.1	21.365	0.000	-1.851
Total DIESEL FUEL					**16.6**	**14.862**	**0.000**	**-1.171**
FRESH WATER								
FRESH WATER TANK 01	16-18	FRESH WATER	10	1.00	0.1	17.368	1.350	-1.463
FRESH WATER TANK 02	16-18	FRESH WATER	10	1.00	0.1	17.368	-1.350	-1.463
Total FRESH WATER					**0.2**	**17.368**	**0.000**	**-1.463**
LUB, OIL								
OIL TANK	10-13	LUB, OIL	10	0.9	0.1	11.582	0.000	-2.010
Total LUB, OIL					**0.1**	**11.582**	**0.000**	**-2.010**
SEA WATER								
AFT MAIN BALLAST TANK	3-5	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	5-6	SEA WATER	64	1.025	1.1	5.683	0.541	-1.294
AFT TRIM TANK 02	5-6	SEA WATER	64	1.025	1.1	5.683	-0.541	-1.294
COMPENSATING TANK 01	17-17	SEA WATER	70	1.025	0.3	16.983	0.631	-1.295
COMPENSATING TANK 02	17-17	SEA WATER	70	1.025	0.3	16.983	-0.631	-1.295

Table 5.48 Summary Table of Loading Condition 4b (30m) (continued…)

COMPENSATING TANK 03	17-18	SEA WATER	70	1.025	0.3	17.796	0.631	-1.295
COMPENSATING TANK 04	17-18	SEA WATER	70	1.025	0.3	17.796	-0.631	-1.295
FWD MAIN BALLAST TANK	26-28	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	25-26	SEA WATER	36	1.025	0.6	25.528	0.531	-1.566
FWD TRIM TANK 02	25-26	SEA WATER	36	1.025	0.6	25.528	-0.531	-1.566
TORPEDO TUBE FLOODING TANK	27-28	SEA WATER	0	0	0.0	0.000	0.000	0.000
WATER ROUND TORPEDO TANK	26-27	SEA WATER	0	0	0.0	0.000	0.000	0.000
Total SEA WATER					**4.6**	**13.900**	**0.000**	**-1.369**
BILGE WATER / SLUDGE								
SANITARY TANK 01	15-16	BILGE WATER / SLUDGE	90	1.005	0.5	15.486	1.487	-1.109
SANITARY TANK 02	15-16	BILGE WATER / SLUDGE	90	1.005	0.5	15.486	-1.487	-1.109
Total BILGE WATER / SLUDGE					**1.0**	**15.486**	**0.000**	**-1.109**
LOx								
Lox TANK	15-16	LOX	10	1.141	0.2	15.464	0.000	-1.493
Total LOx					**0.2**	**15.464**	**0.000**	**-1.493**
LOADING CONDITION 4B FIXED WEIGHTS								
COMPLEMENT					0.3	16.067	0.000	-0.160
OFFICER EQUIPMENT					0.1	16.067	0.000	-0.160
P.O. EQUIPMENT					0.2	16.067	0.000	-0.160
RATING EQUIPMENT					0.0	16.067	0.000	-0.160
GARBAGE					0.2	16.067	0.000	-0.160
PROVISIONS					0.2	16.067	0.000	-0.160
TORPEDO					1.5	27.228	0.000	-1.500
SPECIAL PERSONNEL & OTHER MILITARY LOADS					0.2	16.067	0.000	-0.160
DESIGN MARGIN					2.6	16.067	0.000	-0.160
CONSTRUCTION MARGIN					5.2	16.067	0.000	-0.160
MAINTENANCE MARGIN					2.6	16.067	0.000	-0.160
Loading Condition 4B Fixed Weights					**13.1**	**17.345**	**0.000**	**-0.313**
Lightweight					**259.3**	**16.067**	**0.000**	**-0.160**
Deadweight					**35.6**	**15.676**	**0.000**	**-0.884**
Total Displacement					**294.9**	**16.020**	**0.000**	**-0.247**
Buoyancy					**294.9**	**16.020**	**0.000**	**0.000**
Total Buoyancy					**294.9**	**16.020**	**0.000**	**0.000**

Table 5.49 Hydrostatics at Equilibrium Angle (30m)

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim	No trim	metres
KG	-0.247	metres
KB	0.000	metres
FSC	0.006	metres
KGf	-0.241	metres
GMt	0.241	metres
BMt	0.000	metres
BMl	0.000	metres
Waterplane area	0.000	sq.metres
LCG	16.020	metres
LCB	16.020	metres
TCB	0.000	metres
LCF	35.077	metres
TCF	0.000	metres
TPC	0.000	tonnes/cm
MTC	0.024	tonnes-m/cm

Table 5.50 Summary Stability Table (30m)

Displacement [ton]	Δ	294.9	
Length [m]	L_{DWL}	30.00	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	1.580	3.633
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.247	1.806
Longitudinal Center of Gravity [m]	LCG	16.020	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	-0.011	
Maximum Operational Speed of the Submerged Submarine [knot] / [m/sn]	$v_0\uparrow$	22.000	11.317

Table 5.51 Righting – Heeling Lever Calculations (30m)

Heel Angle	**Righting Lever**	**Heeling Lever**			
[°]	h_{SUB}	k_F	kD	$k_F + k_D$	$h_{SW} - (k_F+k_D)$
10	0.0419	0.001	-0.001	0.000	0.042
20	0.0825	0.002	-0.001	0.001	0.081
30	0.1206	0.003	-0.001	0.002	0.118
45	0.1709	0.004	-0.001	0.004	0.167

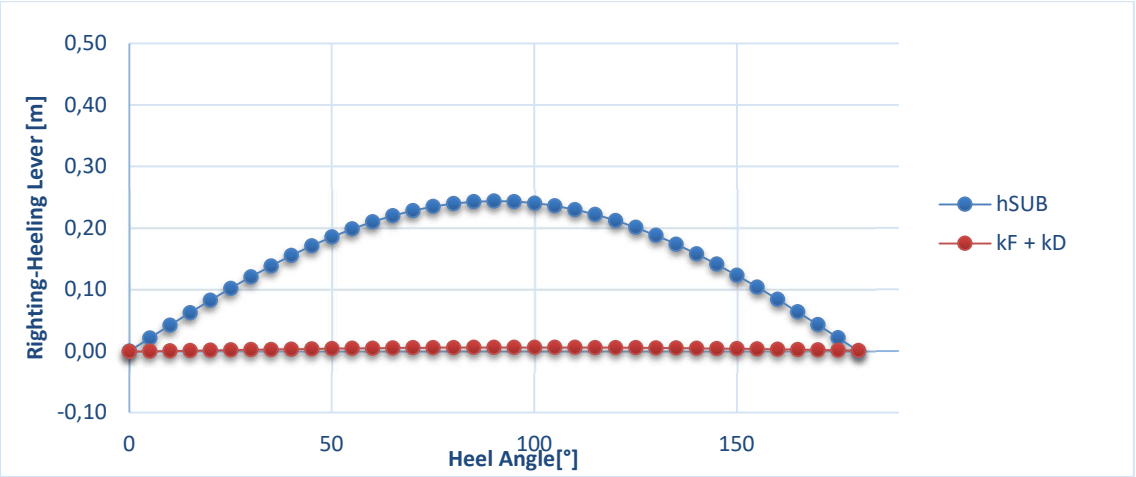

Figure 5.17 Righting – Heeling Lever / Heel Angle (30m)

Table 5.52 Criterion Assessment (30m)

#	Criterion	Actual Value	Critical Value	Result
1	Positive remaining lever h_{rem} at least 0.05 m in dived condition.	0.238	0.050	+
2	Minimum value for BG	0.247	0.220	+

This section focuses on stability analyses specifically related to loading case 4b, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Positive remaining lever h_{rem} is 0.238 m and is above the limit value of 0.05 m.
- The BG value is 0.247 m and is above the limit value of 0.22 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 4b.

5.1.3 Assessment of Compliance with the Rules (30m)

The following summary table compares the limit values with the values observed in the scenarios, in accordance with the rules

Table 5.53 Criterion Assessment (30m)

SURFACED							
#	Criterion	Loading Condition				Critical Value	Result
		1A	1B	2A	2B		
		Actual Value					
1	The buoyancy reserve shall be at least 10% of the pressure tight volume of the submarine.	12.3	12.3	12.3	12.3	10.0	+
2	Positive remaining lever h_{rem} at least 0.1 m.	0.234	0.236	0.237	0.238	0.1	+
3	Minimum value for GM	0.237	0.239	0.239	0.241	0.150	+
SUBMERGED							
#	Criterion	Loading Condition				Critical Value	Result
		3A	3B	4A	4B		
		Actual Value					
1	Positive remaining lever h_{rem} at least 0.05 m.	0.234	0.236	0.237	0.238	0.050	+
2	Minimum value for BG	0.242	0.245	0.243	0.247	0.220	+

Table 5.53 demonstrates that intact stability requirements are fulfilled for all loading conditions.

5.2 48m

5.2.1 Surfaced Submarine (48m)

5.2.1.1 Loading Condition 1a (48m)

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

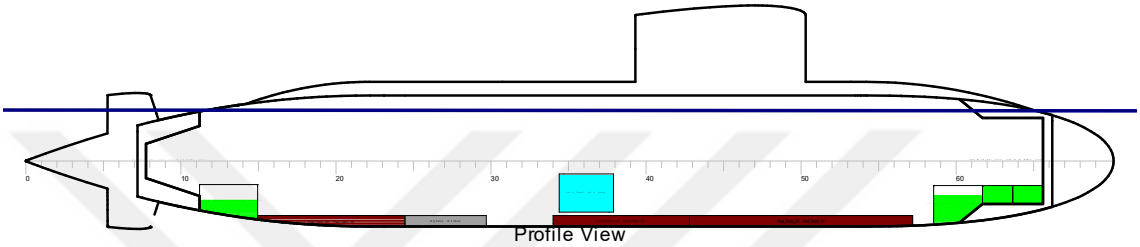

Figure 5.18 Profile View (48m)

Table 5.54 Densities (48m)

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1.000
	DIESEL FUEL	0.830
	LUB. OIL	0.900
	LOX	1.141

Table 5.55 Summary Table of Loading Condition 1a (48m)

Stability Calculations for Loading Condition 1A								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	10-17	DIESEL FUEL	98	0.83	10.3	13.743	2.597	-0.787
FUEL TANK 02	10-17	DIESEL FUEL	98	0.83	10.3	13.743	-2.597	-0.787
FUEL TANK 03	10-17	DIESEL FUEL	98	0.83	5.4	14.053	0.000	-2.940
FUEL TANK 04	23-29	DIESEL FUEL	98	0.83	6.5	26.283	0.000	-2.963
FUEL TANK 05	29-39	DIESEL FUEL	98	0.83	6.4	34.195	2.389	-1.733
FUEL TANK 06	29-39	DIESEL FUEL	98	0.83	6.4	34.195	-2.389	-1.733
FUEL TANK 07	29-39	DIESEL FUEL	98	0.83	10.5	34.185	0.000	-2.962
Total DIESEL FUEL					**55.8**	**23.779**	**0.000**	**-1.874**
FRESH WATER								
FRESH WATER TANK 01	26-29	FRESH WATER	98	1.00	2.4	27.788	2.390	-1.734
FRESH WATER TANK 02	26-29	FRESH WATER	98	1.00	2.4	27.788	-2.390	-1.734
Total FRESH WATER					**4.8**	**27.788**	**0.000**	**-1.734**
LUB, OIL								
OIL TANK	17-20	LUB, OIL	98	0.9	4.2	18.531	0.000	-2.963
Total LUB, OIL					**4.2**	**18.531**	**0.000**	**-2.963**
SEA WATER								
AFT MAIN BALLAST TANK	5-8	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	8-10	SEA WATER	37.5	1.025	2.6	9.148	0.745	-2.279
AFT TRIM TANK 02	8-10	SEA WATER	37.5	1.025	2.6	9.148	-0.745	-2.279
COMPENSATING TANK 01	27-28	SEA WATER	20	1.025	0.3	27.172	1.010	-2.367
COMPENSATING TANK 02	27-28	SEA WATER	20	1.025	0.3	27.172	-1.010	-2.367
COMPENSATING TANK 03	28-29	SEA WATER	20	1.025	0.3	28.472	1.010	-2.367
COMPENSATING TANK 04	28-29	SEA WATER	20	1.025	0.3	28.472	-1.010	-2.367
FWD MAIN BALLAST TANK	41-45	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	40-42	SEA WATER	62.5	1.025	4.4	40.923	0.967	-2.255
FWD TRIM TANK 02	40-42	SEA WATER	62.5	1.025	4.4	40.923	-0.967	-2.255

Table 5.55 Summary Table of Loading Condition 1a (48m) (continued…)

TORPEDO TUBE FLOODING TANK	44-45	SEA WATER	98	1.025	3.0	44.232	0.000	-1.617
WATER ROUND TORPEDO TANK	42-44	SEA WATER	98	1.025	3.0	42.897	0.000	-1.617
Total SEA WATER					**21.2**	**33.066**	**0.000**	**-2.087**
BILGE WATER / SLUDGE								
SANITARY TANK 01	23-26	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
SANITARY TANK 02	23-26	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
Total BILGE WATER / SLUDGE					**0.0**	**0.000**	**0.000**	**0.000**
LOx								
Lox TANK	24-26	LOX	98	1.141	7.6	24.743	0.000	-1.627
Total LOx					**7.6**	**24.743**	**0.000**	**-1.627**
LOADING CONDITION 1A FIXED WEIGHTS								
COMPLEMENT					1.2	25.707	0.000	-0.185
OFFICER EQUIPMENT					0.5	25.707	0.000	-0.185
P.O. EQUIPMENT					0.6	25.707	0.000	-0.185
RATING EQUIPMENT					0.3	25.707	0.000	-0.185
GARBAGE					0.0	0.000	0.000	0.000
PROVISIONS					6.4	25.707	0.000	-0.185
TORPEDO					0.0	0.000	0.000	0.000
SPECIAL PERSONNEL & OTHER MILITARY LOADS					0.0	0.000	0.000	0.000
DESIGN MARGIN					10.6	25.707	0.000	-0.185
CONSTRUCTION MARGIN					21.2	25.707	0.000	-0.185
MAINTENANCE MARGIN					10.6	25.707	0.000	-0.185
Loading Condition 1A Fixed Weights					**51.4**	**25.707**	**0.000**	**-0.185**
Lightweight					**1058.7**	**25.707**	**0.000**	**-0.185**
Deadweight					**145.2**	**25.853**	**0.000**	**-1.321**
Total Displacement					**1203.9**	**25.725**	**0.000**	**-0.322**
Buoyancy					**1203.9**	**25.725**	**0.000**	**-0.160**
Total Buoyancy					**1203.9**	**25.725**	**0.000**	**-0.160**

Table 5.56 Drafts at Equilibrium Angle (48m)

Drafts at equilibrium angle		
Draft at LCF	2.532	metres
Draft at AP	2.554	metres
Draft at FP	2.514	metres
Draft at midships	2.534	metres

Table 5.57 Hydrostatics at Equilibrium Angle (48m)

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim by the stern	0.040	metres
	0.03	degrees
KG	-0.322	metres
KB	-0.160	metres
FSC	0.007	metres
KGf	-0.315	metres
GMt	0.314	metres
BMt	0.160	metres
BMl	11.440	metres
Waterplane area	140.340	sq.metres
LCG	25.725	metres
LCB	25.725	metres
TCB	0.000	metres
LCF	26.410	metres
TCF	0.000	metres
TPC	1.438	tonnes/cm
MTC	2.910	tonnes-m/cm

Table 5.58 Summary Stability Table (48m)

Displacement [ton]	Δ	1203.9	
Length [m]	L_{DWL}	48.00	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	2.532	*5.817*
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.322	*2.963*
Longitudinal Center of Gravity [m]	LCG	25.725	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	0.055	
Wind Pressure [kN/m^2]	q_w	0.358	
Density of Air [t/m^3]	ρ_L	0.001225	
Wind Speed [m/s]	v_w	24.179	
Form Coefficient	c_f	0.600	

Table 5.58 Summary Stability Table (48m) (continued…)

Projected Area Exposed to Wind Forces [m^2]	A_w	74.101	
Height of the Centroid of the Area Exposed to Wind [m] [from Reference Point] / [from Baseline]	A_{wz}	4.171	7.456
Height of the Centroid of the Area Exposed to Wind Above Half Draught [m] [from Baseline]	A_{wz}-0.5T	4.548	
Maximum Operational Speed of the Surfaced Submarine [knot] / [m/sn]	$v_0\uparrow$	12.000	6.173

Table 5.59 Righting – Heeling Lever Calculations (48m)

Heel Angle	**Righting Lever**	**Heeling Lever**				
[°]	hsw	k_F	k_D	k_W	$k_F + k_D + k_W$	$h_{SW} - (k_F+k_D+k_W)$
10	0.0546	0.001	0.001	0.006	0.008	0.046
20	0.1074	0.002	0.001	0.006	0.009	0.098
30	0.1569	0.004	0.001	0.005	0.010	0.147
45	0.2223	0.005	0.001	0.004	0.010	0.212

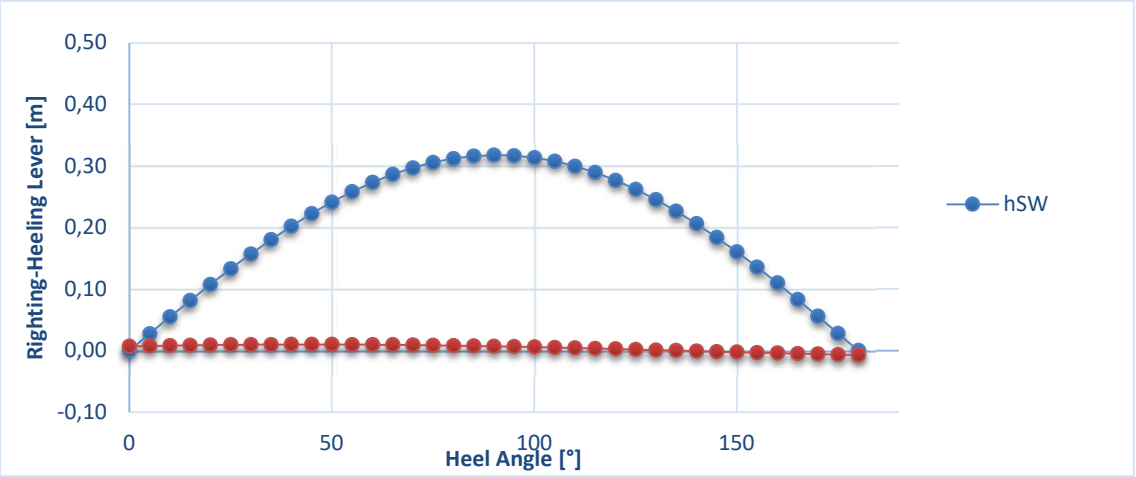

Figure 5.19 Righting – Heeling Lever / Heel Angle (48m)

Table 5.60 Criterion Assessment (48m)

#	Criterion	Actual Value	Critical Value	Result
1	The buoyancy reserve shall be at least 10% of the pressure tight volume of the submarine in surfaced condition.	12.3	10.0	+
2	Positive remaining lever h_{rem} at least 0.1 m in surfaced condition.	0.310	0.1	+
3	Minimum value for GM	0.314	0.200	+

This section focuses on stability analyses specifically related to loading case 1a, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Buoyancy reserve is 12.3% of the pressure tight volume of the submarine. Thus, the 10% limit value has been exceeded.
- Positive remaining lever h_{rem} is 0.31 m and is above the limit value of 0.1 m.
- The GM value is 0.314 m and is above the limit value of 0.2 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 1a.

5.2.1.2 Loading Condition 1b (48m)

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

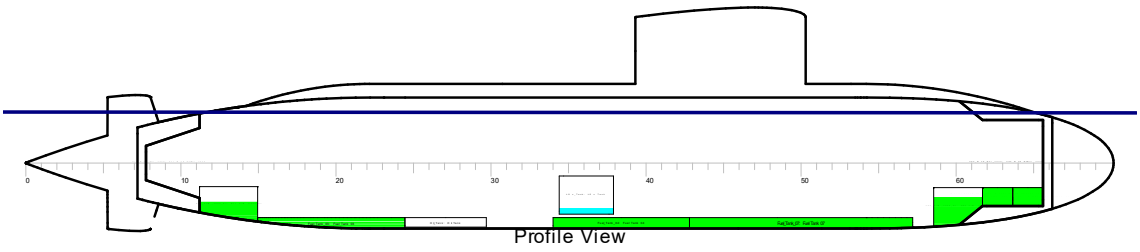

Figure 5.20 Profile View (48m)

Table 5.61 Densities (48m)

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	LUB, OIL	0.9
	BILGE WATER / SLUDGE	1.005
	LOX	1.141
	SEA WATER & DIESEL FUEL	1.005

Table 5.62 Summary Table of Loading Condition 1b (48m)

Stability Calculations for Loading Condition 1B								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	10-17	SEA WATER & DIESEL FUEL	98	1.005	12.5	13.743	2.597	-0.787
FUEL TANK 02	10-17	SEA WATER & DIESEL FUEL	98	1.005	12.5	13.743	-2.597	-0.787
FUEL TANK 03	10-17	SEA WATER & DIESEL FUEL	98	1.005	6.6	14.053	0.000	-2.940
FUEL TANK 04	23-29	SEA WATER & DIESEL FUEL	98	1.005	7.8	26.283	0.000	-2.963
FUEL TANK 05	29-39	SEA WATER & DIESEL FUEL	98	1.005	7.8	34.195	2.389	-1.733
FUEL TANK 06	29-39	SEA WATER & DIESEL FUEL	98	1.005	7.8	34.195	-2.389	-1.733
FUEL TANK 07	29-39	SEA WATER & DIESEL FUEL	98	1.005	12.7	34.185	0.000	-2.962
Total DIESEL FUEL					**67.7**	**23.779**	**0.000**	**-1.874**
FRESH WATER								
FRESH WATER TANK 01	26-29	FRESH WATER	10	1.00	0.2	27.787	2.160	-2.341
FRESH WATER TANK 02	26-29	FRESH WATER	10	1.00	0.2	27.787	-2.160	-2.341
Total FRESH WATER					**0.4**	**27.787**	**0.000**	**-2.341**
LUB, OIL								
OIL TANK	17-20	LUB, OIL	10	0.9	0.4	18.525	0.000	-3.215
Total LUB, OIL					**0.4**	**18.525**	**0.000**	**-3.215**
SEA WATER								
AFT MAIN BALLAST TANK	5-8	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	8-10	SEA WATER	37.5	1.025	2.6	9.148	0.745	-2.279
AFT TRIM TANK 02	8-10	SEA WATER	37.5	1.025	2.6	9.148	-0.745	-2.279
COMPENSATING TANK 01	27-28	SEA WATER	80	1.025	1.2	27.172	1.010	-2.016
COMPENSATING TANK 02	27-28	SEA WATER	80	1.025	1.2	27.172	-1.010	-2.016

Table 5.62 Summary Table of Loading Condition 1b (48m) (continued…)

COMPENSATING TANK 03	28-29	SEA WATER	80	1.025	1.2	28.473	1.010	-2.016
COMPENSATING TANK 04	28-29	SEA WATER	80	1.025	1.2	28.473	-1.010	-2.016
FWD MAIN BALLAST TANK	41-45	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	40-42	SEA WATER	62.5	1.025	4.4	40.923	0.967	-2.255
FWD TRIM TANK 02	40-42	SEA WATER	62.5	1.025	4.4	40.923	-0.967	-2.255
TORPEDO TUBE FLOODING TANK	44-45	SEA WATER	98	1.025	3.0	44.232	0.000	-1.617
WATER ROUND TORPEDO TANK	42-44	SEA WATER	98	1.025	3.0	42.897	0.000	-1.617
Total SEA WATER					**24.8**	**32.290**	**0.000**	**-2.059**
BILGE WATER / SLUDGE								
SANITARY TANK 01	23-26	BILGE WATER / SLUDGE	90	1.005	2.2	24.776	2.379	-1.775
SANITARY TANK 02	23-26	BILGE WATER / SLUDGE	90	1.005	2.2	24.776	-2.379	-1.775
Total BILGE WATER/SLUDGE					**4.4**	**24.776**	**0.000**	**-1.775**
LOx								
Lox TANK	24-26	LOX	10	1.141	0.8	24.742	0.000	-2.389
Total LOx					**0.8**	**24.742**	**0.000**	**-2.389**
LOADING CONDITION 1B FIXED WEIGHTS								
COMPLEMENT					1.2	25.707	0.000	-0.185
OFFICER EQUIPMENT					0.5	25.707	0.000	-0.185
P.O. EQUIPMENT					0.6	25.707	0.000	-0.185
RATING EQUIPMENT					0.0	25.707	0.000	-0.185
GARBAGE					1.0	25.707	0.000	-0.185
PROVISIONS					0.6	25.707	0.000	-0.185
TORPEDO					0.0	0.000	0.000	0.000
SPECIAL PERSONNEL & OTHER MILITARY LOADS					0.0	0.000	0.000	0.000
DESIGN MARGIN					10.6	25.707	0.000	-0.185
CONSTRUCTION MARGIN					21.2	25.707	0.000	-0.185
MAINTENANCE MARGIN					10.6	25.707	0.000	-0.185
Loading Condition 1B Fixed Weights					**46.3**	**25.707**	**0.000**	**-0.185**
Lightweight					**1058.7**	**25.707**	**0.000**	**-0.185**
Deadweight					**145.2**	**25.892**	**0.000**	**-1.372**
Total Displacement					**1203.9**	**25.729**	**0.000**	**-0.328**
Buoyancy					**1203.9**	**25.729**	**0.000**	**-0.160**
Total Buoyancy					**1203.9**	**25.729**	**0.000**	**-0.160**

Table 5.63 Drafts at Equilibrium Angle (48m)

Drafts at equilibrium angle		
Draft at LCF	2.532	metres
Draft at AP	2.543	metres
Draft at FP	2.523	metres
Draft at midships	2.533	metres

Table 5.64 Hydrostatics at Equilibrium Angle (48m)

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim by the stern	0.021	metres
	0.02	degrees
KG	-0.328	metres
KB	-0.160	metres
FSC	0.009	metres
KGf	-0.319	metres
GMt	0.318	metres
BMt	0.160	metres
BMl	11.445	metres
Waterplane area	140.350	sq.metres
LCG	25.729	metres
LCB	25.729	metres
TCB	0.000	metres
LCF	26.364	metres
TCF	0.000	metres
TPC	1.439	tonnes/cm
MTC	2.913	tonnes-m/cm

Table 5.65 Summary Stability Table (48m)

Displacement [ton]	Δ	1203.9	
Length [m]	L_{DWL}	48.00	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	2.532	5.817
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.328	2.957
Longitudinal Center of Gravity [m]	LCG	25.729	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	0.049	
Wind Pressure [kN/m^2]	q_w	0.358	
Density of Air [t/m^3]	ρ_L	0.001225	
Wind Speed [m/s]	v_w	24.179	
Form Coefficient	c_f	0.600	

Table 5.65 Summary Stability Table (48m) (continued…)

Projected Area Exposed to Wind Forces [m^2]	A_w	74.101	
Height of the Centroid of the Area Exposed to Wind [m] [from Reference Point] / [from Baseline]	A_{wz}	4.171	7.456
Height of the Centroid of the Area Exposed to Wind Above Half Draught [m] [from Baseline]	A_{wz}-0.5T	4.548	
Maximum Operational Speed of the Surfaced Submarine [knot] / [m/sn]	$v_0\uparrow$	12.000	6.173

Table 5.66 Righting – Heeling Lever Calculations (48m)

Heel Angle	**Righting Lever**	**Heeling Lever**				
[°]	hsw	k_F	k_D	k_W	$k_F + k_D + k_W$	$h_{SW} - (k_F+k_D+k_W)$
10	0.0553	0.002	0.001	0.006	0.008	0.047
20	0.1088	0.003	0.001	0.006	0.010	0.099
30	0.1591	0.005	0.001	0.005	0.010	0.149
45	0.2257	0.006	0.001	0.004	0.011	0.214

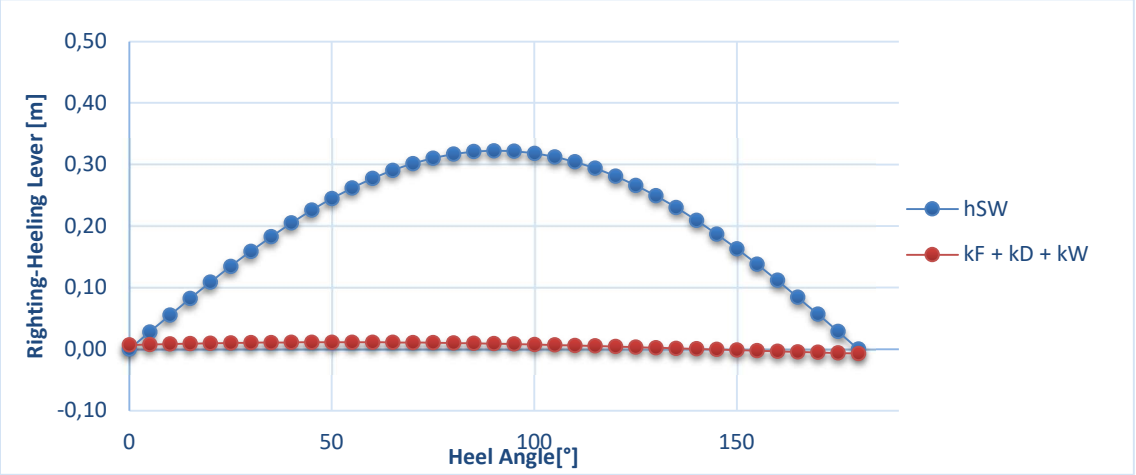

Figure 5.21 Righting – Heeling Lever / Heel Angle (48m)

Table 5.67 Criterion Assessment (48m)

#	Criterion	Actual Value	Critical Value	Result
1	The buoyancy reserve shall be at least 10% of the pressure tight volume of the submarine in surfaced condition.	12.3	10.0	+
2	Positive remaining lever h_{rem} at least 0.1 m in surfaced condition.	0.313	0.1	+
3	Minimum value for GM	0.318	0.200	+

This section focuses on stability analyses specifically related to loading case 1b, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Buoyancy reserve is 12.3% of the pressure tight volume of the submarine. Thus, the 10% limit value has been exceeded.
- Positive remaining lever h_{rem} is 0.313 m and is above the limit value of 0.1 m.
- The GM value is 0.318 m and is above the limit value of 0.2 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 1b.

5.2.1.3 Loading Condition 2a (48m)

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

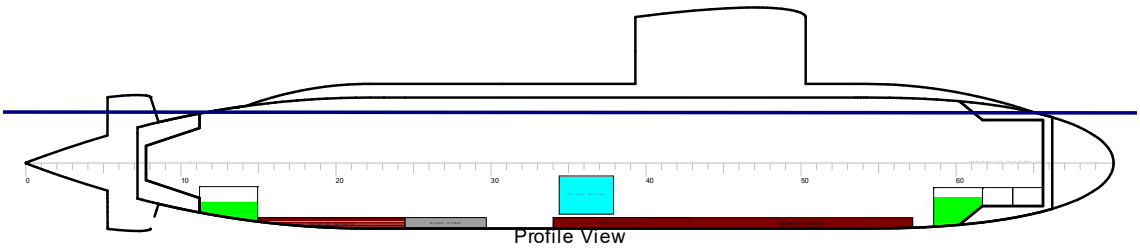

Figure 5.22 Profile View (48m)

Table 5.68 Densities (48m)

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	DIESEL FUEL	0.83
	LUB, OIL	0.9
	LOX	1.141

Table 5.69 Summary Table of Loading Condition 2a (48m)

Stability Calculations for Loading Condition 2A								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	10-17	DIESEL FUEL	98	0.83	10.3	13.743	2.597	-0.787
FUEL TANK 02	10-17	DIESEL FUEL	98	0.83	10.3	13.743	-2.597	-0.787
FUEL TANK 03	10-17	DIESEL FUEL	98	0.83	5.4	14.053	0.000	-2.940
FUEL TANK 04	23-29	DIESEL FUEL	98	0.83	6.5	26.283	0.000	-2.963
FUEL TANK 05	29-39	DIESEL FUEL	98	0.83	6.4	34.195	2.389	-1.733
FUEL TANK 06	29-39	DIESEL FUEL	98	0.83	6.4	34.195	-2.389	-1.733
FUEL TANK 07	29-39	DIESEL FUEL	98	0.83	10.5	34.185	0.000	-2.962
Total DIESEL FUEL					**55.8**	**23.779**	**0.000**	**-1.874**
FRESH WATER								
FRESH WATER TANK 01	26-29	FRESH WATER	98	1.00	2.4	27.788	2.390	-1.734
FRESH WATER TANK 02	26-29	FRESH WATER	98	1.00	2.4	27.788	-2.390	-1.734
Total FRESH WATER					**4.8**	**27.788**	**0.000**	**-1.734**
LUB, OIL								
OIL TANK	17-20	LUB, OIL	98	0.9	4.2	18.531	0.000	-2.963
Total LUB, OIL					**4.2**	**18.531**	**0.000**	**-2.963**
SEA WATER								
AFT MAIN BALLAST TANK	5-8	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	8-10	SEA WATER	37.5	1.025	2.6	9.148	0.745	-2.279
AFT TRIM TANK 02	8-10	SEA WATER	37.5	1.025	2.6	9.148	-0.745	-2.279
COMPENSATING TANK 01	27-28	SEA WATER	10	1.025	0.2	27.172	1.010	-2.443
COMPENSATING TANK 02	27-28	SEA WATER	10	1.025	0.2	27.172	-1.010	-2.443
COMPENSATING TANK 03	28-29	SEA WATER	10	1.025	0.2	28.472	1.010	-2.443
COMPENSATING TANK 04	28-29	SEA WATER	10	1.025	0.2	28.472	-1.010	-2.443
FWD MAIN BALLAST TANK	41-45	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	40-42	SEA WATER	62.5	1.025	4.4	40.923	0.967	-2.255

Table 5.69 Summary Table of Loading Condition 2a (48m) (continued…)

FWD TRIM TANK 02	40-42	SEA WATER	62.5	1.025	4.4	40.923	-0.967	-2.255
TORPEDO TUBE FLOODING TANK	44-45	SEA WATER	0	0	0.0	0.000	0.000	0.000
WATER ROUND TORPEDO TANK	42-44	SEA WATER	0	0	0.0	0.000	0.000	0.000
Total SEA WATER					**14.8**	**28.958**	**0.000**	**-2.272**
BILGE WATER / SLUDGE								
SANITARY TANK 01	23-26	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
SANITARY TANK 02	23-26	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
Total BILGE WATER / SLUDGE					**0.0**	**0.000**	**0.000**	**0.000**
LOx								
Lox TANK	24-26	LOX	98	1.141	7.6	24.743	0.000	-1.627
Total LOx					**7.6**	**24.743**	**0.000**	**-1.627**
LOADING CONDITION 2A FIXED WEIGHTS								
COMPLEMENT					1.2	25.707	0.000	-0.185
OFFICER EQUIPMENT					0.5	25.707	0.000	-0.185
P.O. EQUIPMENT					0.6	25.707	0.000	-0.185
RATING EQUIPMENT					0.3	25.707	0.000	-0.185
GARBAGE					0.0	0.000	0.000	0.000
PROVISIONS					6.4	25.707	0.000	-0.185
TORPEDO					6.0	43.565	0.000	-1.500
SPECIAL PERSONNEL & OTHER MILITARY LOADS					0.6	25.707	0.000	-0.185
DESIGN MARGIN					10.6	25.707	0.000	-0.185
CONSTRUCTION MARGIN					21.2	25.707	0.000	-0.185
MAINTENANCE MARGIN					10.6	25.707	0.000	-0.185
Loading Condition 2A Fixed Weights					**58.0**	**27.554**	**0.000**	**-0.321**
Lightweight					**1058.7**	**25.707**	**0.000**	**-0.185**
Deadweight					**145.2**	**25.844**	**0.000**	**-1.307**
Total Displacement					**1203.9**	**25.724**	**0.000**	**-0.320**
Buoyancy					**1203.9**	**25.724**	**0.000**	**-0.160**
Total Buoyancy					**1203.9**	**25.724**	**0.000**	**-0.160**

Table 5.70 Drafts at Equilibrium Angle (48m)

Drafts at equilibrium angle		
Draft at LCF	2.532	metres
Draft at AP	2.556	metres
Draft at FP	2.512	metres
Draft at midships	2.534	metres

Table 5.71 Hydrostatics at Equilibrium Angle (48m)

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim by the stern	0.044	metres
	0.04	degrees
KG	-0.320	metres
KB	-0.160	metres
FSC	0.007	metres
KGf	-0.313	metres
GMt	0.312	metres
BMt	0.160	metres
BMl	11.439	metres
Waterplane area	140.340	sq.metres
LCG	25.724	metres
LCB	25.724	metres
TCB	0.000	metres
LCF	26.420	metres
TCF	0.000	metres
TPC	1.438	tonnes/cm
MTC	2.909	tonnes-m/cm

Table 5.72 Summary Stability Table (48m)

Displacement [ton]	Δ	1203.9	
Length [m]	L_{DWL}	48.00	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	2.532	5.817
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.320	2.965
Longitudinal Center of Gravity [m]	LCG	25.724	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	0.057	
Wind Pressure [kN/m^2]	q_w	0.358	
Density of Air [t/m^3]	ρ_L	0.001225	
Wind Speed [m/s]	v_w	24.179	
Form Coefficient	c_f	0.600	

Table 5.72 Summary Stability Table (48m) (continued…)

Projected Area Exposed to Wind Forces [m^2]	A_w	74.101	
Height of the Centroid of the Area Exposed to Wind [m] [from Reference Point] / [from Baseline]	A_{wz}	4.171	7.456
Height of the Centroid of the Area Exposed to Wind Above Half Draught [m] [from Baseline]	A_{wz}-0.5T	4.548	
Maximum Operational Speed of the Surfaced Submarine [knot] / [m/sn]	$v_0\uparrow$	12.000	6.173

Table 5.73 Righting – Heeling Lever Calculations (48m)

Heel Angle	**Righting Lever**	**Heeling Lever**				
[°]	h_{SW}	k_F	k_D	k_W	$k_F + k_D + k_W$	$h_{SW} - (k_F+k_D+k_W)$
10	0.0543	0.001	0.001	0.006	0.008	0.046
20	0.1069	0.002	0.001	0.006	0.009	0.098
30	0.1562	0.004	0.001	0.005	0.010	0.147
45	0.2213	0.005	0.001	0.004	0.010	0.211

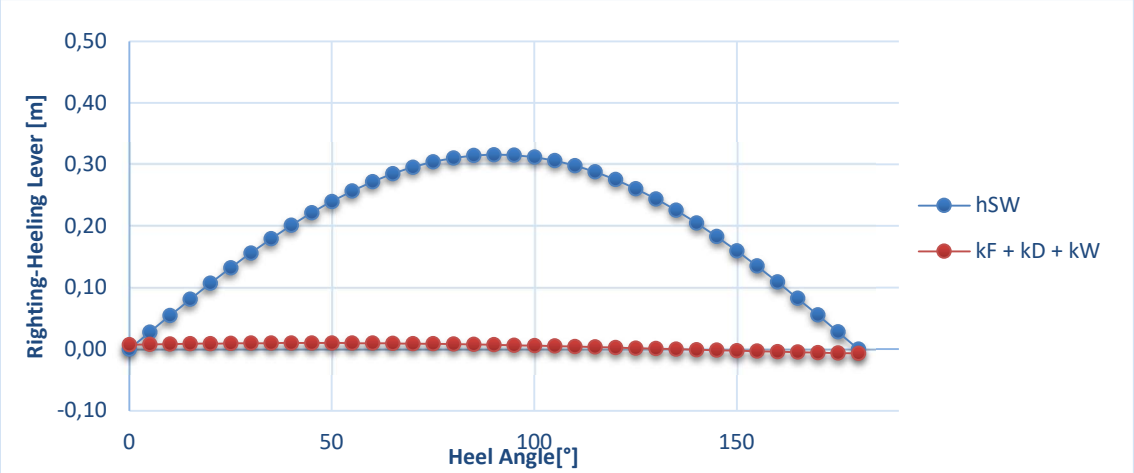

Figure 5.23 Righting – Heeling Lever / Heel Angle (48m)

Table 5.74 Criterion Assessment (48m)

#	Criterion	Actual Value	Critical Value	Result
1	The buoyancy reserve shall be at least 10% of the pressure tight volume of the submarine in surfaced condition.	12.3	10.0	+
2	Positive remaining lever h_{rem} at least 0.1 m in surfaced condition.	0.309	0.1	+
3	Minimum value for GM	0.312	0.200	+

This section focuses on stability analyses specifically related to loading case 2a, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Buoyancy reserve is 12.3% of the pressure tight volume of the submarine. Thus, the 10% limit value has been exceeded.
- Positive remaining lever h_{rem} is 0.309 m and is above the limit value of 0.1 m.
- The GM value is 0.312 m and is above the limit value of 0.2 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 2a.

5.2.1.4 Loading Condition 2b (48m)

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

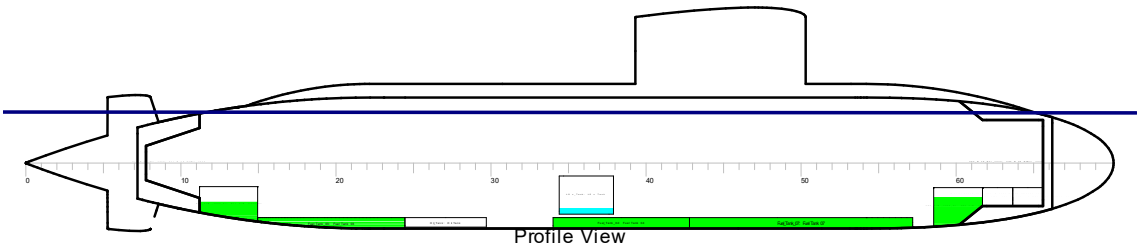

Figure 5.24 Profile View (48m)

Table 5.75 Densities (48m)

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	LUB, OIL	0.9
	BILGE WATER / SLUDGE	1.005
	LOX	1.141
	SEA WATER & DIESEL FUEL	1.005

Table 5.76 Summary Table of Loading Condition 2b (48m)

Stability Calculations for Loading Condition 2B								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	10-17	SEA WATER & DIESEL FUEL	98	1.01	12.5	13.743	2.597	-0.787
FUEL TANK 02	10-17	SEA WATER & DIESEL FUEL	98	1.01	12.5	13.743	-2.597	-0.787
FUEL TANK 03	10-17	SEA WATER & DIESEL FUEL	98	1.01	6.6	14.053	0.000	-2.940
FUEL TANK 04	23-29	SEA WATER & DIESEL FUEL	98	1.01	7.8	26.283	0.000	-2.963
FUEL TANK 05	29-39	SEA WATER & DIESEL FUEL	98	1.01	7.8	34.195	2.389	-1.733
FUEL TANK 06	29-39	SEA WATER & DIESEL FUEL	98	1.01	7.8	34.195	-2.389	-1.733
FUEL TANK 07	29-39	SEA WATER & DIESEL FUEL	98	1.01	12.7	34.185	0.000	-2.962
Total DIESEL FUEL					**67.7**	**23.779**	**0.000**	**-1.874**
FRESH WATER								
FRESH WATER TANK 01	26-29	FRESH WATER	10	1.00	0.2	27.786	2.160	-2.341
FRESH WATER TANK 02	26-29	FRESH WATER	10	1.00	0.2	27.786	-2.160	-2.341
Total FRESH WATER					**0.4**	**27.786**	**0.000**	**-2.341**
LUB, OIL								
OIL TANK	17-20	LUB, OIL	10	0.9	0.4	18.524	0.000	-3.215
Total LUB, OIL					**0.4**	**18.524**	**0.000**	**-3.215**
SEA WATER								
AFT MAIN BALLAST TANK	5-8	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	8-10	SEA WATER	37.5	1.025	2.6	9.148	0.745	-2.279
AFT TRIM TANK 02	8-10	SEA WATER	37.5	1.025	2.6	9.148	-0.745	-2.279
COMPENSATING TANK 01	27-28	SEA WATER	70	1.025	1.1	27.172	1.010	-2.071
COMPENSATING TANK 02	27-28	SEA WATER	70	1.025	1.1	27.172	-1.010	-2.071

Table 5.76 Summary Table of Loading Condition 2b (48m) (continued…)

COMPENSATING TANK 03	28-29	SEA WATER	70	1.025	1.1	28.473	1.010	-2.071
COMPENSATING TANK 04	28-29	SEA WATER	70	1.025	1.1	28.473	-1.010	-2.071
FWD MAIN BALLAST TANK	41-45	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	40-42	SEA WATER	62.5	1.025	4.4	40.923	0.967	-2.255
FWD TRIM TANK 02	40-42	SEA WATER	62.5	1.025	4.4	40.923	-0.967	-2.255
TORPEDO TUBE FLOODING TANK	44-45	SEA WATER	0	0	0.0	0.000	0.000	0.000
WATER ROUND TORPEDO TANK	42-44	SEA WATER	0	0	0.0	0.000	0.000	0.000
Total SEA WATER					**18.4**	**28.730**	**0.000**	**-2.219**
BILGE WATER / SLUDGE								
SANITARY TANK 01	23-26	BILGE WATER / SLUDGE	90	1.005	2.2	24.776	2.379	-1.775
SANITARY TANK 02	23-26	BILGE WATER / SLUDGE	90	1.005	2.2	24.776	-2.379	-1.775
Total BILGE WATER/SLUDGE					**4.4**	**24.776**	**0.000**	**-1.775**
LOx								
Lox TANK	24-26	LOX	10	1.141	0.8	24.741	0.000	-2.389
Total LOx					**0.8**	**24.741**	**0.000**	**-2.389**
LOADING CONDITION 2B FIXED WEIGHTS								
COMPLEMENT					1.2	25.707	0.000	-0.185
OFFICER EQUIPMENT					0.5	25.707	0.000	-0.185
P.O. EQUIPMENT					0.6	25.707	0.000	-0.185
RATING EQUIPMENT					0.0	25.707	0.000	-0.185
GARBAGE					1.0	25.707	0.000	-0.185
PROVISIONS					0.6	25.707	0.000	-0.185
TORPEDO					6.0	43.565	0.000	-1.500
SPECIAL PERSONNEL & OTHER MILITARY LOADS					0.6	25.707	0.000	-0.185
DESIGN MARGIN					10.6	25.707	0.000	-0.185
CONSTRUCTION MARGIN					21.2	25.707	0.000	-0.185
MAINTENANCE MARGIN					10.6	25.707	0.000	-0.185
Loading Condition 2B Fixed Weights					**52.9**	**27.732**	**0.000**	**-0.334**
Lightweight					**1058.7**	**25.707**	**0.000**	**-0.185**
Deadweight					**145.2**	**25.883**	**0.000**	**-1.361**
Total Displacement					**1203.9**	**25.728**	**0.000**	**-0.327**
Buoyancy					**1203.9**	**25.728**	**0.000**	**-0.160**
Total Buoyancy					**1203.9**	**25.728**	**0.000**	**-0.160**

Table 5.77 Drafts at Equilibrium Angle (48m)

Drafts at equilibrium angle		
Draft at LCF	2.532	metres
Draft at AP	2.546	metres
Draft at FP	2.521	metres
Draft at midships	2.533	metres

Table 5.78 Hydrostatics at Equilibrium Angle (48m)

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim by the stern	0.025	metres
	0.02	degrees
KG	-0.327	metres
KB	-0.160	metres
FSC	0.010	metres
KGf	-0.317	metres
GMt	0.316	metres
BMt	0.160	metres
BMl	11.443	metres
Waterplane area	140.350	sq.metres
LCG	25.728	metres
LCB	25.728	metres
TCB	0.000	metres
LCF	26.375	metres
TCF	0.000	metres
TPC	1.439	tonnes/cm
MTC	2.912	tonnes-m/cm

Table 5.79 Summary Stability Table (48m)

Displacement [ton]	Δ	1203.9	
Length [m]	L_{DWL}	48.00	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	2.532	5.817
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.327	2.958
Longitudinal Center of Gravity [m]	LCG	25.728	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	0.050	
Wind Pressure [kN/m^2]	q_w	0.358	
Density of Air [t/m^3]	ρ_L	0.001225	
Wind Speed [m/s]	v_w	24.179	
Form Coefficient	c_f	0.600	

Table 5.79 Summary Stability Table (48m) (continued…)

Projected Area Exposed to Wind Forces [m^2]	A_w	74.101	
Height of the Centroid of the Area Exposed to Wind [m] [from Reference Point] / [from Baseline]	A_{wz}	4.171	7.456
Height of the Centroid of the Area Exposed to Wind Above Half Draught [m] [from Baseline]	A_{wz}-0.5T	4.548	
Maximum Operational Speed of the Surfaced Submarine [knot] / [m/sn]	$v_0\uparrow$	12.000	6.173

Table 5.80 Righting – Heeling Lever Calculations (48m)

Heel Angle	**Righting Lever**	**Heeling Lever**				
[°]	h_{SW}	k_F	k_D	k_W	$k_F + k_D + k_W$	$h_{SW} - (k_F+k_D+k_W)$
10	0.0550	0.002	0.001	0.006	0.009	0.046
20	0.1083	0.003	0.001	0.006	0.010	0.098
30	0.1584	0.005	0.001	0.005	0.011	0.147
45	0.2246	0.007	0.001	0.004	0.012	0.213

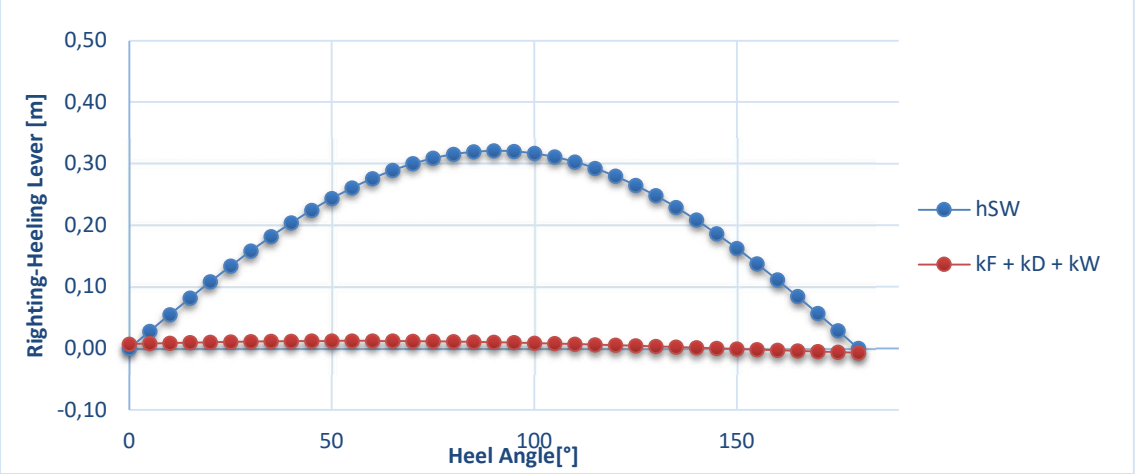

Figure 5.25 Righting – Heeling Lever / Heel Angle (48m)

Table 5.81 Criterion Assessment (48m)

#	Criterion	Actual Value	Critical Value	Result
1	The buoyancy reserve shall be at least 10% of the pressure tight volume of the submarine in surfaced condition.	12.3	10.0	+
2	Positive remaining lever h_{rem} at least 0.1 m in surfaced condition.	0.311	0.1	+
3	Minimum value for GM	0.316	0.200	+

This section focuses on stability analyses specifically related to loading case 2b, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Buoyancy reserve is 12.3% of the pressure tight volume of the submarine. Thus, the 10% limit value has been exceeded.
- Positive remaining lever h_{rem} is 0.311 m and is above the limit value of 0.1 m.
- The GM value is 0.316 m and is above the limit value of 0.2 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 2b.

5.2.2 Submerged Submarine (48m)

5.2.2.1 Loading Condition 3a (48m)

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

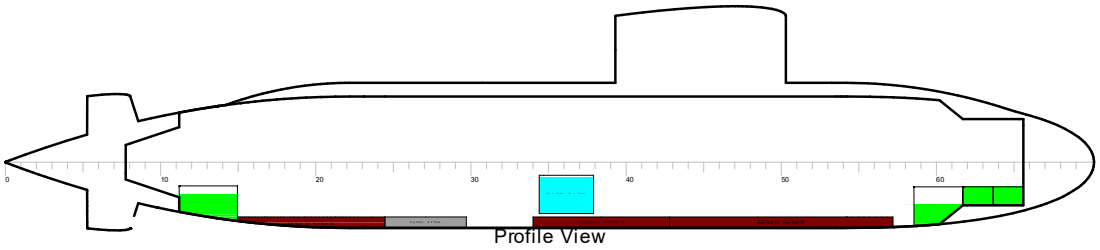

Figure 5.26 Profile View (48m)

Table 5.82 Densities (48m)

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	DIESEL FUEL	0.83
	LUB, OIL	0.9
	LOX	1.141

Table 5.83 Summary Table of Loading Condition 3a (48m)

Stability Calculations for Loading Condition 3A								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	10-17	DIESEL FUEL	98	0.83	10.3	13.743	2.597	-0.787
FUEL TANK 02	10-17	DIESEL FUEL	98	0.83	10.3	13.743	-2.597	-0.787
FUEL TANK 03	10-17	DIESEL FUEL	98	0.83	5.4	14.053	0.000	-2.940
FUEL TANK 04	23-29	DIESEL FUEL	98	0.83	6.5	26.283	0.000	-2.963
FUEL TANK 05	29-39	DIESEL FUEL	98	0.83	6.4	34.195	2.389	-1.733
FUEL TANK 06	29-39	DIESEL FUEL	98	0.83	6.4	34.195	-2.389	-1.733
FUEL TANK 07	29-39	DIESEL FUEL	98	0.83	10.5	34.185	0.000	-2.962
Total DIESEL FUEL					**55.8**	**23.779**	**0.000**	**-1.874**
FRESH WATER								
FRESH WATER TANK 01	26-29	FRESH WATER	98	1.00	2.4	27.788	2.390	-1.734
FRESH WATER TANK 02	26-29	FRESH WATER	98	1.00	2.4	27.788	-2.390	-1.734
Total FRESH WATER					**4.8**	**27.788**	**0.000**	**-1.734**
LUB, OIL								
OIL TANK	17-20	LUB, OIL	98	0.9	4.2	18.531	0.000	-2.963
Total LUB, OIL					**4.2**	**18.531**	**0.000**	**-2.963**
SEA WATER								
AFT MAIN BALLAST TANK	5-8	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	8-10	SEA WATER	62.5	1.025	4.4	9.094	0.860	-2.081
AFT TRIM TANK 02	8-10	SEA WATER	62.5	1.025	4.4	9.094	-0.860	-2.081
COMPENSATING TANK 01	27-28	SEA WATER	20	1.025	0.3	27.172	1.010	-2.367
COMPENSATING TANK 02	27-28	SEA WATER	20	1.025	0.3	27.172	-1.010	-2.367
COMPENSATING TANK 03	28-29	SEA WATER	20	1.025	0.3	28.473	1.010	-2.367
COMPENSATING TANK 04	28-29	SEA WATER	20	1.025	0.3	28.473	-1.010	-2.367
FWD MAIN BALLAST TANK	41-45	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	40-42	SEA WATER	37.5	1.025	2.6	40.851	0.858	-2.490
FWD TRIM TANK 02	40-42	SEA WATER	37.5	1.025	2.6	40.851	-0.858	-2.490

Table 5.83 Summary Table of Loading Condition 3a (48m) (continued…)

TORPEDO TUBE FLOODING TANK	44-45	SEA WATER	98	1.025	3.0	44.232	0.000	-1.617
WATER ROUND TORPEDO TANK	42-44	SEA WATER	98	1.025	3.0	42.897	0.000	-1.617
Total SEA WATER					**21.2**	**27.793**	**0.000**	**-2.067**
BILGE WATER / SLUDGE								
SANITARY TANK 01	23-26	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
SANITARY TANK 02	23-26	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
Total BILGE WATER / SLUDGE					**0.0**	**0.000**	**0.000**	**0.000**
LOx								
Lox TANK	24-26	LOX	98	1.141	7.6	24.743	0.000	-1.627
Total LOx					**7.6**	**24.743**	**0.000**	**-1.627**
LOADING CONDITION 3A FIXED WEIGHTS								
COMPLEMENT					1.2	25.707	0.000	-0.185
OFFICER EQUIPMENT					0.5	25.707	0.000	-0.185
P.O. EQUIPMENT					0.6	25.707	0.000	-0.185
RATING EQUIPMENT					0.3	25.707	0.000	-0.185
GARBAGE					0.0	0.000	0.000	0.000
PROVISIONS					6.4	25.707	0.000	-0.185
TORPEDO					0.0	0.000	0.000	0.000
SPECIAL PERSONNEL & OTHER MILITARY LOADS					0.0	0.000	0.000	0.000
DESIGN MARGIN					10.6	25.707	0.000	-0.185
CONSTRUCTION MARGIN					21.2	25.707	0.000	-0.185
MAINTENANCE MARGIN					10.6	25.707	0.000	-0.185
Loading Condition 3A Fixed Weights					**51.4**	**25.707**	**0.000**	**-0.185**
Lightweight					**1058.7**	**25.707**	**0.000**	**-0.185**
Deadweight					**145.2**	**25.082**	**0.000**	**-1.318**
Total Displacement					**1203.9**	**25.632**	**0.000**	**-0.322**
Buoyancy					**1203.9**	**25.632**	**0.000**	**0.000**
Total Buoyancy					**1203.9**	**25.632**	**0.000**	**0.000**

Table 5.84 Hydrostatics at Equilibrium Angle (48m)

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim	No trim	metres
KG	-0.322	metres
KB	0.000	metres
FSC	0.007	metres
KGf	-0.314	metres
GMt	0.314	metres
BMt	0.000	metres
BMl	0.000	metres
Waterplane area	0.000	sq.metres
LCG	25.632	metres
LCB	25.632	metres
TCB	0.000	metres
LCF	35.077	metres
TCF	0.000	metres
TPC	0.000	tonnes/cm
MTC	0.081	tonnes-m/cm

Table 5.85 Summary Stability Table (48m)

Displacement [ton]	Δ	1203.9	
Length [m]	L_{DWL}	48.00	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	2.532	5.817
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.322	2.963
Longitudinal Center of Gravity [m]	LCG	25.632	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	0.055	
Maximum Operational Speed of the Submerged Submarine [knot] / [m/sn]	$v_0\uparrow$	22.000	11.317

Table 5.86 Righting – Heeling Lever Calculations (48m)

Heel Angle	**Righting Lever**	**Heeling Lever**			
[°]	h_{SUB}	k_F	kD	$k_F + k_D$	$h_{SW} - (k_F+k_D)$
10	0.0546	0.001	0.003	0.004	0.050
20	0.1073	0.002	0.003	0.005	0.102
30	0.1568	0.004	0.003	0.006	0.151
45	0.2221	0.005	0.002	0.007	0.215

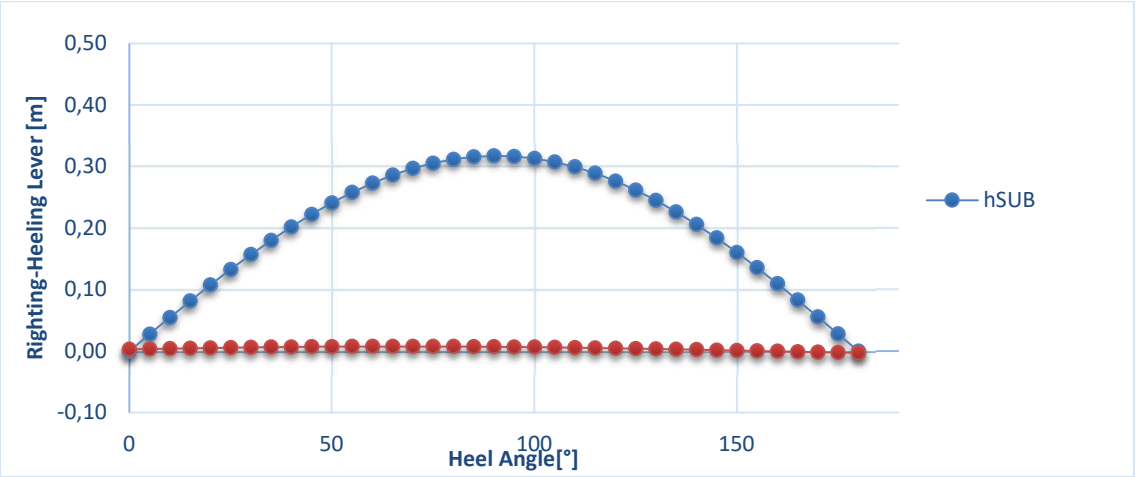

Figure 5.27 Righting – Heeling Lever / Heel Angle (48m)

Table 5.87 Criterion Assessment (48m)

#	Criterion	Actual Value	Critical Value	Result
1	Positive remaining lever h_{rem} at least 0.05 m in dived condition.	0.310	0.050	+
2	Minimum value for BG	0.322	0.320	+

This section focuses on stability analyses specifically related to loading case 3a, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Positive remaining lever h_{rem} is 0.31 m and is above the limit value of 0.05 m.
- The BG value is 0.322 m and is above the limit value of 0.32 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 3a.

5.2.2.2 Loading Condition 3b (48m)

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

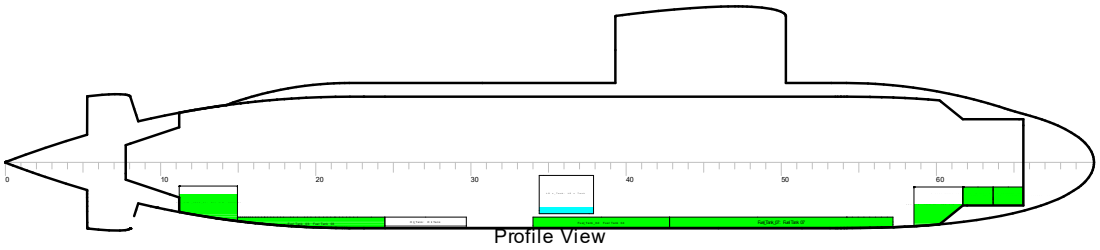

Figure 5.28 Profile View (48m)

Table 5.88 Densities (48m)

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	LUB, OIL	0.9
	BILGE WATER / SLUDGE	1.005
	LOX	1.141
	SEA WATER & DIESEL FUEL	1.005

Vessel is submerged.

Table 5.89 Summary Table of Loading Condition 3b (48m)

Stability Calculations for Loading Condition 3B								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	10-17	SEA WATER & DIESEL FUEL	98	1.01	12.5	13.743	2.597	-0.787
FUEL TANK 02	10-17	SEA WATER & DIESEL FUEL	98	1.01	12.5	13.743	-2.597	-0.787
FUEL TANK 03	10-17	SEA WATER & DIESEL FUEL	98	1.01	6.6	14.053	0.000	-2.940
FUEL TANK 04	23-29	SEA WATER & DIESEL FUEL	98	1.01	7.8	26.283	0.000	-2.963
FUEL TANK 05	29-39	SEA WATER & DIESEL FUEL	98	1.01	7.8	34.195	2.389	-1.733
FUEL TANK 06	29-39	SEA WATER & DIESEL FUEL	98	1.01	7.8	34.195	-2.389	-1.733
FUEL TANK 07	29-39	SEA WATER & DIESEL FUEL	98	1.01	12.7	34.185	0.000	-2.962
Total DIESEL FUEL					**67.7**	**23.779**	**0.000**	**-1.874**
FRESH WATER								
FRESH WATER TANK 01	26-29	FRESH WATER	10	1.00	0.2	27.788	2.160	-2.341
FRESH WATER TANK 02	26-29	FRESH WATER	10	1.00	0.2	27.788	-2.160	-2.341
Total FRESH WATER					**0.4**	**27.788**	**0.000**	**-2.341**
LUB, OIL								
OIL TANK	17-20	LUB, OIL	10	0.9	0.4	18.531	0.000	-3.215
Total LUB, OIL					**0.4**	**18.531**	**0.000**	**-3.215**
SEA WATER								
AFT MAIN BALLAST TANK	5-8	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	8-10	SEA WATER	64	1.025	4.5	9.092	0.866	-2.070
AFT TRIM TANK 02	8-10	SEA WATER	64	1.025	4.5	9.092	-0.866	-2.070
COMPENSATING TANK 01	27-28	SEA WATER	80	1.025	1.2	27.172	1.010	-2.016
COMPENSATING TANK 02	27-28	SEA WATER	80	1.025	1.2	27.172	-1.010	-2.016

Table 5.89 Summary Table of Loading Condition 3b (48m) (continued…)

COMPENSATING TANK 03	28-29	SEA WATER	80	1.025	1.2	28.473	1.010	-2.016
COMPENSATING TANK 04	28-29	SEA WATER	80	1.025	1.2	28.473	-1.010	-2.016
FWD MAIN BALLAST TANK	41-45	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	40-42	SEA WATER	36	1.025	2.5	40.845	0.850	-2.506
FWD TRIM TANK 02	40-42	SEA WATER	36	1.025	2.5	40.845	-0.850	-2.506
TORPEDO TUBE FLOODING TANK	44-45	SEA WATER	98	1.025	3.0	44.232	0.000	-1.617
WATER ROUND TORPEDO TANK	42-44	SEA WATER	98	1.025	3.0	42.897	0.000	-1.617
Total SEA WATER					**24.8**	**27.529**	**0.000**	**-2.038**
BILGE WATER / SLUDGE								
SANITARY TANK 01	23-26	BILGE WATER / SLUDGE	90	1.005	2.2	24.777	2.379	-1.775
SANITARY TANK 02	23-26	BILGE WATER / SLUDGE	90	1.005	2.2	24.777	-2.379	-1.775
Total BILGE WATER / SLUDGE					**4.4**	**24.777**	**0.000**	**-1.775**
LOx								
Lox TANK	24-26	LOX	10	1.141	0.8	24.743	0.000	-2.389
Total LOx					**0.8**	**24.743**	**0.000**	**-2.389**
LOADING CONDITION 3B FIXED WEIGHTS								
COMPLEMENT					1.2	25.707	0.000	-0.185
OFFICER EQUIPMENT					0.5	25.707	0.000	-0.185
P.O. EQUIPMENT					0.6	25.707	0.000	-0.185
RATING EQUIPMENT					0.0	25.707	0.000	-0.185
GARBAGE					1.0	25.707	0.000	-0.185
PROVISIONS					0.6	25.707	0.000	-0.185
TORPEDO					0.0	0.000	0.000	0.000
SPECIAL PERSONNEL & OTHER MILITARY LOADS					0.0	0.000	0.000	0.000
DESIGN MARGIN					10.6	25.707	0.000	-0.185
CONSTRUCTION MARGIN					21.2	25.707	0.000	-0.185
MAINTENANCE MARGIN					10.6	25.707	0.000	-0.185
Loading Condition 3B Fixed Weights					**46.3**	**25.707**	**0.000**	**-0.185**
Lightweight					**1058.7**	**25.707**	**0.000**	**-0.185**
Deadweight					**145.2**	**25.082**	**0.000**	**-1.368**
Total Displacement					**1203.9**	**25.632**	**0.000**	**-0.328**
Buoyancy					**1203.9**	**25.632**	**0.000**	**0.000**
Total Buoyancy					**1203.9**	**25.632**	**0.000**	**0.000**

Table 5.90 Hydrostatics at Equilibrium Angle (48m)

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim	No trim	metres
KG	-0.328	metres
KB	0.000	metres
FSC	0.009	metres
KGf	-0.318	metres
GMt	0.318	metres
BMt	0.000	metres
BMl	0.000	metres
Waterplane area	0.000	sq.metres
LCG	25.632	metres
LCB	25.632	metres
TCB	0.000	metres
LCF	35.077	metres
TCF	0.000	metres
TPC	0.000	tonnes/cm
MTC	0.082	tonnes-m/cm

Table 5.91 Summary Stability Table (48m)

Displacement [ton]	Δ	1203.9	
Length [m]	L_{DWL}	48.00	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	2.532	5.817
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.328	2.957
Longitudinal Center of Gravity [m]	LCG	25.632	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	0.049	
Maximum Operational Speed of the Submerged Submarine [knot] / [m/sn]	$v_0\uparrow$	22.000	11.317

Table 5.92 Righting – Heeling Lever Calculations (48m)

Heel Angle	**Righting Lever**	**Heeling Lever**			
[°]	h_{SUB}	k_F	kD	$k_F + k_D$	$h_{SW} - (k_F+k_D)$
10	0.0552	0.002	0.003	0.004	0.051
20	0.1087	0.003	0.002	0.006	0.103
30	0.1590	0.005	0.002	0.007	0.152
45	0.2255	0.006	0.002	0.008	0.217

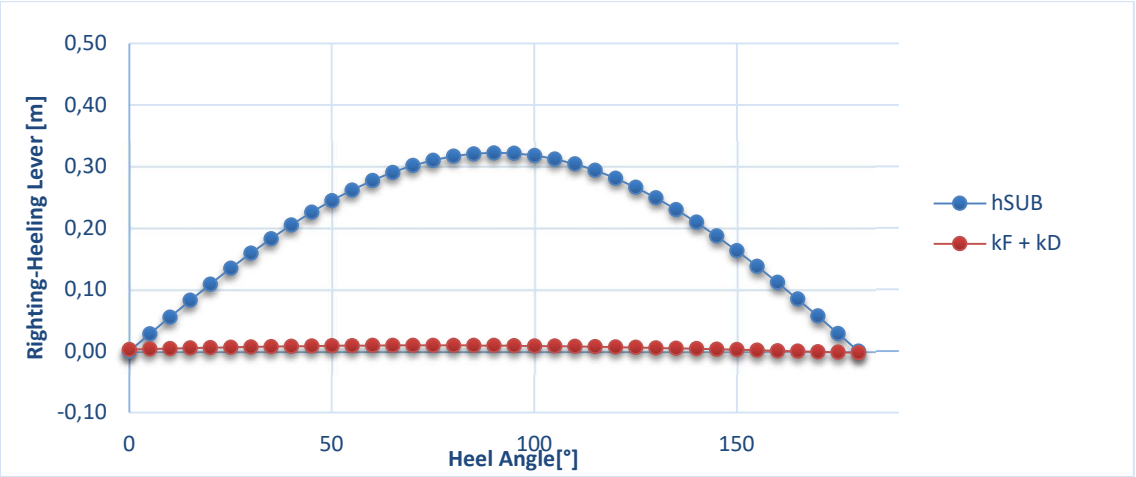

Figure 5.29 Righting – Heeling Lever / Heel Angle (48m)

Table 5.93 Criterion Assessment (48m)

#	Criterion	Actual Value	Critical Value	Result
1	Positive remaining lever h_{rem} at least 0.05 m in dived condition.	0.313	0.050	+
2	Minimum value for BG	0.328	0.320	+

This section focuses on stability analyses specifically related to loading case 3b, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Positive remaining lever h_{rem} is 0.313 m and is above the limit value of 0.05 m.
- The BG value is 0.328 m and is above the limit value of 0.32 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 3b.

5.2.2.3 Loading Condition 4a (48m)

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

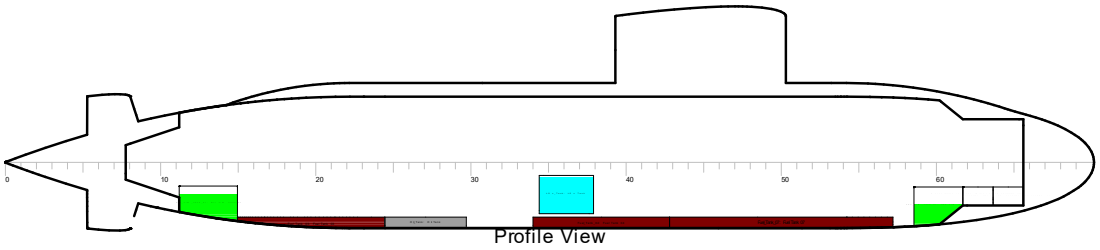

Figure 5.30 Profile View (48m)

Table 5.94 Densities (48m)

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	DIESEL FUEL	0.83
	LUB, OIL	0.9
	LOX	1.141

Vessel is submerged.

Table 5.95 Summary Table of Loading Condition 4a (48m)

Stability Calculations for Loading Condition 4A								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	10-17	DIESEL FUEL	98	0.83	10.3	13.743	2.597	-0.787
FUEL TANK 02	10-17	DIESEL FUEL	98	0.83	10.3	13.743	-2.597	-0.787
FUEL TANK 03	10-17	DIESEL FUEL	98	0.83	5.4	14.053	0.000	-2.940
FUEL TANK 04	23-29	DIESEL FUEL	98	0.83	6.5	26.283	0.000	-2.963
FUEL TANK 05	29-39	DIESEL FUEL	98	0.83	6.4	34.195	2.389	-1.733
FUEL TANK 06	29-39	DIESEL FUEL	98	0.83	6.4	34.195	-2.389	-1.733
FUEL TANK 07	29-39	DIESEL FUEL	98	0.83	10.5	34.185	0.000	-2.962
Total DIESEL FUEL					**55.8**	**23.779**	**0.000**	**-1.874**
FRESH WATER								
FRESH WATER TANK 01	26-29	FRESH WATER	98	1.00	2.4	27.788	2.390	-1.734
FRESH WATER TANK 02	26-29	FRESH WATER	98	1.00	2.4	27.788	-2.390	-1.734
Total FRESH WATER					**4.8**	**27.788**	**0.000**	**-1.734**
LUB, OIL								
OIL TANK	17-20	LUB, OIL	98	0.9	4.2	18.531	0.000	-2.963
Total LUB, OIL					**4.2**	**18.531**	**0.000**	**-2.963**
SEA WATER								
AFT MAIN BALLAST TANK	5-8	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	8-10	SEA WATER	62.5	1.025	4.4	9.094	0.860	-2.081
AFT TRIM TANK 02	8-10	SEA WATER	62.5	1.025	4.4	9.094	-0.860	-2.081
COMPENSATING TANK 01	27-28	SEA WATER	10	1.025	0.2	27.172	1.010	-2.443
COMPENSATING TANK 02	27-28	SEA WATER	10	1.025	0.2	27.172	-1.010	-2.443
COMPENSATING TANK 03	28-29	SEA WATER	10	1.025	0.2	28.473	1.010	-2.443
COMPENSATING TANK 04	28-29	SEA WATER	10	1.025	0.2	28.473	-1.010	-2.443
FWD MAIN BALLAST TANK	41-45	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	40-42	SEA WATER	37.5	1.025	2.6	40.851	0.858	-2.490
FWD TRIM TANK 02	40-42	SEA WATER	37.5	1.025	2.6	40.851	-0.858	-2.490

Table 5.95 Summary Table of Loading Condition 4a (48m) (continued…)

TORPEDO TUBE FLOODING TANK	44-45	SEA WATER	0	0	0.0	0.000	0.000	0.000
WATER ROUND TORPEDO TANK	42-44	SEA WATER	0	0	0.0	0.000	0.000	0.000
Total SEA WATER					**14.8**	**21.290**	**0.000**	**-2.243**
BILGE WATER / SLUDGE								
SANITARY TANK 01	23-26	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
SANITARY TANK 02	23-26	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
Total BILGE WATER / SLUDGE					**0.0**	**0.000**	**0.000**	**0.000**
LOx								
Lox TANK	24-26	LOX	98	1.141	7.6	24.743	0.000	-1.627
Total LOx					**7.6**	**24.743**	**0.000**	**-1.627**
LOADING CONDITION 4A FIXED WEIGHTS								
COMPLEMENT					1.2	25.707	0.000	-0.185
OFFICER EQUIPMENT					0.5	25.707	0.000	-0.185
P.O. EQUIPMENT					0.6	25.707	0.000	-0.185
RATING EQUIPMENT					0.3	25.707	0.000	-0.185
GARBAGE					0.0	0.000	0.000	0.000
PROVISIONS					6.4	25.707	0.000	-0.185
TORPEDO					6.0	43.565	0.000	-1.500
SPECIAL PERSONNEL & OTHER MILITARY LOADS					0.6	25.707	0.000	-0.185
DESIGN MARGIN					10.6	25.707	0.000	-0.185
CONSTRUCTION MARGIN					21.2	25.707	0.000	-0.185
MAINTENANCE MARGIN					10.6	25.707	0.000	-0.185
Loading Condition 4A Fixed Weights					**58.0**	**27.554**	**0.000**	**-0.321**
Lightweight					**1058.7**	**25.707**	**0.000**	**-0.185**
Deadweight					**145.2**	**25.082**	**0.000**	**-1.304**
Total Displacement					**1203.9**	**25.632**	**0.000**	**-0.320**
Buoyancy					**1203.9**	**25.632**	**0.000**	**0.000**
Total Buoyancy					**1203.9**	**25.632**	**0.000**	**0.000**

Table 5.96 Hydrostatics at Equilibrium Angle (48m)

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim	No trim	metres
KG	-0.320	metres
KB	0.000	metres
FSC	0.007	metres
KGf	-0.313	metres
GMt	0.313	metres
BMt	0.000	metres
BMl	0.000	metres
Waterplane area	0.000	sq.metres
LCG	25.632	metres
LCB	25.632	metres
TCB	0.000	metres
LCF	35.077	metres
TCF	0.000	metres
TPC	0.000	tonnes/cm
MTC	0.080	tonnes-m/cm

Table 5.97 Summary Stability Table (48m)

Displacement [ton]	Δ	1203.9	
Length [m]	L_{DWL}	48.00	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	2.532	5,817
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.320	2,965
Longitudinal Center of Gravity [m]	LCG	25.632	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	0.057	
Maximum Operational Speed of the Submerged Submarine [knot] / [m/sn]	$v_0\uparrow$	22.000	11.317

Table 5.98 Righting – Heeling Lever Calculations (48m)

Heel Angle	**Righting Lever**	**Heeling Lever**			
[°]	h_{SUB}	k_F	kD	$k_F + k_D$	$h_{SW} - (k_F+k_D)$
10	0.0543	0.001	0.003	0.004	0.050
20	0.1068	0.002	0.003	0.005	0.102
30	0.1561	0.004	0.003	0.006	0.150
45	0.2210	0.005	0.002	0.007	0.214

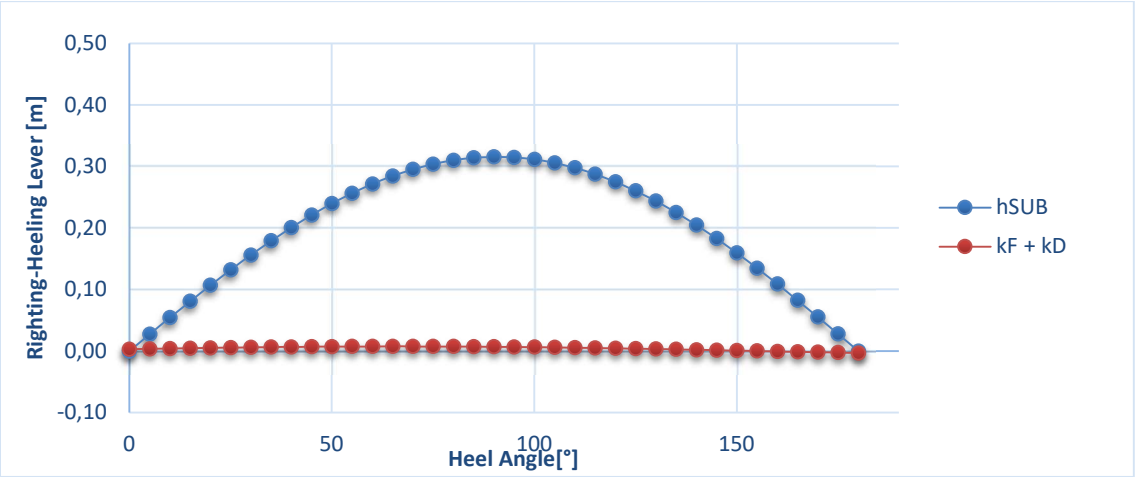

Figure 5.31 Righting – Heeling Lever / Heel Angle (48m)

Table 5.99 Criterion Assessment (48m)

#	Criterion	Actual Value	Critical Value	Result
1	Positive remaining lever h_{rem} at least 0.05 m in dived condition.	0.309	0.050	+
2	Minimum value for BG	0.320	0.320	+

This section focuses on stability analyses specifically related to loading case 4a, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Positive remaining lever h_{rem} is 0.309 m and is above the limit value of 0.05 m.
- The BG value is 0.32 m which equals the limit value.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 4a.

5.2.2.4 Loading Condition 4b (48m)

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

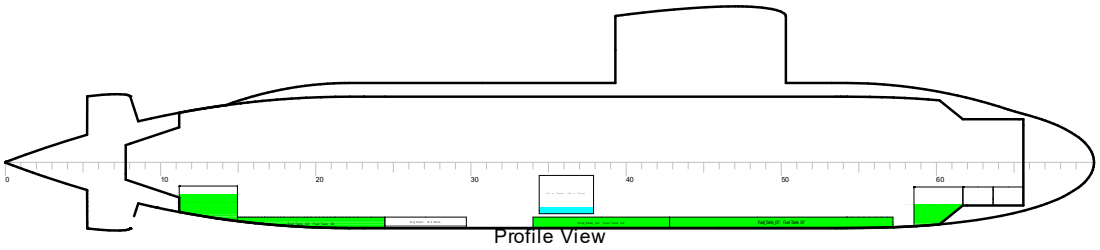

Figure 5.32 Profile View (48m)

Table 5.100 Densities (48m)

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	LUB, OIL	0.9
	BILGE WATER / SLUDGE	1.005
	LOX	1.141
	SEA WATER & DIESEL FUEL	1.005

Table 5.101 Summary Table of Loading Condition 4b (48m)

Stability Calculations for Loading Condition 4B								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	10-17	SEA WATER & DIESEL FUEL	98	1.01	12.5	13.743	2.597	-0.787
FUEL TANK 02	10-17	SEA WATER & DIESEL FUEL	98	1.01	12.5	13.743	-2.597	-0.787
FUEL TANK 03	10-17	SEA WATER & DIESEL FUEL	98	1.01	6.6	14.053	0.000	-2.940
FUEL TANK 04	23-29	SEA WATER & DIESEL FUEL	98	1.01	7.8	26.283	0.000	-2.963
FUEL TANK 05	29-39	SEA WATER & DIESEL FUEL	98	1.01	7.8	34.195	2.389	-1.733
FUEL TANK 06	29-39	SEA WATER & DIESEL FUEL	98	1.01	7.8	34.195	-2.389	-1.733
FUEL TANK 07	29-39	SEA WATER & DIESEL FUEL	98	1.01	12.7	34.185	0.000	-2.962
Total DIESEL FUEL					**67.7**	**23.779**	**0.000**	**-1.874**
FRESH WATER								
FRESH WATER TANK 01	26-29	FRESH WATER	10	1.00	0.2	27.788	2.160	-2.341
FRESH WATER TANK 02	26-29	FRESH WATER	10	1.00	0.2	27.788	-2.160	-2.341
Total FRESH WATER					**0.4**	**27.788**	**0.000**	**-2.341**
LUB, OIL								
OIL TANK	17-20	LUB, OIL	10	0.9	0.4	18.531	0.000	-3.215
Total LUB, OIL					**0.4**	**18.531**	**0.000**	**-3.215**
SEA WATER								
AFT MAIN BALLAST TANK	5-8	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	8-10	SEA WATER	64	1.025	4.5	9.092	0.866	-2.070
AFT TRIM TANK 02	8-10	SEA WATER	64	1.025	4.5	9.092	-0.866	-2.070
COMPENSATING TANK 01	27-28	SEA WATER	70	1.025	1.1	27.172	1.010	-2.071
COMPENSATING TANK 02	27-28	SEA WATER	70	1.025	1.1	27.172	-1.010	-2.071

Table 5.101 Summary Table of Loading Condition 4b (48m) (continued…)

COMPENSATING TANK 03	28-29	SEA WATER	70	1.025	1.1	28.473	1.010	-2.071
COMPENSATING TANK 04	28-29	SEA WATER	70	1.025	1.1	28.473	-1.010	-2.071
FWD MAIN BALLAST TANK	41-45	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	40-42	SEA WATER	36	1.025	2.5	40.845	0.850	-2.506
FWD TRIM TANK 02	40-42	SEA WATER	36	1.025	2.5	40.845	-0.850	-2.506
TORPEDO TUBE FLOODING TANK	44-45	SEA WATER	0	0	0.0	0.000	0.000	0.000
WATER ROUND TORPEDO TANK	42-44	SEA WATER	0	0	0.0	0.000	0.000	0.000
Total SEA WATER					**18.4**	**22.241**	**0.000**	**-2.190**
BILGE WATER / SLUDGE								
SANITARY TANK 01	23-26	BILGE WATER / SLUDGE	90	1.005	2.2	24.777	2.379	-1.775
SANITARY TANK 02	23-26	BILGE WATER / SLUDGE	90	1.005	2.2	24.777	-2.379	-1.775
Total BILGE WATER/SLUDGE					**4.4**	**24.777**	**0.000**	**-1.775**
LOx								
Lox TANK	24-26	LOX	10	1.141	0.8	24.743	0.000	-2.389
Total LOx					**0.8**	**24.743**	**0.000**	**-2.389**
LOADING CONDITION 4B FIXED WEIGHTS								
COMPLEMENT					1.2	25.707	0.000	-0.185
OFFICER EQUIPMENT					0.5	25.707	0.000	-0.185
P.O. EQUIPMENT					0.6	25.707	0.000	-0.185
RATING EQUIPMENT					0.0	25.707	0.000	-0.185
GARBAGE					1.0	25.707	0.000	-0.185
PROVISIONS					0.6	25.707	0.000	-0.185
TORPEDO					6.0	43.565	0.000	-1.500
SPECIAL PERSONNEL & OTHER MILITARY LOADS					0.6	25.707	0.000	-0.185
DESIGN MARGIN					10.6	25.707	0.000	-0.185
CONSTRUCTION MARGIN					21.2	25.707	0.000	-0.185
MAINTENANCE MARGIN					10.6	25.707	0.000	-0.185
Loading Condition 4B Fixed Weights					**52.9**	**27.732**	**0.000**	**-0.334**
Lightweight					**1058.7**	**25.707**	**0.000**	**-0.185**
Deadweight					**145.2**	**25.082**	**0.000**	**-1.357**
Total Displacement					**1203.9**	**25.632**	**0.000**	**-0.326**
Buoyancy					**1203.9**	**25.632**	**0.000**	**0.000**
Total Buoyancy					**1203.9**	**25.632**	**0.000**	**0.000**

Table 5.102 Hydrostatics at Equilibrium Angle (48m)

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim	No trim	metres
KG	-0.326	metres
KB	0.000	metres
FSC	0.009	metres
KGf	-0.317	metres
GMt	0.317	metres
BMt	0.000	metres
BMl	0.000	metres
Waterplane area	0.000	sq.metres
LCG	25.632	metres
LCB	25.632	metres
TCB	0.000	metres
LCF	35.077	metres
TCF	0.000	metres
TPC	0.000	tonnes/cm
MTC	0.082	tonnes-m/cm

Table 5.103 Summary Stability Table (48m)

Displacement [ton]	Δ	1203.9	
Length [m]	L_{DWL}	48.00	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	2.532	5.817
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.326	2.959
Longitudinal Center of Gravity [m]	LCG	25.632	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	0.051	
Maximum Operational Speed of the Submerged Submarine [knot] / [m/sn]	$v_0\uparrow$	22.000	11.317

Table 5.104 Righting – Heeling Lever Calculations (48m)

Heel Angle	**Righting Lever**	**Heeling Lever**			
[°]	h_{SUB}	k_F	kD	$k_F + k_D$	$h_{SW} - (k_F+k_D)$
10	0.0550	0.002	0.003	0.004	0.051
20	0.1082	0.003	0.003	0.006	0.103
30	0.1583	0.005	0.002	0.007	0.151
45	0.2245	0.006	0.002	0.008	0.216

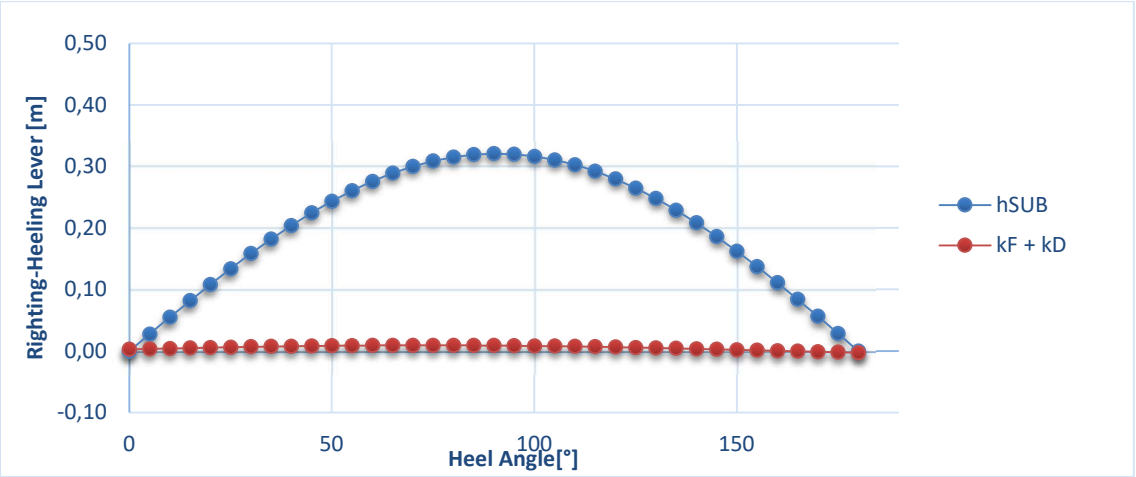

Figure 5.33 Righting – Heeling Lever / Heel Angle (48m)

Table 5.105 Criterion Assessment (48m)

#	Criterion	Actual Value	Critical Value	Result
1	Positive remaining lever h_{rem} at least 0.05 m in dived condition.	0.312	0.050	+
2	Minimum value for BG	0.326	0.320	+

This section focuses on stability analyses specifically related to loading case 4b, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Positive remaining lever h_{rem} is 0.312 m and is above the limit value of 0.05 m.
- The BG value is 0.326 m and is above the limit value of 0.32 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 4b.

5.2.3 Assessment of Compliance with the Rules (48m)

The following summary table compares the limit values with the values observed in the scenarios, in accordance with the rules.

Table 5.106 Criterion Assessment (48m)

SURFACED							
#	Criterion	Loading Condition				Critical Value	Result
		1A	1B	2A	2B		
		Actual Value					
1	The buoyancy reserve shall be at least 10% of the pressure tight volume of the submarine.	12.3	12.3	12.3	12.3	10.0	+
2	Positive remaining lever h_{rem} at least 0.1 m.	0.310	0.313	0.309	0.311	0.1	+
3	Minimum value for GM	0.314	0.318	0.312	0.316	0.200	+
SUBMERGED							
#	Criterion	Loading Condition				Critical Value	Result
		3A	3B	4A	4B		
		Actual Value					
1	Positive remaining lever h_{rem} at least 0.05 m.	0.310	0.313	0.309	0.312	0.050	+
2	Minimum value for BG	0.322	0.328	0.320	0.326	0.320	+

Table 5.106 demonstrates that intact stability requirements are fulfilled for all loading conditions.

5.3 100m

5.3.1 Surfaced Submarine (100m)

5.3.1.1 Loading Condition 1a (100m)

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

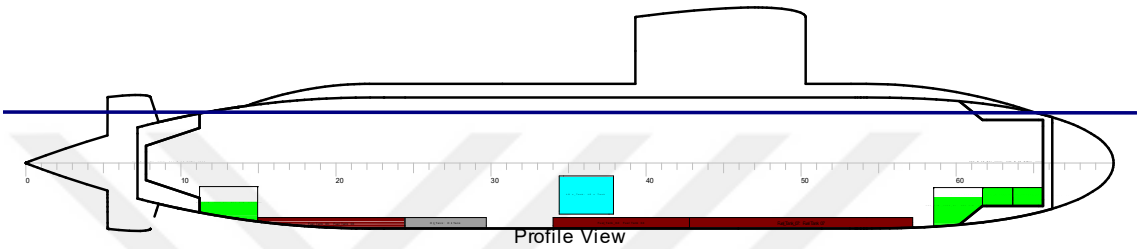

Figure 5.34 Profile View (100m)

Table 5.107 Densities (100m)

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1.000
	DIESEL FUEL	0.830
	LUB. OIL	0.900
	LOX	1.141

Table 5.108 Summary Table of Loading Condition 1a (100m)

Stability Calculations for Loading Condition 1A								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	21-35	DIESEL FUEL	98	0.83	93.3	28.631	5.410	-1.639
FUEL TANK 02	21-35	DIESEL FUEL	98	0.83	93.3	28.631	-5.410	-1.639
FUEL TANK 03	21-35	DIESEL FUEL	98	0.83	49.1	29.276	0.000	-6.124
FUEL TANK 04	48-61	DIESEL FUEL	98	0.83	58.6	54.755	0.000	-6.172
FUEL TANK 05	61-82	DIESEL FUEL	98	0.83	58.3	71.239	4.978	-3.610
FUEL TANK 06	61-82	DIESEL FUEL	98	0.83	58.3	71.239	-4.978	-3.610
FUEL TANK 07	61-82	DIESEL FUEL	98	0.83	95.0	71.218	0.000	-6.170
Total DIESEL FUEL					**505.9**	**49.539**	**0.000**	**-3.904**
FRESH WATER								
FRESH WATER TANK 01	55-61	FRESH WATER	98	1.00	21.6	57.893	4.980	-3.613
FRESH WATER TANK 02	55-61	FRESH WATER	98	1.00	21.6	57.893	-4.980	-3.613
Total FRESH WATER					**43.2**	**57.893**	**0.000**	**-3.613**
LUB, OIL								
OIL TANK	35-42	LUB, OIL	98	0.9	37.9	38.607	0.000	-6.172
Total LUB, OIL					**37.9**	**38.607**	**0.000**	**-6.172**
SEA WATER								
AFT MAIN BALLAST TANK	10-16	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	16-21	SEA WATER	37.5	1.025	23.8	19.058	1.552	-4.749
AFT TRIM TANK 02	16-21	SEA WATER	37.5	1.025	23.8	19.058	-1.552	-4.749
COMPENSATING TANK 01	55-58	SEA WATER	20	1.025	2.8	56.608	2.103	-4.930
COMPENSATING TANK 02	55-58	SEA WATER	20	1.025	2.8	56.608	-2.103	-4.930
COMPENSATING TANK 03	58-60	SEA WATER	20	1.025	2.8	59.318	2.103	-4.930
COMPENSATING TANK 04	58-60	SEA WATER	20	1.025	2.8	59.318	-2.103	-4.930
FWD MAIN BALLAST TANK	86-94	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	83-88	SEA WATER	62.5	1.025	39.6	85.256	2.015	-4.698
FWD TRIM TANK 02	83-88	SEA WATER	62.5	1.025	39.6	85.256	-2.015	-4.698

Table 5.108 Summary Table of Loading Condition 1a (100m) (continued…)

TORPEDO TUBE FLOODING TANK	91-94	SEA WATER	98	1.025	27.3	92.150	0.000	-3.369
WATER ROUND TORPEDO TANK	88-91	SEA WATER	98	1.025	27.3	89.370	0.000	-3.369
Total SEA WATER					**192.6**	**68.887**	**0.000**	**-4.347**
BILGE WATER / SLUDGE								
SANITARY TANK 01	48-55	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
SANITARY TANK 02	48-55	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
Total BILGE WATER / SLUDGE					**0.0**	**0.000**	**0.000**	**0.000**
LOx								
Lox TANK	49-54	LOX	98	1.141	68.5	51.547	0.000	-3.389
Total LOx					**68.5**	**51.547**	**0.000**	**-3.389**
LOADING CONDITION 1A FIXED WEIGHTS								
COMPLEMENT					10.9	53.556	0.000	-0.160
OFFICER EQUIPMENT					4.8	53.556	0.000	-0.160
P.O. EQUIPMENT					5.8	53.556	0.000	-0.160
RATING EQUIPMENT					2.3	53.556	0.000	-0.160
GARBAGE					0.0	0.000	0.000	0.000
PROVISIONS					58.0	53.556	0.000	-0.160
TORPEDO					0.0	0.000	0.000	0.000
SPECIAL PERSONNEL & OTHER MILITARY LOADS					0.0	0.000	0.000	0.000
DESIGN MARGIN					95.4	53.556	0.000	-0.160
CONSTRUCTION MARGIN					190.9	53.556	0.000	-0.160
MAINTENANCE MARGIN					95.4	53.556	0.000	-0.160
Loading Condition 1A Fixed Weights					**463.5**	**53.556**	**0.000**	**-0.160**
Lightweight					**9544.3**	**53.556**	**0.000**	**-0.160**
Deadweight					**1311.4**	**53.861**	**0.000**	**-2.675**
Total Displacement					**10855.6**	**53.593**	**0.000**	**-0.464**
Buoyancy					**10855.4**	**53.593**	**0.000**	**-0.332**
Total Buoyancy					**10855.4**	**53.593**	**0.000**	**-0.332**

Table 5.109 Drafts at Equilibrium Angle (100m)

Drafts at equilibrium angle		
Draft at LCF	5.280	metres
Draft at AP	5.327	metres
Draft at FP	5.241	metres
Draft at midships	5.284	metres

Table 5.110 Hydrostatics at Equilibrium Angle (100m)

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim by the stern	0.086	metres
	0.07	degrees
KG	-0.464	metres
KB	-0.332	metres
FSC	0.015	metres
KGf	-0.448	metres
GMt	0.447	metres
BMt	0.332	metres
BMl	23.820	metres
Waterplane area	607.350	sq.metres
LCG	53.593	metres
LCB	53.593	metres
TCB	0.000	metres
LCF	55.029	metres
TCF	0.000	metres
TPC	6.225	tonnes/cm
MTC	26.000	tonnes-m/cm

Table 5.111 Summary Stability Table (100m)

Displacement [ton]	Δ	10855.6	
Length [m]	L_{DWL}	100.00	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	5.280	12.124
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.464	*6.380*
Longitudinal Center of Gravity [m]	LCG	53.593	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	0.318	
Wind Pressure [kN/m^2]	q_w	0.358	
Density of Air [t/m^3]	ρ_L	0.001225	
Wind Speed [m/s]	v_w	24.179	
Form Coefficient	c_f	0.600	

Table 5.111 Summary Stability Table (100m) (continued…)

Projected Area Exposed to Wind Forces [m^2]	A_w	321.236	
Height of the Centroid of the Area Exposed to Wind [m] [from Reference Point] / [from Baseline]	A_{wz}	8.076	14.920
Height of the Centroid of the Area Exposed to Wind Above Half Draught [m] [from Baseline]	A_{wz}-0.5T	8.858	
Maximum Operational Speed of the Surfaced Submarine [knot] / [m/sn]	$v_0\uparrow$	12.000	6.173

Table 5.112 Righting – Heeling Lever Calculations (100m)

Heel Angle	**Righting Lever**	**Heeling Lever**				
[°]	hsw	k_F	k_D	k_W	$k_F + k_D + k_W$	$h_{SW} - (k_F+k_D+k_W)$
10	0.0778	0.003	0.002	0.006	0.011	0.067
20	0.1529	0.005	0.002	0.005	0.013	0.140
30	0.2234	0.008	0.002	0.005	0.015	0.209
45	0.3167	0.011	0.002	0.004	0.016	0.300

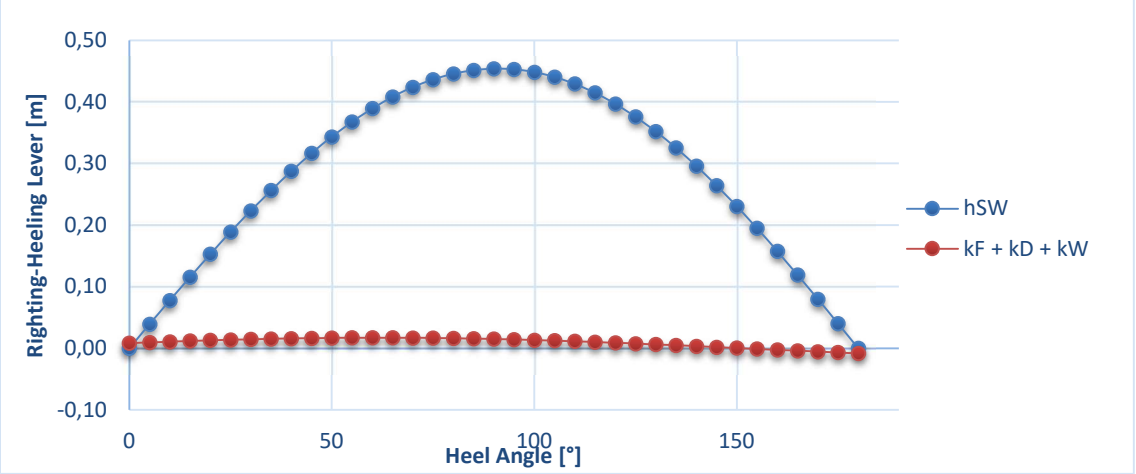

Figure 5.35 Righting – Heeling Lever / Heel Angle (100m)

Table 5.113 Criterion Assessment (100m)

#	Criterion	Actual Value	Critical Value	Result
1	The buoyancy reserve shall be at least 10% of the pressure tight volume of the submarine in surfaced condition.	12.3	10.0	+
2	Positive remaining lever h_{rem} at least 0.1 m in surfaced condition.	0.439	0.1	+
3	Minimum value for GM	0.447	0.220	+

This section focuses on stability analyses specifically related to loading case 1a, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Buoyancy reserve is 12.3% of the pressure tight volume of the submarine. Thus, the 10% limit value has been exceeded.
- Positive remaining lever h_{rem} is 0.439 m and is above the limit value of 0.1 m.
- The GM value is 0.447 m and is above the limit value of 0.22 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 1a.

5.3.1.2 Loading Condition 1b (100m)

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

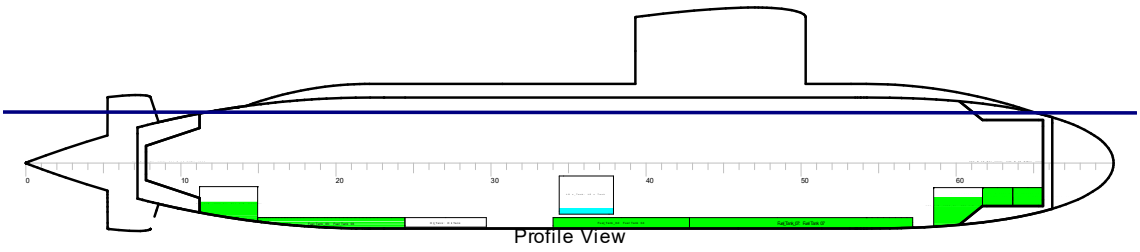

Figure 5.36 Profile View (100m)

Table 5.114 Densities (100m)

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	LUB, OIL	0.9
	BILGE WATER / SLUDGE	1.005
	LOX	1.141
	SEA WATER & DIESEL FUEL	1.005

Table 5.115 Summary Table of Loading Condition 1b (100m)

Stability Calculations for Loading Condition 1B								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	21-35	SEA WATER& DIESEL FUEL	98	1.005	113.0	28.631	5.410	-1.639
FUEL TANK 02	21-35	SEA WATER& DIESEL FUEL	98	1.005	113.0	28.631	-5.410	-1.639
FUEL TANK 03	21-35	SEA WATER& DIESEL FUEL	98	1.005	59.4	29.276	0.000	-6.124
FUEL TANK 04	48-61	SEA WATER& DIESEL FUEL	98	1.005	70.9	54.755	0.000	-6.172
FUEL TANK 05	61-82	SEA WATER& DIESEL FUEL	98	1.005	70.6	71.239	4.978	-3.610
FUEL TANK 06	61-82	SEA WATER& DIESEL FUEL	98	1.005	70.6	71.239	-4.978	-3.610
FUEL TANK 07	61-82	SEA WATER& DIESEL FUEL	98	1.005	115.1	71.218	0.000	-6.170
Total DIESEL FUEL					**612.6**	**49.539**	**0.000**	**-3.904**
FRESH WATER								
FRESH WATER TANK 01	55-61	FRESH WATER	10	1.00	2.2	57.889	4.499	-4.878
FRESH WATER TANK 02	55-61	FRESH WATER	10	1.00	2.2	57.889	-4.499	-4.878
Total FRESH WATER					**4.4**	**57.889**	**0.000**	**-4.878**
LUB, OIL								
OIL TANK	35-42	LUB, OIL	10	0.9	3.9	38.594	0.000	-6.699
Total LUB, OIL					**3.9**	**38.594**	**0.000**	**-6.699**
SEA WATER								
AFT MAIN BALLAST TANK	10-16	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	16-21	SEA WATER	37.5	1.025	23.8	19.059	1.552	-4.749
AFT TRIM TANK 02	16-21	SEA WATER	37.5	1.025	23.8	19.059	-1.552	-4.749
COMPENSATING TANK 01	55-58	SEA WATER	80	1.025	11.1	56.609	2.103	-4.200
COMPENSATING TANK 02	55-58	SEA WATER	80	1.025	11.1	56.609	-2.103	-4.200

Table 5.115 Summary Table of Loading Condition 1b (100m) (continued…)

COMPENSATING TANK 03	58-60	SEA WATER	80	1.025	11.1	59.318	2.103	-4.200
COMPENSATING TANK 04	58-60	SEA WATER	80	1.025	11.1	59.318	-2.103	-4.200
FWD MAIN BALLAST TANK	86-94	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	83-88	SEA WATER	62.5	1.025	39.6	85.256	2.015	-4.698
FWD TRIM TANK 02	83-88	SEA WATER	62.5	1.025	39.6	85.256	-2.015	-4.698
TORPEDO TUBE FLOODING TANK	91-94	SEA WATER	98	1.025	27.3	92.150	0.000	-3.369
WATER ROUND TORPEDO TANK	88-91	SEA WATER	98	1.025	27.3	89.370	0.000	-3.369
Total SEA WATER					**225.8**	**67.271**	**0.000**	**-4.289**
BILGE WATER / SLUDGE								
SANITARY TANK 01	48-55	BILGE WATER / SLUDGE	90	1.005	19.9	51.617	4.956	-3.697
SANITARY TANK 02	48-55	BILGE WATER / SLUDGE	90	1.005	19.9	51.617	-4.956	-3.697
Total BILGE WATER/SLUDGE					**39.8**	**51.617**	**0.000**	**-3.697**
LOx								
Lox TANK	49-54	LOX	10	1.141	7.0	51.545	0.000	-4.976
Total LOx					**7.0**	**51.545**	**0.000**	**-4.976**
LOADING CONDITION 1B FIXED WEIGHTS								
COMPLEMENT					10.9	53.556	0.000	-0.160
OFFICER EQUIPMENT					4.8	53.556	0.000	-0.160
P.O. EQUIPMENT					5.8	53.556	0.000	-0.160
RATING EQUIPMENT					0.2	53.556	0.000	-0.160
GARBAGE					8.7	53.556	0.000	-0.160
PROVISIONS					5.8	53.556	0.000	-0.160
TORPEDO					0.0	0.000	0.000	0.000
SPECIAL PERSONNEL & OTHER MILIT. LOADS					0.0	0.000	0.000	0.000
DESIGN MARGIN					95.4	53.556	0.000	-0.160
CONSTRUCTION MARGIN					190.9	53.556	0.000	-0.160
MAINTENANCE MARGIN					95.4	53.556	0.000	-0.160
Loading Condition 1B Fixed Weights					**417.9**	**53.556**	**0.000**	**-0.160**
Lightweight					**9544.3**	**53.556**	**0.000**	**-0.160**
Deadweight					**1311.4**	**53.941**	**0.000**	**-2.788**
Total Displacement					**10855.7**	**53.603**	**0.000**	**-0.477**
Buoyancy					**10855.5**	**53.603**	**0.000**	**-0.332**
Total Buoyancy					**10855.5**	**53.603**	**0.000**	**-0.332**

Table 5.116 Drafts at Equilibrium Angle (100m)

Drafts at equilibrium angle		
Draft at LCF	5.280	metres
Draft at AP	5.305	metres
Draft at FP	5.260	metres
Draft at midships	5.282	metres

Table 5.117 Hydrostatics at Equilibrium Angle (100m)

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim by the stern	0.045	metres
	0.04	degrees
KG	-0.477	metres
KB	-0.332	metres
FSC	0.020	metres
KGf	-0.458	metres
GMt	0.457	metres
BMt	0.332	metres
BMl	23.830	metres
Waterplane area	607.400	sq.metres
LCG	53.603	metres
LCB	53.603	metres
TCB	0.000	metres
LCF	54.932	metres
TCF	0.000	metres
TPC	6.226	tonnes/cm
MTC	26.026	tonnes-m/cm

Table 5.118 Summary Stability Table (100m)

Displacement [ton]	Δ	10855.7	
Length [m]	L_{DWL}	100.00	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	5.280	12.124
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.477	6.367
Longitudinal Center of Gravity [m]	LCG	53.603	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	0.305	
Wind Pressure [kN/m^2]	q_w	0.358	
Density of Air [t/m^3]	ρ_L	0.001225	
Wind Speed [m/s]	v_w	24.179	
Form Coefficient	c_f	0.600	

Table 5.118 Summary Stability Table (100m) (continued…)

Projected Area Exposed to Wind Forces [m^2]	A_w	321.236	
Height of the Centroid of the Area Exposed to Wind [m] [from Reference Point] / [from Baseline]	A_{wz}	8.076	14.920
Height of the Centroid of the Area Exposed to Wind Above Half Draught [m] [from Baseline]	A_{wz}-0.5T	8.858	
Maximum Operational Speed of the Surfaced Submarine [knot] / [m/sn]	$v_0\uparrow$	12.000	6.173

Table 5.119 Righting – Heeling Lever Calculations (100m)

Heel Angle	**Righting Lever**	**Heeling Lever**				
[°]	hsw	k_F	k_D	k_W	$k_F + k_D + k_W$	h_{SW} - (k_F+k_D+k_W)
10	0.0794	0.003	0.002	0.006	0.011	0.068
20	0.1562	0.007	0.002	0.005	0.014	0.142
30	0.2285	0.010	0.002	0.005	0.017	0.211
45	0.3244	0.014	0.002	0.004	0.020	0.305

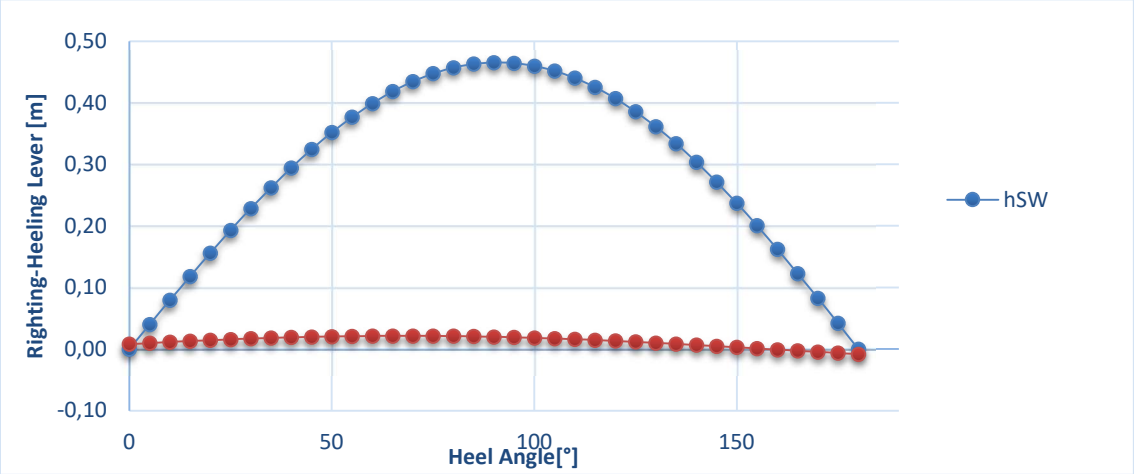

Figure 5.37 Righting – Heeling Lever / Heel Angle (100m)

Table 5.120 Criterion Assessment (100m)

#	Criterion	Actual Value	Critical Value	Result
1	The buoyancy reserve shall be at least 10% of the pressure tight volume of the submarine in surfaced condition.	12.3	10.0	+
2	Positive remaining lever h_{rem} at least 0.1 m in surfaced condition.	0.446	0.1	+
3	Minimum value for GM	0.457	0.220	+

This section focuses on stability analyses specifically related to loading case 1b, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Buoyancy reserve is 12.3% of the pressure tight volume of the submarine. Thus, the 10% limit value has been exceeded.
- Positive remaining lever h_{rem} is 0.446 m and is above the limit value of 0.1 m.
- The GM value is 0.457 m and is above the limit value of 0.22 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 1b.

5.3.1.3 Loading Condition 2a (100m)

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

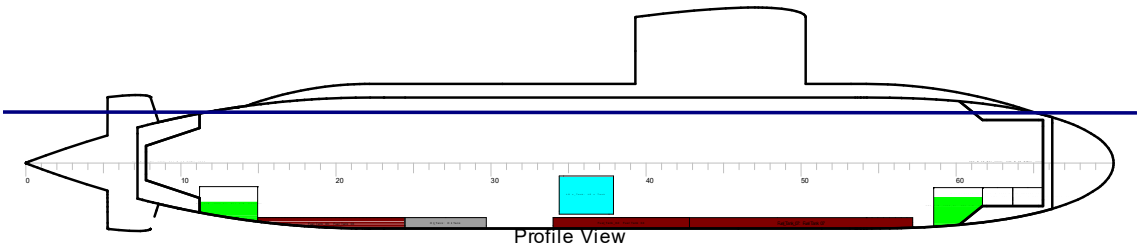

Figure 5.38 Profile View (100m)

Table 5.121 Densities (100m)

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	DIESEL FUEL	0.83
	LUB, OIL	0.9
	LOX	1.141

Table 5.122 Summary Table of Loading Condition 2a (100m)

Stability Calculations for Loading Condition 2A								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	21-35	DIESEL FUEL	98	0.83	93.3	28.631	5.410	-1.639
FUEL TANK 02	21-35	DIESEL FUEL	98	0.83	93.3	28.631	-5.410	-1.639
FUEL TANK 03	21-35	DIESEL FUEL	98	0.83	49.1	29.276	0.000	-6.124
FUEL TANK 04	48-61	DIESEL FUEL	98	0.83	58.6	54.755	0.000	-6.172
FUEL TANK 05	61-82	DIESEL FUEL	98	0.83	58.3	71.239	4.978	-3.610
FUEL TANK 06	61-82	DIESEL FUEL	98	0.83	58.3	71.239	-4.978	-3.610
FUEL TANK 07	61-82	DIESEL FUEL	98	0.83	95.0	71.218	0.000	-6.170
Total DIESEL FUEL					**505.9**	**49.539**	**0.000**	**-3.904**
FRESH WATER								
FRESH WATER TANK 01	55-61	FRESH WATER	98	1.00	21.6	57.893	4.980	-3.613
FRESH WATER TANK 02	55-61	FRESH WATER	98	1.00	21.6	57.893	-4.980	-3.613
Total FRESH WATER					**43.2**	**57.893**	**0.000**	**-3.613**
LUB, OIL								
OIL TANK	35-42	LUB, OIL	98	0.9	37.9	38.607	0.000	-6.172
Total LUB, OIL					**37.9**	**38.607**	**0.000**	**-6.172**
SEA WATER								
AFT MAIN BALLAST TANK	10-16	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	16-21	SEA WATER	37.5	1.025	23.8	19.058	1.552	-4.749
AFT TRIM TANK 02	16-21	SEA WATER	37.5	1.025	23.8	19.058	-1.552	-4.749
COMPENSATING TANK 01	55-58	SEA WATER	10	1.025	1.4	56.608	2.103	-5.089
COMPENSATING TANK 02	55-58	SEA WATER	10	1.025	1.4	56.608	-2.103	-5.089
COMPENSATING TANK 03	58-60	SEA WATER	10	1.025	1.4	59.317	2.103	-5.089
COMPENSATING TANK 04	58-60	SEA WATER	10	1.025	1.4	59.317	-2.103	-5.089
FWD MAIN BALLAST TANK	86-94	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	83-88	SEA WATER	62.5	1.025	39.6	85.256	2.015	-4.698
FWD TRIM TANK 02	83-88	SEA WATER	62.5	1.025	39.6	85.256	-2.015	-4.698

Table 5.122 Summary Table of Loading Condition 2a (100m) (continued…)

TORPEDO TUBE FLOODING TANK	91-94	SEA WATER	0	0	0.0	0.000	0.000	0.000
WATER ROUND TORPEDO TANK	88-91	SEA WATER	0	0	0.0	0.000	0.000	0.000
Total SEA WATER					**132.4**	**60.330**	**0.000**	**-4.733**
BILGE WATER / SLUDGE								
SANITARY TANK 01	48-55	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
SANITARY TANK 02	48-55	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
Total BILGE WATER / SLUDGE					**0.0**	**0.000**	**0.000**	**0.000**
LOx								
Lox TANK	49-54	LOX	98	1.141	68.5	51.547	0.000	-3.389
Total LOx					**68.5**	**51.547**	**0.000**	**-3.389**
LOADING CONDITION 2A FIXED WEIGHTS								
COMPLEMENT					10.9	53.556	0.000	-0.160
OFFICER EQUIPMENT					4.8	53.556	0.000	-0.160
P.O. EQUIPMENT					5.8	53.556	0.000	-0.160
RATING EQUIPMENT					2.3	53.556	0.000	-0.160
GARBAGE					0.0	0.000	0.000	0.000
PROVISIONS					58.0	53.556	0.000	-0.160
TORPEDO					54.5	90.760	0.000	-1.500
SPECIAL PERSONNEL & OTHER MILITARY LOADS					5.6	53.556	0.000	-0.160
DESIGN MARGIN					95.4	53.556	0.000	-0.160
CONSTRUCTION MARGIN					190.9	53.556	0.000	-0.160
MAINTENANCE MARGIN					95.4	53.556	0.000	-0.160
Loading Condition 2A Fixed Weights					**523.6**	**57.428**	**0.000**	**-0.299**
Lightweight					**9544.3**	**53.556**	**0.000**	**-0.160**
Deadweight					**1311.4**	**53.842**	**0.000**	**-2.577**
Total Displacement					**10855.6**	**53.591**	**0.000**	**-0.452**
Buoyancy					**10855.4**	**53.591**	**0.000**	**-0.332**
Total Buoyancy					**10855.4**	**53.591**	**0.000**	**-0.332**

Table 5.123 Drafts at Equilibrium Angle (100m)

Drafts at equilibrium angle		
Draft at LCF	5.280	metres
Draft at AP	5.333	metres
Draft at FP	5.237	metres
Draft at midships	5.285	metres

Table 5.124 Hydrostatics at Equilibrium Angle (100m)

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim by the stern	0.096	metres
	0.08	degrees
KG	-0.452	metres
KB	-0.332	metres
FSC	0.015	metres
KGf	-0.437	metres
GMt	0.436	metres
BMt	0.332	metres
BMl	23.815	metres
Waterplane area	607.300	sq.metres
LCG	53.591	metres
LCB	53.591	metres
TCB	0.000	metres
LCF	55.052	metres
TCF	0.000	metres
TPC	6.225	tonnes/cm
MTC	25.982	tonnes-m/cm

Table 5.125 Summary Stability Table (100m)

Displacement [ton]	Δ	10855.6	
Length [m]	L_{DWL}	100.00	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	5.280	12.124
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.452	6.392
Longitudinal Center of Gravity [m]	LCG	53.591	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	0.330	
Wind Pressure [kN/m^2]	q_w	0.358	
Density of Air [t/m^3]	ρ_L	0.001225	
Wind Speed [m/s]	v_w	24.179	
Form Coefficient	c_f	0.600	

Table 5.125 Summary Stability Table (100m) (continued…)

Projected Area Exposed to Wind Forces [m^2]	A_w	321.236	
Height of the Centroid of the Area Exposed to Wind [m] [from Reference Point] / [from Baseline]	A_{wz}	8.076	14.920
Height of the Centroid of the Area Exposed to Wind Above Half Draught [m] [from Baseline]	A_{wz}-0.5T	8.858	
Maximum Operational Speed of the Surfaced Submarine [knot] / [m/sn]	$v_0\uparrow$	12.000	6.173

Table 5.126 Righting – Heeling Lever Calculations (100m)

Heel Angle	**Righting Lever**	**Heeling Lever**				
[°]	hsw	k_F	k_D	k_W	$k_F + k_D + k_W$	$h_{SW} - (k_F+k_D+k_W)$
10	0.0758	0.003	0.003	0.006	0.011	0.065
20	0.1490	0.005	0.002	0.005	0.013	0.136
30	0.2177	0.008	0.002	0.005	0.015	0.203
45	0.3087	0.011	0.002	0.004	0.016	0.292

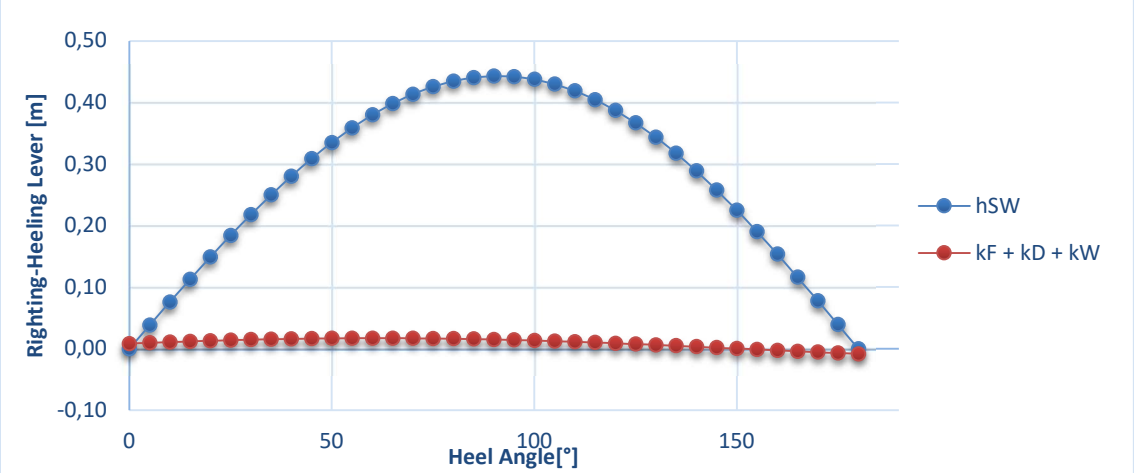

Figure 5.39 Righting – Heeling Lever / Heel Angle (100m)

Table 5.127 Criterion Assessment (100m)

#	Criterion	Actual Value	Critical Value	Result
1	The buoyancy reserve shall be at least 10% of the pressure tight volume of the submarine in surfaced condition.	12.3	10.0	+
2	Positive remaining lever h_{rem} at least 0.1 m in surfaced condition.	0.428	0.1	+
3	Minimum value for GM	0.436	0.220	+

This section focuses on stability analyses specifically related to loading case 2a, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Buoyancy reserve is 12.3% of the pressure tight volume of the submarine. Thus, the 10% limit value has been exceeded.
- Positive remaining lever h_{rem} is 0.428 m and is above the limit value of 0.1 m.
- The GM value is 0.436 m and is above the limit value of 0.22 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 2a.

5.3.1.4 Loading Condition 2b (100m)

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

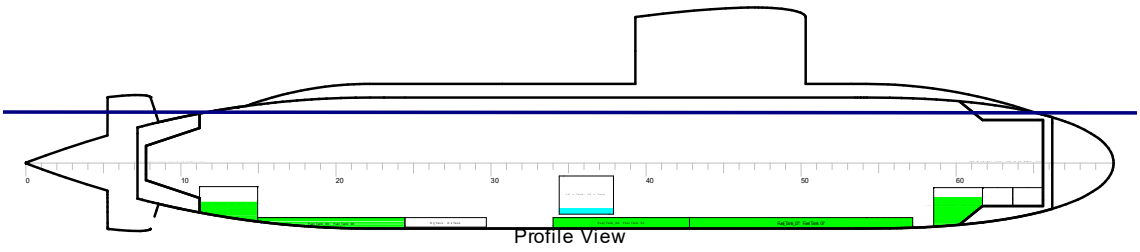

Figure 5.40 Profile View (100m)

Table 5.128 Densities (100m)

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	LUB, OIL	0.9
	BILGE WATER / SLUDGE	1.005
	LOX	1.141
	SEA WATER & DIESEL FUEL	1.005

Table 5.129 Summary Table of Loading Condition 2b (100m)

Stability Calculations for Loading Condition 2B								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	21-35	SEA WATER & DIESEL FUEL	98	1.01	113.0	28.631	5.410	-1.639
FUEL TANK 02	21-35	SEA WATER & DIESEL FUEL	98	1.01	113.0	28.631	-5.410	-1.639
FUEL TANK 03	21-35	SEA WATER & DIESEL FUEL	98	1.01	59.4	29.276	0.000	-6.124
FUEL TANK 04	48-61	SEA WATER & DIESEL FUEL	98	1.01	70.9	54.755	0.000	-6.172
FUEL TANK 05	61-82	SEA WATER & DIESEL FUEL	98	1.01	70.6	71.239	4.978	-3.610
FUEL TANK 06	61-82	SEA WATER & DIESEL FUEL	98	1.01	70.6	71.239	-4.978	-3.610
FUEL TANK 07	61-82	SEA WATER & DIESEL FUEL	98	1.01	115.1	71.218	0.000	-6.170
Total DIESEL FUEL					**612.6**	**49.539**	**0.000**	**-3.904**
FRESH WATER								
FRESH WATER TANK 01	55-61	FRESH WATER	10	1.00	2.2	57.888	4.499	-4.878
FRESH WATER TANK 02	55-61	FRESH WATER	10	1.00	2.2	57.888	-4.499	-4.878
Total FRESH WATER					**4.4**	**57.888**	**0.000**	**-4.878**
LUB, OIL								
OIL TANK	35-42	LUB, OIL	10	0.9	3.9	38.591	0.000	-6.699
Total LUB, OIL					**3.9**	**38.591**	**0.000**	**-6.699**
SEA WATER								
AFT MAIN BALLAST TANK	10-16	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	16-21	SEA WATER	37.5	1.025	23.8	19.059	1.552	-4.749
AFT TRIM TANK 02	16-21	SEA WATER	37.5	1.025	23.8	19.059	-1.552	-4.749
COMPENSATING TANK 01	55-58	SEA WATER	70	1.025	9.7	56.609	2.103	-4.315
COMPENSATING TANK 02	55-58	SEA WATER	70	1.025	9.7	56.609	-2.103	-4.315

Table 5.129 Summary Table of Loading Condition 2b (100m) (continued…)

COMPENSATING TANK 03	58-60	SEA WATER	70	1.025	9.7	59.318	2.103	-4.315
COMPENSATING TANK 04	58-60	SEA WATER	70	1.025	9.7	59.318	-2.103	-4.315
FWD MAIN BALLAST TANK	86-94	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	83-88	SEA WATER	62.5	1.025	39.6	85.256	2.015	-4.698
FWD TRIM TANK 02	83-88	SEA WATER	62.5	1.025	39.6	85.256	-2.015	-4.698
TORPEDO TUBE FLOODING TANK	91-94	SEA WATER	0	0	0.0	0.000	0.000	0.000
WATER ROUND TORPEDO TANK	88-91	SEA WATER	0	0	0.0	0.000	0.000	0.000
Total SEA WATER					**165.6**	**59.853**	**0.000**	**-4.623**
BILGE WATER / SLUDGE								
SANITARY TANK 01	48-55	BILGE WATER / SLUDGE	90	1.005	19.9	51.617	4.956	-3.697
SANITARY TANK 02	48-55	BILGE WATER / SLUDGE	90	1.005	19.9	51.617	-4.956	-3.697
Total BILGE WATER/SLUDGE					**39.8**	**51.617**	**0.000**	**-3.697**
LOx								
Lox TANK	49-54	LOX	10	1.141	7.0	51.544	0.000	-4.976
Total LOx					**7.0**	**51.544**	**0.000**	**-4.976**
LOADING CONDITION 2B FIXED WEIGHTS								
COMPLEMENT					10.9	53.556	0.000	-0.160
OFFICER EQUIPMENT					4.8	53.556	0.000	-0.160
P.O. EQUIPMENT					5.8	53.556	0.000	-0.160
RATING EQUIPMENT					0.2	53.556	0.000	-0.160
GARBAGE					8.7	53.556	0.000	-0.160
PROVISIONS					5.8	53.556	0.000	-0.160
TORPEDO					54.5	90.760	0.000	-1.500
SPECIAL PERSONNEL & OTHER MILIT. LOADS					5.6	53.556	0.000	-0.160
DESIGN MARGIN					95.4	53.556	0.000	-0.160
CONSTRUCTION MARGIN					190.9	53.556	0.000	-0.160
MAINTENANCE MARGIN					95.4	53.556	0.000	-0.160
Loading Condition 2B Fixed Weights					**478.0**	**57.798**	**0.000**	**-0.313**
Lightweight					**9544.3**	**53.556**	**0.000**	**-0.160**
Deadweight					**1311.4**	**53.923**	**0.000**	**-2.697**
Total Displacement					**10855.7**	**53.600**	**0.000**	**-0.466**
Buoyancy					**10855.4**	**53.600**	**0.000**	**-0.332**
Total Buoyancy					**10855.4**	**53.600**	**0.000**	**-0.332**

Table 5.130 Drafts at Equilibrium Angle (100m)

Drafts at equilibrium angle		
Draft at LCF	5.280	metres
Draft at AP	5.31	metres
Draft at FP	5.255	metres
Draft at midships	5.283	metres

Table 5.131 Hydrostatics at Equilibrium Angle (100m)

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim by the stern	0.055	metres
	0.04	degrees
KG	-0.466	metres
KB	-0.332	metres
FSC	0.020	metres
KGf	-0.446	metres
GMt	0.446	metres
BMt	0.332	metres
BMl	23.827	metres
Waterplane area	607.400	sq.metres
LCG	53.600	metres
LCB	53.600	metres
TCB	0.000	metres
LCF	54.955	metres
TCF	0.000	metres
TPC	6.226	tonnes/cm
MTC	26.011	tonnes-m/cm

Table 5.132 Summary Stability Table (100m)

Displacement [ton]	Δ	10855.7	
Length [m]	L_{DWL}	100.00	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	5.280	12.124
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.466	6.378
Longitudinal Center of Gravity [m]	LCG	53.600	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	0.316	
Wind Pressure [kN/m^2]	q_w	0.358	
Density of Air [t/m^3]	ρ_L	0.001225	
Wind Speed [m/s]	v_w	24.179	
Form Coefficient	c_f	0.600	

Table 5.132 Summary Stability Table (100m) (continued…)

Projected Area Exposed to Wind Forces [m^2]	A_w	321.236	
Height of the Centroid of the Area Exposed to Wind [m] [from Reference Point] / [from Baseline]	A_{wz}	8.076	14.920
Height of the Centroid of the Area Exposed to Wind Above Half Draught [m] [from Baseline]	A_{wz}-0.5T	8.858	
Maximum Operational Speed of the Surfaced Submarine [knot] / [m/sn]	$v_0\uparrow$	12.000	6.173

Table 5.133 Righting – Heeling Lever Calculations (100m)

Heel Angle	**Righting Lever**	**Heeling Lever**				
[°]	hsw	k_F	k_D	k_W	$k_F + k_D + k_W$	$h_{SW} - (k_F+k_D+k_W)$
10	0.0774	0.003	0.002	0.006	0.012	0.066
20	0.1523	0.007	0.002	0.005	0.015	0.138
30	0.2228	0.010	0.002	0.005	0.017	0.206
45	0.3164	0.014	0.002	0.004	0.020	0.296

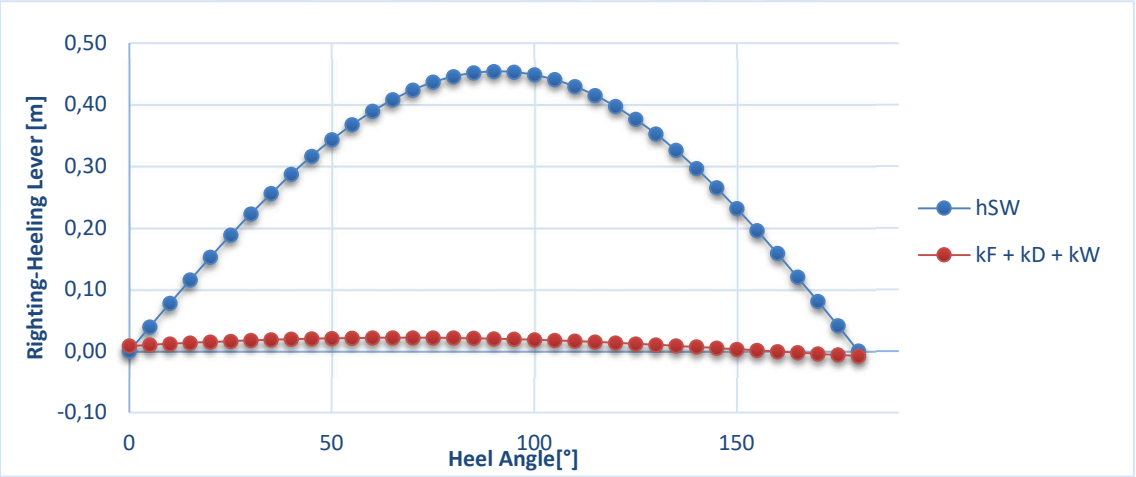

Figure 5.41 Righting – Heeling Lever / Heel Angle (100m)

Table 5.134 Criterion Assessment (100m)

#	Criterion	Actual Value	Critical Value	Result
1	The buoyancy reserve shall be at least 10% of the pressure tight volume of the submarine in surfaced condition.	12.3	10.0	+
2	Positive remaining lever h_{rem} at least 0.1 m in surfaced condition.	0.434	0.1	+
3	Minimum value for GM	0.446	0.220	+

This section focuses on stability analyses specifically related to loading case 2b, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Buoyancy reserve is 12.3% of the pressure tight volume of the submarine. Thus, the 10% limit value has been exceeded.
- Positive remaining lever h_{rem} is 0.434 m and is above the limit value of 0.1 m.
- The GM value is 0.446 m and is above the limit value of 0.22 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 2b.

5.3.2 Submerged Submarine (100m)

5.3.2.1 Loading Condition 3a (100m)

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

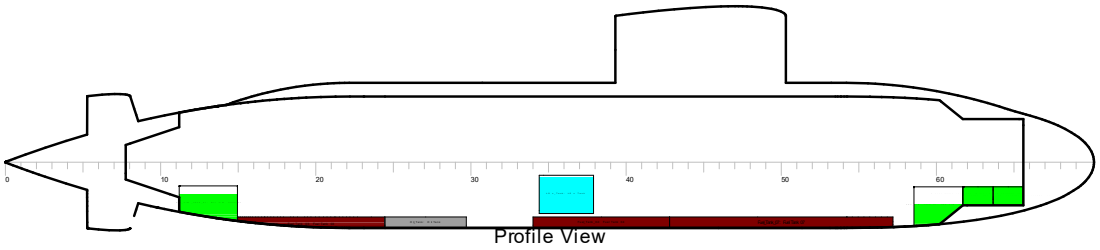

Figure 5.42 Profile View (100m)

Table 5.135 Densities (100m)

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	DIESEL FUEL	0.83
	LUB, OIL	0.9
	LOX	1.141

Table 5.136 Summary Table of Loading Condition 3a (100m)

Stability Calculations for Loading Condition 3A								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	21-35	DIESEL FUEL	98	0.83	93.3	28.631	5.410	-1.639
FUEL TANK 02	21-35	DIESEL FUEL	98	0.83	93.3	28.631	-5.410	-1.639
FUEL TANK 03	21-35	DIESEL FUEL	98	0.83	49.1	29.276	0.000	-6.124
FUEL TANK 04	48-61	DIESEL FUEL	98	0.83	58.6	54.755	0.000	-6.172
FUEL TANK 05	61-82	DIESEL FUEL	98	0.83	58.3	71.239	4.978	-3.610
FUEL TANK 06	61-82	DIESEL FUEL	98	0.83	58.3	71.239	-4.978	-3.610
FUEL TANK 07	61-82	DIESEL FUEL	98	0.83	95.0	71.218	0.000	-6.170
Total DIESEL FUEL					**505.9**	**49.539**	**0.000**	**-3.904**
FRESH WATER								
FRESH WATER TANK 01	55-61	FRESH WATER	98	1.00	21.6	57.893	4.980	-3.613
FRESH WATER TANK 02	55-61	FRESH WATER	98	1.00	21.6	57.893	-4.980	-3.613
Total FRESH WATER					**43.2**	**57.893**	**0.000**	**-3.613**
LUB, OIL								
OIL TANK	35-42	LUB, OIL	98	0.9	37.9	38.607	0.000	-6.172
Total LUB, OIL					**37.9**	**38.607**	**0.000**	**-6.172**
SEA WATER								
AFT MAIN BALLAST TANK	10-16	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	16-21	SEA WATER	62.5	1.025	39.6	18.947	1.791	-4.335
AFT TRIM TANK 02	16-21	SEA WATER	62.5	1.025	39.6	18.947	-1.791	-4.335
COMPENSATING TANK 01	55-58	SEA WATER	20	1.025	2.8	56.609	2.103	-4.930
COMPENSATING TANK 02	55-58	SEA WATER	20	1.025	2.8	56.609	-2.103	-4.930
COMPENSATING TANK 03	58-60	SEA WATER	20	1.025	2.8	59.318	2.103	-4.930
COMPENSATING TANK 04	58-60	SEA WATER	20	1.025	2.8	59.318	-2.103	-4.930
FWD MAIN BALLAST TANK	86-94	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	83-88	SEA WATER	37.5	1.025	23.8	85.106	1.787	-5.188
FWD TRIM TANK 02	83-88	SEA WATER	37.5	1.025	23.8	85.106	-1.787	-5.188

Table 5.136 Summary Table of Loading Condition 3a (100m) (continued…)

TORPEDO TUBE FLOODING TANK	91-94	SEA WATER	98	1.025	27.3	92.150	0.000	-3.369
WATER ROUND TORPEDO TANK	88-91	SEA WATER	98	1.025	27.3	89.370	0.000	-3.369
Total SEA WATER					**192.6**	**57.903**	**0.000**	**-4.306**
BILGE WATER / SLUDGE								
SANITARY TANK 01	48-55	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
SANITARY TANK 02	48-55	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
Total BILGE WATER / SLUDGE					**0.0**	**0.000**	**0.000**	**0.000**
LOx								
Lox TANK	49-54	LOX	98	1.141	68.5	51.547	0.000	-3.389
Total LOx					**68.5**	**51.547**	**0.000**	**-3.389**
LOADING CONDITION 3A FIXED WEIGHTS								
COMPLEMENT					10.9	53.556	0.000	-0.160
OFFICER EQUIPMENT					4.8	53.556	0.000	-0.160
P.O. EQUIPMENT					5.8	53.556	0.000	-0.160
RATING EQUIPMENT					2.3	53.556	0.000	-0.160
GARBAGE					0.0	0.000	0.000	0.000
PROVISIONS					58.0	53.556	0.000	-0.160
TORPEDO					0.0	0.000	0.000	0.000
SPECIAL PERSONNEL & OTHER MILITARY LOADS					0.0	0.000	0.000	0.000
DESIGN MARGIN					95.4	53.556	0.000	-0.160
CONSTRUCTION MARGIN					190.9	53.556	0.000	-0.160
MAINTENANCE MARGIN					95.4	53.556	0.000	-0.160
Loading Condition 3A Fixed Weights					**463.5**	**53.556**	**0.000**	**-0.160**
Lightweight					**9544.3**	**53.556**	**0.000**	**-0.160**
Deadweight					**1311.4**	**52.259**	**0.000**	**-2.669**
Total Displacement					**10855.7**	**53.399**	**0.000**	**-0.463**
Buoyancy					**10855.7**	**53.399**	**0.000**	**0.000**
Total Buoyancy					**10855.7**	**53.399**	**0.000**	**0.000**

Table 5.137 Hydrostatics at Equilibrium Angle (100m)

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim	No trim	metres
KG	-0.463	metres
KB	0.000	metres
FSC	0.015	metres
KGf	-0.448	metres
GMt	0.448	metres
BMt	0.000	metres
BMl	0.000	metres
Waterplane area	0.000	sq.metres
LCG	53.399	metres
LCB	53.399	metres
TCB	0.000	metres
LCF	35.077	metres
TCF	0.000	metres
TPC	0.000	tonnes/cm
MTC	0.503	tonnes-m/cm

Table 5.138 Summary Stability Table (100m)

Displacement [ton]	Δ	10855.7	
Length [m]	L_{DWL}	100.00	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	5.280	12.124
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.463	6.381
Longitudinal Center of Gravity [m]	LCG	53.399	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	0.319	
Maximum Operational Speed of the Submerged Submarine [knot] / [m/sn]	$v_0\uparrow$	22.000	11.317

Table 5.139 Righting – Heeling Lever Calculations (100m)

Heel Angle	**Righting Lever**	**Heeling Lever**			
[°]	h_{SUB}	k_F	kD	$k_F + k_D$	$h_{SW} - (k_F+k_D)$
10	0.0777	0.003	0.008	0.011	0.067
20	0.1527	0.005	0.008	0.013	0.140
30	0.2231	0.008	0.007	0.015	0.208
45	0.3163	0.011	0.006	0.016	0.300

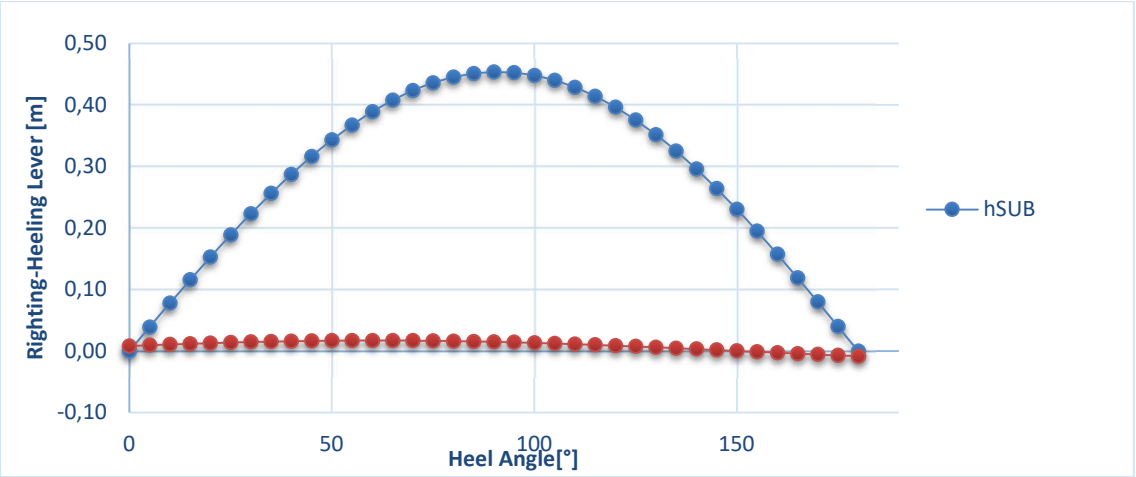

Figure 5.43 Righting – Heeling Lever / Heel Angle (100m)

Table 5.140 Criterion Assessment (100m)

#	Criterion	Actual Value	Critical Value	Result
1	Positive remaining lever h_{rem} at least 0.05 m in dived condition.	0.438	0.050	+
2	Minimum value for BG	0.463	0.350	+

This section focuses on stability analyses specifically related to loading case 3a, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Positive remaining lever h_{rem} is 0.438 m and is above the limit value of 0.05 m.
- The BG value is 0.463 m and is above the limit value of 0.35 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 3a.

5.3.2.2 Loading Condition 3b (100m)

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

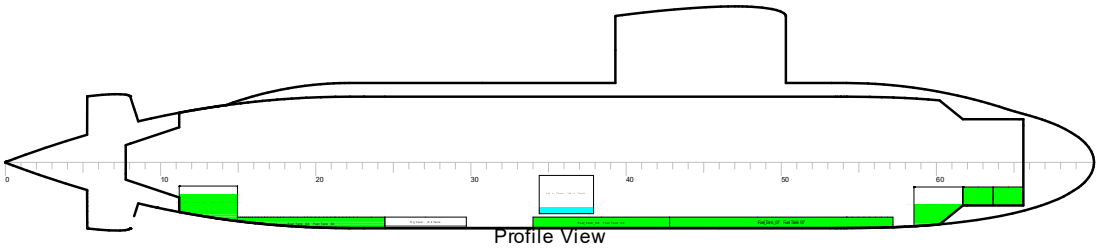

Figure 5.44 Profile View (100m)

Table 5.141 Densities (100m)

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	LUB, OIL	0.9
	BILGE WATER / SLUDGE	1.005
	LOX	1.141
	SEA WATER & DIESEL FUEL	1.005

Table 5.142 Summary Table of Loading Condition 3b (100m)

Stability Calculations for Loading Condition 3B								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	21-35	SEA WATER & DIESEL FUEL	98	1.01	113.0	28.631	5.410	-1.639
FUEL TANK 02	21-35	SEA WATER & DIESEL FUEL	98	1.01	113.0	28.631	-5.410	-1.639
FUEL TANK 03	21-35	SEA WATER & DIESEL FUEL	98	1.01	59.4	29.276	0.000	-6.124
FUEL TANK 04	48-61	SEA WATER & DIESEL FUEL	98	1.01	70.9	54.755	0.000	-6.172
FUEL TANK 05	61-82	SEA WATER & DIESEL FUEL	98	1.01	70.6	71.239	4.978	-3.610
FUEL TANK 06	61-82	SEA WATER & DIESEL FUEL	98	1.01	70.6	71.239	-4.978	-3.610
FUEL TANK 07	61-82	SEA WATER & DIESEL FUEL	98	1.01	115.1	71.218	0.000	-6.170
Total DIESEL FUEL					**612.6**	**49.539**	**0.000**	**-3.904**
FRESH WATER								
FRESH WATER TANK 01	55-61	FRESH WATER	10	1.00	2.2	57.893	4.499	-4.878
FRESH WATER TANK 02	55-61	FRESH WATER	10	1.00	2.2	57.893	-4.499	-4.878
Total FRESH WATER					**4.4**	**57.893**	**0.000**	**-4.878**
LUB, OIL								
OIL TANK	35-42	LUB, OIL	10	0.9	3.9	38.607	0.000	-6.699
Total LUB, OIL					**3.9**	**38.607**	**0.000**	**-6.699**
SEA WATER								
AFT MAIN BALLAST TANK	10-16	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	16-21	SEA WATER	64	1.025	40.5	18.942	1.803	-4.312
AFT TRIM TANK 02	16-21	SEA WATER	64	1.025	40.5	18.942	-1.803	-4.312
COMPENSATING TANK 01	55-58	SEA WATER	80	1.025	11.1	56.609	2.103	-4.200
COMPENSATING TANK 02	55-58	SEA WATER	80	1.025	11.1	56.609	-2.103	-4.200

Table 5.142 Summary Table of Loading Condition 3b (100m) (continued…)

COMPENSATING TANK 03	58-60	SEA WATER	80	1.025	11.1	59.318	2.103	-4.200
COMPENSATING TANK 04	58-60	SEA WATER	80	1.025	11.1	59.318	-2.103	-4.200
FWD MAIN BALLAST TANK	86-94	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	83-88	SEA WATER	36	1.025	22.8	85.093	1.771	-5.221
FWD TRIM TANK 02	83-88	SEA WATER	36	1.025	22.8	85.093	-1.771	-5.221
TORPEDO TUBE FLOODING TANK	91-94	SEA WATER	98	1.025	27.3	92.150	0.000	-3.369
WATER ROUND TORPEDO TANK	88-91	SEA WATER	98	1.025	27.3	89.370	0.000	-3.369
Total SEA WATER					**225.6**	**57.352**	**0.000**	**-4.246**
BILGE WATER / SLUDGE								
SANITARY TANK 01	48-55	BILGE WATER / SLUDGE	90	1.005	19.9	51.618	4.956	-3.697
SANITARY TANK 02	48-55	BILGE WATER / SLUDGE	90	1.005	19.9	51.618	-4.956	-3.697
Total BILGE WATER/SLUDGE					**39.8**	**51.618**	**0.000**	**-3.697**
LOx								
Lox TANK	49-54	LOX	10	1.141	7.0	51.547	0.000	-4.976
Total LOx					**7.0**	**51.547**	**0.000**	**-4.976**
LOADING CONDITION 3B FIXED WEIGHTS								
COMPLEMENT					10.9	53.556	0.000	-0.160
OFFICER EQUIPMENT					4.8	53.556	0.000	-0.160
P.O. EQUIPMENT					5.8	53.556	0.000	-0.160
RATING EQUIPMENT					0.2	53.556	0.000	-0.160
GARBAGE					8.7	53.556	0.000	-0.160
PROVISIONS					5.8	53.556	0.000	-0.160
TORPEDO					0.0	0.000	0.000	0.000
SPECIAL PERSONNEL & OTHER MILITARY LOADS					0.0	0.000	0.000	0.000
DESIGN MARGIN					95.4	53.556	0.000	-0.160
CONSTRUCTION MARGIN					190.9	53.556	0.000	-0.160
MAINTENANCE MARGIN					95.4	53.556	0.000	-0.160
Loading Condition 3B Fixed Weights					**417.9**	**53.556**	**0.000**	**-0.160**
Lightweight					**9544.3**	**53.556**	**0.000**	**-0.160**
Deadweight					**1311.4**	**52.259**	**0.000**	**-2.781**
Total Displacement					**10855.7**	**53.399**	**0.000**	**-0.477**
Buoyancy					**10855.7**	**53.399**	**0.000**	**0.000**
Total Buoyancy					**10855.7**	**53.399**	**0.000**	**0.000**

Table 5.143 Hydrostatics at Equilibrium Angle (100m)

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim	No trim	metres
KG	-0.477	metres
KB	0.000	metres
FSC	0.020	metres
KGf	-0.457	metres
GMt	0.457	metres
BMt	0.000	metres
BMl	0.000	metres
Waterplane area	0.000	sq.metres
LCG	53.399	metres
LCB	53.399	metres
TCB	0.000	metres
LCF	35.077	metres
TCF	0.000	metres
TPC	0.000	tonnes/cm
MTC	0.517	tonnes-m/cm

Table 5.144 Summary Stability Table (100m)

Displacement [ton]	Δ	10855.7	
Length [m]	L_{DWL}	100.00	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	5.280	12.124
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.477	6.367
Longitudinal Center of Gravity [m]	LCG	53.399	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	0.305	
Maximum Operational Speed of the Submerged Submarine [knot] / [m/sn]	$v_0\uparrow$	22.000	11.317

Table 5.145 Righting – Heeling Lever Calculations (100m)

Heel Angle	**Righting Lever**	**Heeling Lever**			
[°]	h_{SUB}	k_F	kD	$k_F + k_D$	$h_{SW} - (k_F+k_D)$
10	0.0793	0.003	0.008	0.011	0.068
20	0.1560	0.007	0.007	0.014	0.142
30	0.2283	0.010	0.007	0.017	0.211
45	0.3240	0.014	0.006	0.020	0.304

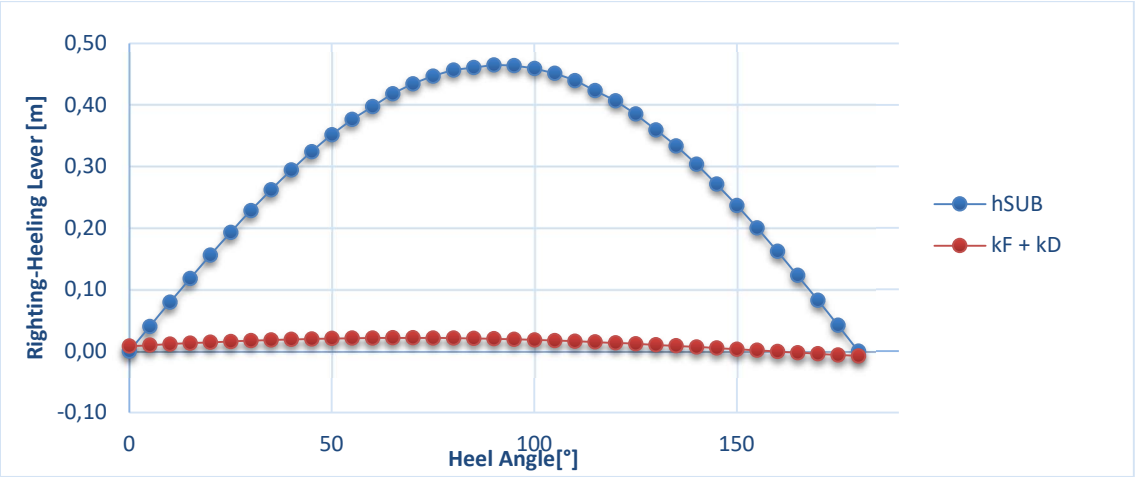

Figure 5.45 Righting – Heeling Lever / Heel Angle (100m)

Table 5.146 Criterion Assessment (100m)

#	Criterion	Actual Value	Critical Value	Result
1	Positive remaining lever h_{rem} at least 0.05 m in dived condition.	0.445	0.050	+
2	Minimum value for BG	0.477	0.350	+

This section focuses on stability analyses specifically related to loading case 3b, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Positive remaining lever h_{rem} is 0.445 m and is above the limit value of 0.05 m.
- The BG value is 0.477 m and is above the limit value of 0.35 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 3b.

5.3.2.3 Loading Condition 4a (100m)

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

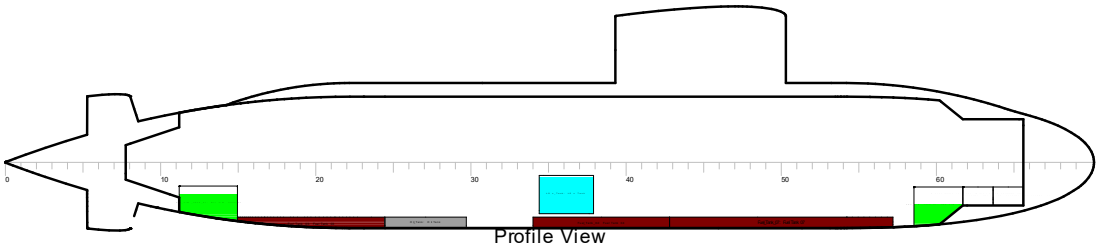

Figure 5.46 Profile View (100m)

Table 5.147 Densities (100m)

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	DIESEL FUEL	0.83
	LUB, OIL	0.9
	LOX	1.141

Table 5.148 Summary Table of Loading Condition 4a (100m)

Stability Calculations for Loading Condition 4A								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	21-35	DIESEL FUEL	98	0.83	93.3	28.631	5.410	-1.639
FUEL TANK 02	21-35	DIESEL FUEL	98	0.83	93.3	28.631	-5.410	-1.639
FUEL TANK 03	21-35	DIESEL FUEL	98	0.83	49.1	29.276	0.000	-6.124
FUEL TANK 04	48-61	DIESEL FUEL	98	0.83	58.6	54.755	0.000	-6.172
FUEL TANK 05	61-82	DIESEL FUEL	98	0.83	58.3	71.239	4.978	-3.610
FUEL TANK 06	61-82	DIESEL FUEL	98	0.83	58.3	71.239	-4.978	-3.610
FUEL TANK 07	61-82	DIESEL FUEL	98	0.83	95.0	71.218	0.000	-6.170
Total DIESEL FUEL					**505.9**	**49.539**	**0.000**	**-3.904**
FRESH WATER								
FRESH WATER TANK 01	55-61	FRESH WATER	98	1.00	21.6	57.893	4.980	-3.613
FRESH WATER TANK 02	55-61	FRESH WATER	98	1.00	21.6	57.893	-4.980	-3.613
Total FRESH WATER					**43.2**	**57.893**	**0.000**	**-3.613**
LUB, OIL								
OIL TANK	35-42	LUB, OIL	98	0.9	37.9	38.607	0.000	-6.172
Total LUB, OIL					**37.9**	**38.607**	**0.000**	**-6.172**
SEA WATER								
AFT MAIN BALLAST TANK	10-16	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	16-21	SEA WATER	62.5	1.025	39.6	18.947	1.791	-4.335
AFT TRIM TANK 02	16-21	SEA WATER	62.5	1.025	39.6	18.947	-1.791	-4.335
COMPENSATING TANK 01	55-58	SEA WATER	10	1.025	1.4	56.609	2.103	-5.089
COMPENSATING TANK 02	55-58	SEA WATER	10	1.025	1.4	56.609	-2.103	-5.089
COMPENSATING TANK 03	58-60	SEA WATER	10	1.025	1.4	59.318	2.103	-5.089
COMPENSATING TANK 04	58-60	SEA WATER	10	1.025	1.4	59.318	-2.103	-5.089
FWD MAIN BALLAST TANK	86-94	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	83-88	SEA WATER	37.5	1.025	23.8	85.106	1.787	-5.188
FWD TRIM TANK 02	83-88	SEA WATER	37.5	1.025	23.8	85.106	-1.787	-5.188

Table 5.148 Summary Table of Loading Condition 4a (100m) (continued…)

TORPEDO TUBE FLOODING TANK	91-94	SEA WATER	0	0	0.0	0.000	0.000	0.000
WATER ROUND TORPEDO TANK	88-91	SEA WATER	0	0	0.0	0.000	0.000	0.000
Total SEA WATER					**45.8**	**31.107**	**0.000**	**-3.277**
BILGE WATER / SLUDGE								
SANITARY TANK 01	48-55	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
SANITARY TANK 02	48-55	BILGE WATER / SLUDGE	0	0	0.0	0.000	0.000	0.000
Total BILGE WATER / SLUDGE					**0.0**	**0.000**	**0.000**	**0.000**
LOx								
Lox TANK	49-54	LOX	98	1.141	68.5	51.547	0.000	-3.389
Total LOx					**68.5**	**51.547**	**0.000**	**-3.389**
LOADING CONDITION 4A FIXED WEIGHTS								
COMPLEMENT					10.9	53.556	0.000	-0.160
OFFICER EQUIPMENT					4.8	53.556	0.000	-0.160
P.O. EQUIPMENT					5.8	53.556	0.000	-0.160
RATING EQUIPMENT					2.3	53.556	0.000	-0.160
GARBAGE					0.0	0.000	0.000	0.000
PROVISIONS					58.0	53.556	0.000	-0.160
TORPEDO					54.5	90.760	0.000	-1.500
SPECIAL PERSONNEL & OTHER MILITARY LOADS					5.6	53.556	0.000	-0.160
DESIGN MARGIN					95.4	53.556	0.000	-0.160
CONSTRUCTION MARGIN					190.9	53.556	0.000	-0.160
MAINTENANCE MARGIN					95.4	53.556	0.000	-0.160
Loading Condition 4A Fixed Weights					**523.6**	**57.428**	**0.000**	**-0.299**
Lightweight					**9544.3**	**53.556**	**0.000**	**-0.160**
Deadweight					**1311.4**	**52.259**	**0.000**	**-2.571**
Total Displacement					**10855.7**	**53.399**	**0.000**	**-0.451**
Buoyancy					**10855.7**	**53.399**	**0.000**	**0.000**
Total Buoyancy					**10855.7**	**53.399**	**0.000**	**0.000**

Table 5.149 Hydrostatics at Equilibrium Angle (100m)

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim	No trim	metres
KG	-0.451	metres
KB	0.000	metres
FSC	0.015	metres
KGf	-0.436	metres
GMt	0.436	metres
BMt	0.000	metres
BMl	0.000	metres
Waterplane area	0.000	sq.metres
LCG	53.399	metres
LCB	53.399	metres
TCB	0.000	metres
LCF	35.077	metres
TCF	0.000	metres
TPC	0.000	tonnes/cm
MTC	0.490	tonnes-m/cm

Table 5.150 Summary Stability Table (100m)

Displacement [ton]	Δ	10855.7	
Length [m]	L_{DWL}	100.00	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	5.280	12.124
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.451	6.393
Longitudinal Center of Gravity [m]	LCG	53.399	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	0.331	
Maximum Operational Speed of the Submerged Submarine [knot] / [m/sn]	$v_0\uparrow$	22.000	11.317

Table 5.151 Righting – Heeling Lever Calculations (100m)

Heel Angle	**Righting Lever**	**Heeling Lever**			
[°]	h_{SUB}	k_F	kD	$k_F + k_D$	$h_{SW} - (k_F+k_D)$
10	0.0757	0.003	0.009	0.011	0.065
20	0.1489	0.005	0.008	0.013	0.136
30	0.2175	0.008	0.007	0.015	0.203
45	0.3082	0.011	0.006	0.017	0.291

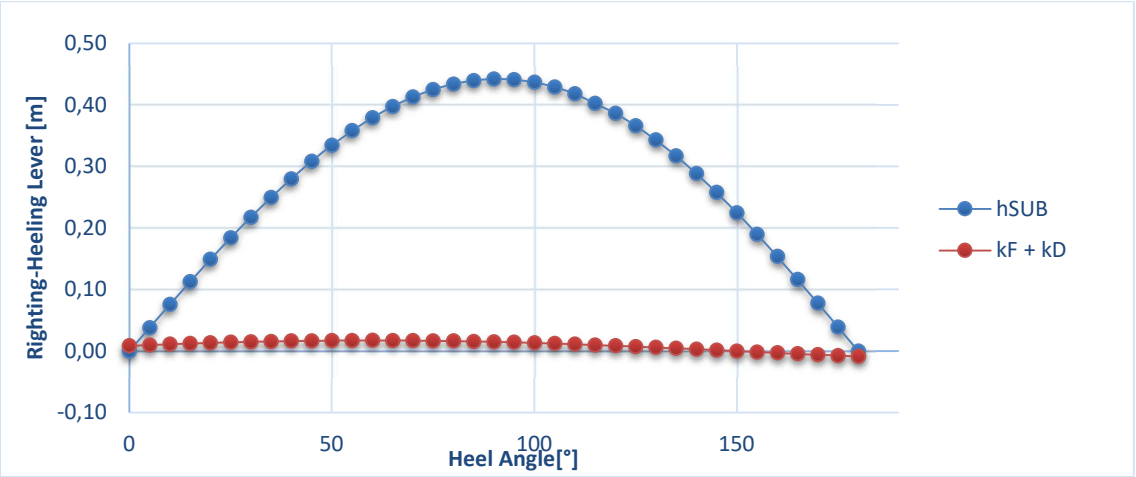

Figure 5.47 Righting – Heeling Lever / Heel Angle (100m)

Table 5.152 Criterion Assessment (100m)

#	Criterion	Actual Value	Critical Value	Result
1	Positive remaining lever h_{rem} at least 0.05 m in dived condition.	0.427	0.050	+
2	Minimum value for BG	0.451	0.350	+

This section focuses on stability analyses specifically related to loading case 4a, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn:

- Positive remaining lever h_{rem} is 0.427 m and is above the limit value of 0.05 m.
- The BG value is 0.451 m and is above the limit value of 0.35 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 4a.

5.3.2.4 Loading Condition 4b (100m)

The following tables provide essential information such as weight items and their center of gravity, drafts, hydrostatics, as well as calculations for righting and heeling moments. Additionally, the stability curve and a table for criterion assessment related to the loading condition are presented below.

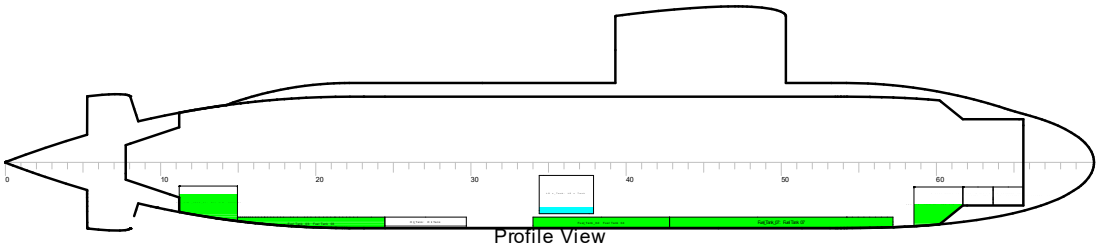

Figure 5.48 Profile View (100m)

Table 5.153 Densities (100m)

Key	Name	Density
		(t/m3)
	SEA WATER	1.025
	FRESH WATER	1
	LUB, OIL	0.9
	BILGE WATER / SLUDGE	1.005
	LOX	1.141
	SEA WATER & DIESEL FUEL	1.005

Table 5.154 Summary Table of Loading Condition 4b (100m)

Stability Calculations for Loading Condition 4B								
Title	Frames	Cargo	% full	SG	Weight	LCG	TCG	VCG
				(t/m3)	(t)	(m)	(m)	(m)
DIESEL FUEL								
FUEL TANK 01	21-35	SEA WATER& DIESEL FUEL	98	1.01	113.0	28.631	5.410	-1.639
FUEL TANK 02	21-35	SEA WATER& DIESEL FUEL	98	1.01	113.0	28.631	-5.410	-1.639
FUEL TANK 03	21-35	SEA WATER& DIESEL FUEL	98	1.01	59.4	29.276	0.000	-6.124
FUEL TANK 04	48-61	SEA WATER& DIESEL FUEL	98	1.01	70.9	54.755	0.000	-6.172
FUEL TANK 05	61-82	SEA WATER& DIESEL FUEL	98	1.01	70.6	71.239	4.978	-3.610
FUEL TANK 06	61-82	SEA WATER& DIESEL FUEL	98	1.01	70.6	71.239	-4.978	-3.610
FUEL TANK 07	61-82	SEA WATER& DIESEL FUEL	98	1.01	115.1	71.218	0.000	-6.170
Total DIESEL FUEL					**612.6**	**49.539**	**0.000**	**-3.904**
FRESH WATER								
FRESH WATER TANK 01	55-61	FRESH WATER	10	1.00	2.2	57.893	4.499	-4.878
FRESH WATER TANK 02	55-61	FRESH WATER	10	1.00	2.2	57.893	-4.499	-4.878
Total FRESH WATER					**4.4**	**57.893**	**0.000**	**-4.878**
LUB, OIL								
OIL TANK	35-42	LUB, OIL	10	0.9	3.9	38.607	0.000	-6.699
Total LUB, OIL					**3.9**	**38.607**	**0.000**	**-6.699**
SEA WATER								
AFT MAIN BALLAST TANK	10-16	SEA WATER	0	0	0.0	0.000	0.000	0.000
AFT TRIM TANK 01	16-21	SEA WATER	64	1.025	40.5	18.942	1.803	-4.312
AFT TRIM TANK 02	16-21	SEA WATER	64	1.025	40.5	18.942	-1.803	-4.312
COMPENSATING TANK 01	55-58	SEA WATER	70	1.025	9.7	56.609	2.103	-4.315
COMPENSATING TANK 02	55-58	SEA WATER	70	1.025	9.7	56.609	-2.103	-4.315

Table 5.154 Summary Table of Loading Condition 4b (100m) (continued...)

COMPENSATING TANK 03	58-60	SEA WATER	70	1.025	9.7	59.318	2.103	-4.315
COMPENSATING TANK 04	58-60	SEA WATER	70	1.025	9.7	59.318	-2.103	-4.315
FWD MAIN BALLAST TANK	86-94	SEA WATER	0	0	0.0	0.000	0.000	0.000
FWD TRIM TANK 01	83-88	SEA WATER	36	1.025	22.8	85.093	1.771	-5.221
FWD TRIM TANK 02	83-88	SEA WATER	36	1.025	22.8	85.093	-1.771	-5.221
TORPEDO TUBE FLOODING TANK	91-94	SEA WATER	0	0	0.0	0.000	0.000	0.000
WATER ROUND TORPEDO TANK	88-91	SEA WATER	0	0	0.0	0.000	0.000	0.000
Total SEA WATER					**165.4**	**46.335**	**0.000**	**-4.563**
BILGE WATER / SLUDGE								
SANITARY TANK 01	48-55	BILGE WATER / SLUDGE	90	1.005	19.9	51.618	4.956	-3.697
SANITARY TANK 02	48-55	BILGE WATER / SLUDGE	90	1.005	19.9	51.618	-4.956	-3.697
Total BILGE WATER/SLUDGE					**39.8**	**51.618**	**0.000**	**-3.697**
LOx								
Lox TANK	49-54	LOX	10	1.141	7.0	51.547	0.000	-4.976
Total LOx					**7.0**	**51.547**	**0.000**	**-4.976**
LOADING CONDITION 4B FIXED WEIGHTS								
COMPLEMENT					10.9	53.556	0.000	-0.160
OFFICER EQUIPMENT					4.8	53.556	0.000	-0.160
P.O. EQUIPMENT					5.8	53.556	0.000	-0.160
RATING EQUIPMENT					0.2	53.556	0.000	-0.160
GARBAGE					8.7	53.556	0.000	-0.160
PROVISIONS					5.8	53.556	0.000	-0.160
TORPEDO					54.5	90.760	0.000	-1.500
SPECIAL PERSONNEL & OTHER MILITARY LOADS					5.6	53.556	0.000	-0.160
DESIGN MARGIN					95.4	53.556	0.000	-0.160
CONSTRUCTION MARGIN					190.9	53.556	0.000	-0.160
MAINTENANCE MARGIN					95.4	53.556	0.000	-0.160
Loading Condition 4B Fixed Weights					**478.0**	**57.798**	**0.000**	**-0.313**
Lightweight					**9544.3**	**53.556**	**0.000**	**-0.160**
Deadweight					**1311.4**	**52.259**	**0.000**	**-2.689**
Total Displacement					**10855.7**	**53.399**	**0.000**	**-0.466**
Buoyancy					**10855.7**	**53.399**	**0.000**	**0.000**
Total Buoyancy					**10855.7**	**53.399**	**0.000**	**0.000**

Table 5.155 Hydrostatics at Equilibrium Angle (100m)

Hydrostatics at equilibrium angle		
Density of water	1.025	tonnes/cu.m
Heel	No heel	degrees
Trim	No trim	metres
KG	-0.466	metres
KB	0.000	metres
FSC	0.020	metres
KGf	-0.446	metres
GMt	0.446	metres
BMt	0.000	metres
BMl	0.000	metres
Waterplane area	0.000	sq.metres
LCG	53.399	metres
LCB	53.399	metres
TCB	0.000	metres
LCF	35.077	metres
TCF	0.000	metres
TPC	0.000	tonnes/cm
MTC	0.505	tonnes-m/cm

Table 5.156 Summary Stability Table (100m)

Displacement [ton]	Δ	10855.7	
Length [m]	L_{DWL}	100.00	
Draught (@LCF) [m] [from Reference Point] / [from Baseline]	T	5.280	12.124
Center of Gravity [m] [from Reference Point] / [from Baseline]	KG	-0.466	6.378
Longitudinal Center of Gravity [m]	LCG	53.399	
Transverse Center of Gravity [m]	TCG	0.000	
Distance between the Centre of Gravity Above Baseline and the Draught [m]	KG-0.5T	0.316	
Maximum Operational Speed of the Submerged Submarine [knot] / [m/sn]	$v_0\uparrow$	22.000	11.317

Table 5.157 Righting – Heeling Lever Calculations (100m)

Heel Angle	**Righting Lever**	**Heeling Lever**			
[°]	h_{SUB}	k_F	kD	$k_F + k_D$	$h_{SW} - (k_F+k_D)$
10	0.0773	0.003	0.008	0.012	0.066
20	0.1521	0.007	0.008	0.015	0.138
30	0.2226	0.010	0.007	0.017	0.205
45	0.3160	0.014	0.006	0.020	0.296

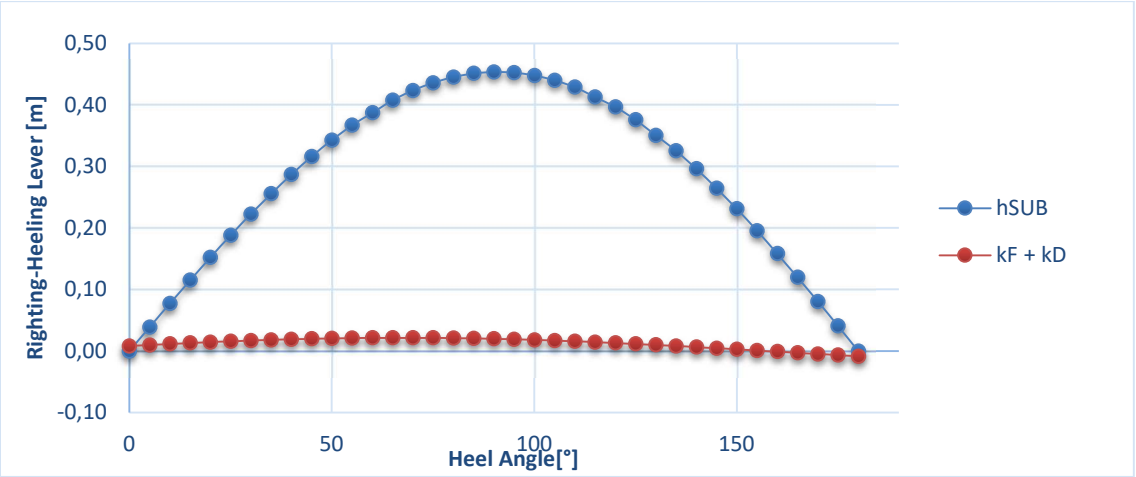

Figure 5.49 Righting – Heeling Lever / Heel Angle (100m)

Table 5.158 Criterion Assessment (100m)

#	Criterion	Actual Value	Critical Value	Result
1	Positive remaining lever h_{rem} at least 0.05 m in dived condition.	0.434	0.050	+
2	Minimum value for BG	0.466	0.350	+

This section focuses on stability analyses specifically related to loading case 4b, which is determined based on the requirements of DNV Rules. Righting and heeling levers were calculated, and an assessment was conducted to determine if the stability criteria were met in this direction. Based on these calculations and assessments, the following conclusions can be drawn

- Positive remaining lever h_{rem} is 0.434 m and is above the limit value of 0.05 m.
- The BG value is 0.466 m and is above the limit value of 0.35 m.

Therefore, it can be concluded that the requirements of DNV Rules are satisfied for load case 4b.

5.3.3 Assessment of Compliance with the Rules (100m)

The following summary table compares the limit values with the values observed in the scenarios, in accordance with the rules.

Table 5.159 Criterion Assessment (100m)

SURFACED							
#	Criterion	Loading Condition				Critical Value	Result
		1A	1B	2A	2B		
		Actual Value					
1	The buoyancy reserve shall be at least 10% of the pressure tight volume of the submarine.	12.3	12.3	12.3	12.3	10.0	+
2	Positive remaining lever h_{rem} at least 0.1 m.	0.439	0.446	0.428	0.434	0.1	+
3	Minimum value for GM	0.447	0.457	0.436	0.446	0.220	+
SUBMERGED							
#	Criterion	Loading Condition				Critical Value	Result
		3A	3B	4A	4B		
		Actual Value					
1	Positive remaining lever h_{rem} at least 0.05 m.	0.438	0.445	0.427	0.434	0.050	+
2	Minimum value for BG	0.463	0.477	0.451	0.466	0.350	+

Table 5.159 demonstrates that intact stability requirements are fulfilled for all loading conditions.

6
RESULTS AND DISCUSSION

In this study, intact and damaged stability analyzes are performed for a generic submarine, BB2 Joubert.

The submarine has a simple general arrangement, which can be found in the open literature. According to the general arrangement of the submarine; press hull design, tank arrangement and tank capacities is determined.

The estimation of weight is conducted based on the submerged state. The maximum weight required for the submarine to reach neutral buoyancy while submerged is determined. Furthermore, the lightweight and center of gravity of the lightship are determined, taking into consideration variables such as tank capacities, required weight margins, and the presence of deadweight items.

The determination of the required reserve buoyancy for the BB2 Joubert Submarine is a fundamental consideration from the outset of the study, and subsequent calculations are conducted accordingly. The capacities of the main ballast tanks are directly correlated with the buoyancy reserve. Thus, the main ballast tanks are designed by considering the surfaced submarine's 10% reserve buoyancy requirement.

Weight variations resulting from fuel, water, provisions, or other consumables have negligible impact on the stability of surface ships, but they hold significant importance for submarines. These weight losses during the seaway must be tolerated. For this, it is crucial to determine the necessary compensating tank capacities during the design phase, taking into consideration the submarine's cruising time and the expected weight loss.

The DNV Rules define the vertical distance (BG) required between the center of gravity and the center of buoyancy of a submerged submarine. In this study, this distance was identified as the limit KG value. Weight and center of gravity calculations were conducted to ensure that the center of gravity of the submerged submarine met the limit KG. Notably, analysis of the results revealed that meeting other criteria specified in the DNV Rules was simplified by adhering to this requirement. Consequently, it can be interpreted that prioritizing the minimum BG value provided in Table 3.2 is crucial when estimating the center of gravity during the preliminary design phase of a submarine.

Stability analyses are conducted using commercial software in accordance with the January 2018 DNV Submarine Rules. The analyses encompass both intact and damaged stability scenarios, focusing on eight distinct loading conditions specified at the designated water density. For surface conditions, four loading conditions (1a, 1b, 2a, 2b) are defined, while four loading conditions (3a, 3b, 4a, 4b) are established for submerged situations. The effects of free liquid surface, turning circle, and wind on the righting lever and heeling levers are carefully accounted for, ensuring the examination of the required remaining righting levers.

During the analysis of damaged stability, particular attention is given to the failure of a significant tank, such as a diving tank, located within the exostructure, in accordance with DNV rules. To evaluate the impact of this damage, both the aft main ballast tank and the fore main ballast tank are independently subjected to damage scenarios for each loading condition. Within this framework, the damaged stability criteria are carefully examined to ensure compliance.

The determination of buoyancy elements plays a crucial role in the analysis of submarine stability. In the surfaced analysis model, the pressure hull and main ballast tanks are considered as contributing elements to the buoyancy. The main ballast tanks are assumed to be empty in this analysis. On the other hand, free flooding areas, which are open to the sea, are excluded from the analysis model as they do not contribute to buoyancy. In the submerged model, as water fills the main ballast tanks and these areas become exposed to the sea, they are not included as buoyant elements like the free flooding areas. Consequently, in the submerged analysis model, only the pressure hull is considered as the buoyant element. With this assumption regarding the main ballast tanks, the weight of the surfaced submarine is considered equal to the weight of the submerged submarine. In the analysis of damaged stability, it is accepted that the aft or fore main ballast tank, whichever is damaged, no longer contributes to buoyancy.

Similar to surface ships, weight margins for submarines should be determined during the design stage, taking into account the potential increase in weight in the future due to factors such as maintenance or repairs. By considering such possibilities, appropriate weight margins can be established to accommodate potential weight changes over time.

The BB2 Joubert submarine used in the calculations has a length of 70.13 m and a depth of 10.6 m. To investigate the stability rules across submarines with varying

displacements, the model is scaled accordingly. Scaled submarine geometries, with lengths of 30 m, 48 m, and 100 m, are created for this purpose. Weight determination studies conducted for the BB2 Joubert are also carried out for the scaled submarines. Additionally, intact stability analyzes are carried out for the same loading conditions.

The critical KG values for the BB2 Joubert Submarine and the scaled models are determined in this study. Consequently, the lightweight and the lightship KG values are calculated accordingly. In Table 6.1, lightship KG, pressure hull diameters (D) and the ratio of these two values are given for each submarine model. Also, displacement values of the submarines and recommended minimum values for GM and BG depending of the displacement in accordance with the DNV rules are given in table 6.1. Figure 6.1 illustrates the relationship between the KG/D ratio and the pressure hull diameter. Furthermore, a formula (6.1) is suggested to estimate the lightship KG/D ratio based on the pressure hull diameter.

Table 6.1 Comparison of Lightship KG and Diameter of Pressure Hull

Submarine	Displacement [ton]	Minimum Required GM According to DNV [m]	Minimum Required BG According to DNV [m]	Lightship KG [m]	Diameter [D] of Pressure Hull [m]	Ratio [KG/D]
30m	295	0.15	0.22	1.893	4.106	0.46
48m	1204	0.20	0.32	3.100	6.570	0.47
BB2 Joubert (70m)	3748	0.22	0.35	4.640	9.600	0.48
100m	10855	0.22	0.35	6.684	13.688	0.49

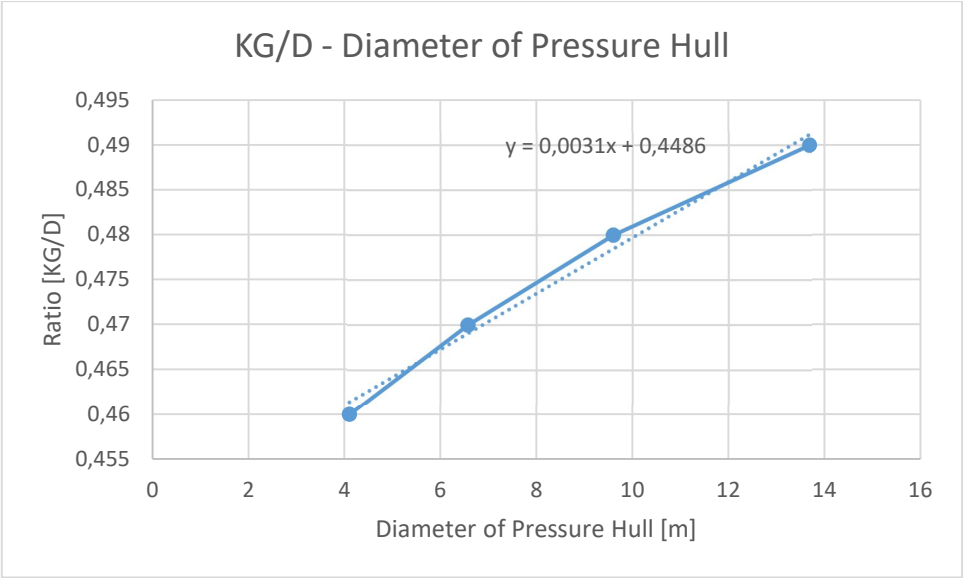

Figure 6.1 KG/D Ratio

$$Ratio\ \frac{KG}{D} = 0.0031D + 0.4486 \tag{6.1}$$

This study gives an insight into the application of the DNV Submarine Stability Rules on a generic submarine model.

REFERENCES

[1] S. Hedberg, “Investigation of submarine roll behaviour,” M.S. thesis, KTH Royal Institute of Technology, Sweden, 2006.

[2] E. Thornhill, G. Hermanski, “Numerical and experimental analysis of surfaced submarine roll decay behaviour,” Journal of Ocean Technology, vol. 3(1), pp. 91-100, 2008.

[3] Y. Liu et al., “Research on the influence of balance weight parameters on the motion performance of the seafloor mapping AUV in vertical plane,” Ocean Eng., vol. 109, pp. 217–225, 2015.

[4] R.H. Vogels, “On the roll damping of surfaced submarines,” M.S. thesis, Delft University of Technology, Delft, 2016.

[5] S. Zhang, H. Li, Y. Pang, Q. Chen, P. Yan, “Experimental investigation on roll stability of blunt-nose submarine in buoyantly rising maneuvers,” Appl. Ocean Res., vol. 81, pp. 34–46, 2018.

[6] A.L. Scott, “Development of longitudinal stability criteria for surfaced submarines through use of near real time modeling,” M.S. thesis, Massachusetts Institute of Technology, Cambridge, 2021.

[7] M.Y. Cansız, B. Yıldız, “Mathematical model of roll decay motion for a surfaced submarine,” GMO Journal of Ship and Marine Technology, no. 219, pp. 107-123, 2021.

[8] W. Büsken, P. Russel, C. Frühling, “Outdoor seakeeping model tests for the development of a safety regulation for submarines of the German Navy,” STG Sprechtag, Lübeck, 2022.

[9] R.K. Burcher, L.J. Rydill, Concepts in submarine design, Cambridge University Press, 1994.

[10] Marine insight,

https://www.marineinsight.com/naval-architecture/understanding-stability-submarine/, 25.05.2021.

[11] United States Navy Training Film,

https://www.youtube.com/watch?v=cir6IoAMpRE, 16.05.2017.

[12] U. Gabler, Submarine design, Bernard & Graefe Verlag, 2000.

[13] DNV, Rules for Classification, Naval Vessels, Part 4 Sub-surface ships, Chapter 1 Submarines. 2018.

[14] Prof. P.N. Joubert, Some aspects of submarine design part 2. shape of a submarine 2026, Defence Science and Technology Organisation, 2006.

[15] Naval engineering education center,
https://www.youtube.com/watch?v=V8aIz2jreA4, 13.05.2014.

[16] Maritime research institute Netherlands,
https://www.marin.nl/en, 30.10.2021.

[17] Building regulations for German naval vessels BV1030-1, Federal Office of Defence Technology and Procurement (BWB), 2001.

[18] Beaufort wind ccale with corresponding sea states codes. https://tyrannosurusrex.wordpress.com/2016/04/08/deniz-durumu-sea-state/, 08.04.2016.

[19] Aveva initial design,
https://www.aveva.com/content/dam/aveva/documents/brochures/Brochure_, 12.03.2023.

PUBLICATIONS FROM THE THESIS

Papers

1. S. Eken, Y. Arıkan Özden, "Intact Stability Assessment of the BB2 Joubert Submarine," GMO Journal of Ship and Marine Technology, no.224, 2024.