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Zihan Wang

The impact of different ice classes on the hull design and steel weight of ROPAX vessels



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The impact of different ice classes on the hull design and steel weight of ROPAX vessels

Ice class is one of the main criteria for vessels operating in cold regions. Ice-classed ships usually have remarkable power output and thicker structures in the ice belt region. This thesis studied the hull steel weight increase caused by different ice classes. This thesis was commissioned by Deltamarin Ltd.

The objective of this thesis was to give an approximate percentage of hull steel weight increase of a Ro-on/Ro-off Passenger vessel between Finnish-Swedish Ice class 1A Super, 1A and 1C. In this thesis, the classification society is set as DNV (Det Norske Veritas), and the vessel follows its rules.

In this thesis, the hull design was assumed to be the same for all ice classes, the only difference is the thicknesses of plates and scantlings of profiles. Which were selected based on the minimum requirement calculated from DNV Rules. The results of this thesis show that Ice Class 1A is 88.22% of Ice Class 1A Super and Ice Class 1C is 62.31% of Ice Class 1A Super in the comparison of the weight of steel structures affected by ice class.

Keywords:

Ropax, Hull steel weight, Ice class, DNV

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Zihan Wang

Eri jääluokkien vaikutukset Ropax aluksen rungon suunnitteluun ja teräs painoon

Jääluokka on yksi tärkeimmistä kriteereistä talvella kylmillä alueilla toimiville aluksille. Jääluokitetuilla aluksilla on yleensä huomattavan suuri teho ja paksummat rakenteet jäävyöhykealueella. Tässä työssä tutkitaan eri jääluokkien aiheuttamaa rungon teräspainon kasvua. Opinnäytetyön toimeksiantaja on Deltamarin Oy.

Tämän opinnäytetyön tarkoituksena on määrittää likimääräinen prosentuaalinen rungon teräspainon lisäys RoPax-aluksen rungon painonlisäys suomalais-ruotsalaisen jääluokan 1A Super, 1A ja 1C välillä. Tässä työssä luokituslaitokseksi on valittu DNV (Det Norske Veritas), ja alus noudattaa sen sääntöjä.

Tässä opinnäytetyössä rungon suunnittelun oletetaan olevan sama kaikissa jääluokissa, ainoa ero on levyjen paksuudet ja profiilien mitoitus. Ne valitaan DNV:n säännöistä laskettujen vähimmäisvaatimusten perusteella. Tässä työssä saadun tuloksen mukaan, kun verrataan jääluokan vaikutuksen kohteena olevien rakenteiden painoa, jääluokka 1A on 88,22 % jääluokan 1A Super painosta ja jääluokka 1C on 62,31 %.

Asiasanat:

Ropax, Rungon teräksen paino, jääluokka, DNV.

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List of abbreviations (or) symbols

Ropax	Roll-on/roll-off passenger
SFICR	Finnish-Swedish Ice Class Rules
RoRo	Roll-on/roll-off
Δ_f	Displacement of the ship, in tonnes, on the maximum ice class draught.
Long.	Longitudinal stiffeners
h_o	Maximum level ice thickness
h	Design ice height
P	Ice pressure
t_c	increment for abrasion and corrosion
R_e	Yield strength
aft fr 219	regions in bow area after frame 219

1 Introduction

1.1 The purpose and implementation plan of this thesis

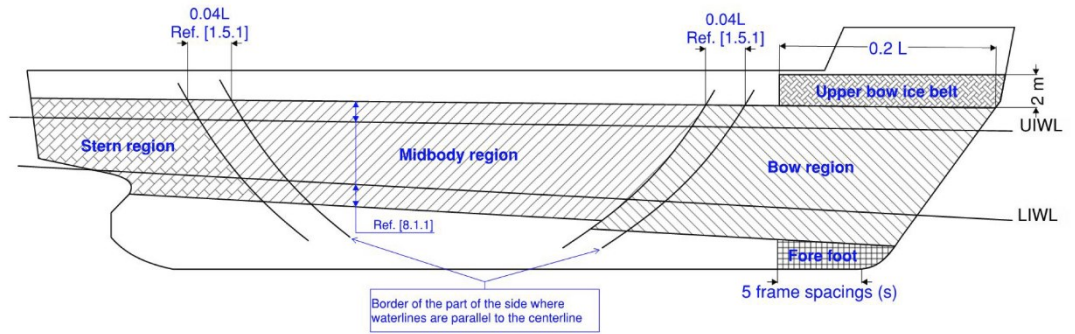
This thesis aims to provide an approximate percentage of hull steel weight change of Ropax vessels between different Finnish-Swedish ice classes. This thesis shall give a general understanding and be beneficial when choosing ice classes for new vessels and when customers want to order a sister ship with a higher or lower ice class.

This thesis is a comparative analysis. Firstly, it will acquire a hull design of an ongoing Ropax vessel project in Deltamarin Ltd (the dimension of affected plates and the length of the affected stiffeners), regardless of the scantling of the structures. For this thesis studying differences between different ice classes, this thesis concerns only the areas of the hatched area in picture 1 and the structures in picture 2 as it's specified in the DNV rules, the table of the vertical extension of ice strengthening of framing, which is shown in picture 3. For simplifying the work, all the structures between the Deck and Tank top are considered. The concerned structures are:

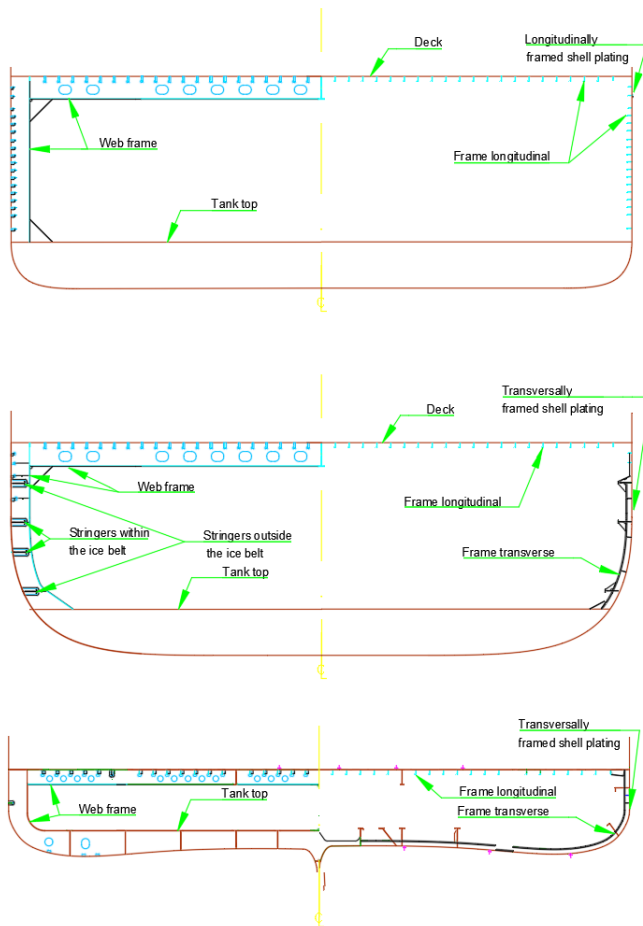
- Longitudinally framed shell plating: The outer shell plating of a vessel, which is welded with longitudinally arranged stiffeners.
- Transversally framed shell plating: The outer shell plating of a vessel, which is welded with transversally arranged stiffeners.
- Frame transverse: Transversally arranged stiffener.
- Frame longitudinal: Longitudinally arranged stiffener.
- Ice stringer: Longitudinally arranged T-beam. Which is usually designed for transferring ice loads.
- Web frame: transversally arranged T-beam.

Secondly, this thesis will calculate the required structure scantling for 1A super, 1A and 1C classed vessels based on DNV rules, and selections will be made based on the calculated requirements. After this, the weight of ice class affected

structures will be calculated, and a conclusion will then be carried out.



Picture 1. Ice belt regions. (DET NORSKE VERITAS AS, 2022a, p.30.)



Picture 2. Structures in concern of this thesis.

<i>Ice class</i>	<i>Region</i>	<i>Above UIWL [m]</i>	<i>Below LIWL [m]</i>
Ice(1A*F), Ice(1A*)	Bow	1.2	to double bottom or below top of floors
	Midbody		2.0
	Stern		1.6
Ice(1A), (1B), (1C)	Bow	1.0	1.6
	Midship		1.3
	Stern		1.0

Picture 3. The vertical extension of ice strengthening of the framing. (DET NORSE VERITAS AS, 2022a, p.40.)

1.2 Deltamarin

Deltamarin is a group founded in 1990, which provides ship design, offshore engineering, and construction support services, with references back to 1984. The group is headquartered in Turku and has offices in Helsinki and Rauma, subsidiaries in China and Poland, and an associated company in Croatia. (Deltamarin intranet, 2022).

Deltamarin's parent company is Wing Hing Ship Investment Ltd (earlier name: AVIC International Maritime Holdings Limited), which is part of the China Merchants Group. It owns 79.57% of the company. The remaining 20.43% is controlled by DM Holding Ltd which is owned by the active management. (Deltamarin intranet, 2022.)

In December 2018, the group had 336 employees worldwide. Two hundred thirty-six of these employees work in Finland. The managing director of the group is Mr. Janne Uotila. The company's turnover is EUR 42.6 million. (Deltamarin intranet, 2022.)

2 General descriptions

2.1 Roll on/Roll off passenger vessels (Ropax)

A Ropax is a vessel with a large roll-on roll-off deck and limited passenger facilities. Typically, the superstructure covers part of the upper deck. The vessel's design usually allows drive-in traffic, i.e., loading at the stern and unloading at the front or vice versa. The internal distribution of vehicles can be accomplished by deploying internal ramps or loading on both decks via two shore ramps. To increase flexibility, Ropax vessels are often equipped with liftable car decks. (Wärtsilä, 2022)

A Ropax vessel is shown in picture 4.



Picture 4. Example of Ropax vessel (Deltamain, 2022)

2.2 Finnish-Swedish Ice Class Rules (FSICR)

The Finnish and Swedish authorities developed the Finnish-Swedish Ice Class Rules (FSICR) based on accumulated experience and extensive research. The rules aim to ensure that ships trading in the northern Baltic Sea have sufficient ice capacity to maintain safe and efficient navigation to Finnish and Swedish ports throughout the year. The channel fees paid by ships and the availability of icebreaker escorts are determined according to the ice class of the ship. (TRAFICOM, 2022.)

The Ice Class is assigned to vessels operating in the first year ice in the Baltic Sea and calling at Finnish or Swedish ports. The rules are based on regulations issued by the Finnish Transport and Communications Agency (Traficom) and the Swedish Maritime Authority and are divided into six ice classes based on the requirements for hull structural design, engine output and performance in ice.

The ice classes in concern of this thesis are 1A Super, 1A and 1C, they are defined as follows:

Ice class 1A Super: Ships with such a structure, engine output and other properties that they are normally capable of navigating in difficult ice conditions without the assistance of icebreakers. (TRAFICOM, 2021, p.6)

Ice class 1A: Ships with such a structure, engine output and other properties that they are capable of navigating in difficult ice conditions, with the assistance of icebreakers when necessary. (TRAFICOM, 2021, p.6)

Ice class 1C: Ships with such a structure, engine output and other properties that they are capable of navigating in light ice conditions, with the assistance of icebreakers when necessary. (TRAFICOM, 2021, p.6)

2.3 Icebreaking

The ice pressure on the hull varies in the different hull regions. The highest loads are experienced in the bow region, while the lowest loads are experienced in the bottom region of the ship. (Government of Canada, 2019.)

An ice-going ship's structural design and arrangement must withstand both global and local loads. For high-ice class ships, e.g., arctic icebreakers, the most common global consideration is a hull beam with adequate section modulus. Still, a higher section modulus is not necessarily required for low-ice class ships, such as FSICR class ships, because the bending stresses experienced in routine operations are not considered to exceed those in heavy seas. The local structure must be able to resist failure caused by bending, shear, buckling and tripping. Ships of lower ice classes should never be used on ice with the bow raised to break the ice with the ship's weight, as is the case with icebreakers. However, a ballasted ship trimmed too far aft may find an ice floe stuck under the bow some distance from the bow. If a heavy ice floe is forced against the ship's bottom plate, the ship's bottom plate is usually lighter than the plate in the ice belt and can easily cause damage to the ship's bottom. Recognizing that frame buckling and tripping are critical failure modes, simpler structural arrangements have been developed. This arrangement typically has the steel plates between the two decks supported by a large main frame with greater spacing than in conventional arrangements. It is based on the assumption that the strength of the shell-plating membrane can also be included in the strength calculations. The frames are designed for bending, buckling and tripping, which results in heavier frames and eliminates the need for stringers. The resulting structural arrangement has thinner plates and a larger main frame but very few components and connections, which is easier to build and has lower construction costs. (Government of Canada, 2019.)

The integrity of the structure requires the correct selection of hull materials. The two main types of steel used for ship construction are normal strength and high-strength steel (meaning their minimum yield strength). Within these two

categories, several grades of steel are assigned according to their chemical composition and other mechanical properties (Government of Canada, 2019.)

The critical factor associated with the properties of steel in ice-classed vessels (Arctic ships) is resistance to brittle fracture at low temperatures and under high loading conditions, which is typical for operation in ice. At low temperatures, ductility and fracture toughness decrease; the steel becomes brittle, increasing the likelihood of catastrophic brittle fracture. Such fractures are more frequent above the waterline, as the steel is exposed to very low air temperatures. (Government of Canada, 2019.)

2.4 Shipbuilding steel

Shipbuilding steel plates are carbon and alloy steel plates used in offshore and marine construction. Common grades include A, B, D, E, AH32/36/40, DH32/36/40 and EH32/36/40, which vary in strength. These steel plates are commonly used to manufacture hulls, bulkheads, upper decks and hatch covers for tankers, bulk carriers, container ships and LNG carriers. (Octal Metals, 2019.)

For high strength shipbuilding plates, such as AH36, DH36, and EH36 steel plates, they have been widely used in high-stress areas of ships, providing the same strength at a smaller thickness compared to normal-strength steels. (Octal Metals, 2019.)

Picture 5 is a chart of the mechanical properties of different steel grades.

Mechanical Properties							
Steel Grade	Thickness/ mm	Yield point/ MPa	Tensile strength/ MPa	Elongation/ %	V-type impact test		
					Temperatu re/ °C	Average impact absorption work A_{kv} /J	
						Vertical	Horizontal
A	≤50	≥235	400~490	≥22	-	-	-
B	≤50	≥235	400~490	≥22	0	≥27	≥20
D	≤50	≥235	400~490	≥22	-10	≥27	≥20
E	≤50	≥235	400~490	≥22	-40	≥27	≥20
AH32	≤50	≥315	440~590	≥22	0	≥31	≥22
DH32	≤50	≥315	440~590	≥22	-20	≥31	≥22
EH32	≤50	≥315	440~590	≥22	-40	≥31	≥22
AH36	≤50	≥355	490~620	≥22	0	≥34	≥24
DH36	≤50	≥355	490~620	≥22	-20	≥34	≥24
EH36	≤50	≥355	490~620	≥22	-40	≥34	≥24

Picture 5. Mechanical properties of different grades of steel. (Octal Metals, 2019.)

2.5 The basic information about the ship

The ship discussed in this thesis is based on an ongoing project in Deltamarin Ltd and is described in table 1:

Table 1. Basic information about the ship

LOA	203 m
Lpp	190 m
B	27.8 m
T	6.6 m
Δ_f	23 527 tonnes

Machinery Output (P_s)	2 ×13 740 kW
Class	DNV
Rules	DNV Rules 2022
Span of ice stringer	2.521 m
	2.678 m (aft fr 219, only for the upper stringer outside of the ice belt)
Frame spacing	0.8 m (before frame 219)
	0.6 m (after frame 219)
Web frame spacing	2.52 m (before frame 219)
	1.8 m (after frame 219)
Span of frame	2.52 m

The hull design is assumed to be the same, and the only difference is the thickness of the concerned plates and the scantling of stiffeners for different ice classes. In this thesis, all steel material is assumed to be high-strength steel with 355 MPa yield strength. For the density of all steel grades with 355 MPa yield strength is identical, therefore this thesis shall not further discuss the steel grade for different hull parts. The ice class relative plate area and stiffener length are shown in table 2.

Table 2. Ice class relative plate area and stiffener length

Web plate area	
Stern region	352.17 m ²
Midbody region	996.20 m ²
Bow region	934.57 m ²
Aft fr 219	120
Forefoot (1A Super & 1A)	137.14 m ²
Upper bow region (1A Super)	32.26 m ²
Shell plate	7 668.83 m ²
Stringer plate area	

Within ice stringer	426.15 m ²
Outside ice stringer upper	410 m ²
Outside ice stringer lower	390 m ²
Shell plate area	
Aft fr 219	76.33 m ²
Bow	756.97 m ²
Midbody	680.88 m ²
Stern	427,58 m ²
Upper bow region before fr 219	83.28 m ²
Upper bow region after fr 219	25.37 m ²
Forefoot before fr 219	26.43 m ²
Forefoot after fr 219	15.66 m ²
Stiffener length	
Stern	1 292.65 m
Midbody/Stern overlap	37.34 m
Midbody	3 799.71 m
Midbody/bow overlap	30.07 m
Bow	7 242.70 m
Aft fr 219	990.31 m

3 Scantlings

This section will calculate the required net plate thickness and stiffener size based on DNV-RU-SHIP Pt.6 Ch.6 Sc.3 and select plate thicknesses and stiffeners based on the requirements. As specified in the DNV rules, the level ice thickness and design ice height are shown in table 3.

Table 3. Value of the maximum level ice thickness h_0 and design ice height h . (DET NORSKE VERITAS AS, 2022a, p.36.)

Ice Class	h_0	h
1A Super	1	0.35
1A	0.8	0.3
1C	0.4	0.22

3.1 Ice pressure

The design ice pressure, in kN/m^2 , is determined by equation 1

$$P = 5600 * c_d * c_1 * c_a$$

Equation 1. Ice pressure. (DET NORSKE VERITAS AS, 2022a, p.36.)

Where:

$$c_d = \frac{a_1 * k_1 + b_1}{1000}$$

$$k_1 = \frac{\sqrt{\Delta_f P_S}}{1000}$$

$$c_a = \sqrt{\frac{l_0}{l_a}}, \text{maximum } 1.0, \text{minimum } 0.35, l_0 = 0.6$$

c_1 can be find in table 4.

l_a can be find in table 5.

Table 4 Value of c_1 . (DET NORSKE VERITAS AS, 2022a, p.37.)

Ice class	Region		
	Bow	Midbody	Stern
Ice 1A super	1	1	0.75
Ice 1A	1	0.85	0.65
Ice 1C	1	0.5	0.25

Table 5 Value of l_a . (DET NORSKE VERITAS AS, 2022a, p.38.)

Structure	Type of framing	l_a
Shell	Transverse	Frame spacing
	Longitudinal	1.7 * Frame spacing
Frame	Transverse	Frame spacing
	Longitudinal	Span of frame
Ice stringer		Span of stringer
Web frame		2 * web frame spacing

The ice pressures for different structures at different areas are calculated in table 6 for ice class 1A Super, table 7 for ice class 1A, table 8 for ice class 1C.

Table 6 Ice pressure calculation for ice class 1A Super

	Shell trans	Shell longi	Frame trans	Frame Longi	Ice stringer	Web frame
c(d)(bow)	0.67	0.67	0.67	0.67	0.67	0.67
c(d)(mid&stern)	0.34	0.34	0.34	0.34	0.34	0.34
a(1)(bow)	6.00	6.00	6.00	6.00	6.00	6.00
a(1)(mid&stern)	2.00	2.00	2.00	2.00	2.00	2.00
k(1)	25.43	25.43	25.43	25.43	25.43	25.43
b(1)(bow)	518.00	518.00	518.00	518.00	518.00	518.00
b(1)(mid&stern)	286.00	286.00	286.00	286.00	286.00	286.00
c(1)(bow)	1.00	1.00	1.00	1.00	1.00	1.00
c(1)(mid)	1.00	1.00	1.00	1.00	1.00	1.00
c(1)(stern)	0.75	0.75	0.75	0.75	0.75	0.75
c(a)	1.00	0.77	1.00	0.49	0.49	0.41
c(a)(aft fr 219)	0.85	0.65	0.85	0.49	0.49	0.35
l(0)	0.60	0.60	0.60	0.60	0.60	0.60
l(a)	0.60	1.02	0.60	2.52	2.52	3.60
l(a)(aft fr 219)	0.84	1.43	0.84	2.52	2.52	5.04
P(bow)	3 755.14	2 880.06	3 755.14	1 832.32	1 831.96	1 533.03
P(b)(aft fr 219)	3 173.67	2 434.10	3 173.67	1 832.32	1 831.96	1 295.65
P(mid)	1 886.38	1 446.79	1 886.38	920.46	920.28	770.11
P(stern)	1 414.79	1 085.09	1 414.79	690.34	690.21	577.58

Table 7 Ice pressure calculation for ice class 1A

	Shell trans	Shell longi	Frame trans	Frame Longi	Ice stringer	Web frame
c(d)(bow)	0.67	0.67	0.67	0.67	0.67	0.67
c(d)(mid&stern)	0.34	0.34	0.34	0.34	0.34	0.34
a(1)(bow)	6.00	6.00	6.00	6.00	6.00	6.00
a(1)(mid&stern)	2.00	2.00	2.00	2.00	2.00	2.00
k(1)	25.43	25.43	25.43	25.43	25.43	25.43
b(1)(bow)	518.00	518.00	518.00	518.00	518.00	518.00
b(1)(mid&stern)	286.00	286.00	286.00	286.00	286.00	286.00
c(1)(bow)	1.00	1.00	1.00	1.00	1.00	1.00
c(1)(mid)	0.85	0.85	0.85	0.85	0.85	0.85
c(1)(stern)	0.65	0.65	0.65	0.65	0.65	0.65
c(a)	1.00	0.77	1.00	0.49	0.49	0.41
c(a)(aft fr 219)	0.85	0.65	0.85	0.49	0.49	0.35
l(0)	0.60	0.60	0.60	0.60	0.60	0.60
l(a)	0.60	1.02	0.60	2.52	2.52	3.60
l(a)(aft fr 219)	0.84	1.43	0.84	2.52	2.52	5.04
P(bow)	3 755.14	2 880.06	3 755.14	1 832.32	1 831.96	1 533.03
P(b)(aft fr 219)	3 173.67	2 434.10	3 173.67	1 832.32	1 831.96	1 295.65
P(mid)	1 603.42	1 229.77	1 603.42	782.39	782.24	654.59
P(stern)	1 226.15	940.41	1 226.15	598.30	598.18	500.57

Table 8 Ice pressure calculation for ice class 1C

	Shell trans	Shell longi	Frame trans	Frame Longi	Ice stringer	Web frame
c(d)(bow)	0.67	0.67	0.67	0.67	0.67	0.67
c(d)(mid&stren)	0.34	0.34	0.34	0.34	0.34	0.34
a(1)(bow)	6.00	6.00	6.00	6.00	6.00	6.00
a(1)(mid&stern)	2.00	2.00	2.00	2.00	2.00	2.00
k(1)	25.43	25.43	25.43	25.43	25.43	25.43
b(1)(bow)	518.00	518.00	518.00	518.00	518.00	518.00
b(1)(mid&stern)	286.00	286.00	286.00	286.00	286.00	286.00
c(1)(bow)	1.00	1.00	1.00	1.00	1.00	1.00
c(1)(mid)	0.50	0.50	0.50	0.50	0.50	0.50
c(1)(stern)	0.25	0.25	0.25	0.25	0.25	0.25
c(a)	1.00	0.77	1.00	0.49	0.49	0.41
c(a)(aft fr 219)	0.85	0.65	0.85	0.49	0.49	0.35
l(0)	0.60	0.60	0.60	0.60	0.60	0.60
l(a)	0.60	1.02	0.60	2.52	2.52	3.60
l(a)(aft fr 219)	0.84	1.43	0.84	2.52	2.52	5.04
P(bow)	3 755.14	2 880.06	3 755.14	1 832.32	1 831.96	1 533.03
P(b)(aft fr 219)	3 173.67	2 434.10	3 173.67	1 832.32	1 831.96	1 295.65
P(mid)	943.19	723.39	943.19	460.23	460.14	385.06
P(stern)	471.60	361.70	471.60	230.11	230.07	192.53

3.2 Shell plating

For longitudinal framing the thickness of shell plating, in mm, is determined by equation 2:

$$t = 21.1 * s_1 \sqrt{\frac{f_1 * P_{PL}}{R_{eH}}} + t_c$$

Equation 2. Shell plating thickness for longitudinal framing. (DET NORSKE VERITAS AS, 2022a, p.39.)

For transverse framing the thickness of shell plating, in mm, is determined by equation 3:

$$t = 21.1 * s_1 \sqrt{\frac{P}{f_2 * R_{eH}}} + t_c$$

Equation 3. Shell plating thickness for transverse framing. (DET NORSKE VERITAS AS, 2022a, p.39.)

Where:

$$P_{PL} = 0.75P$$

s_1 = ordinary stiffener spacing = 0.8 m

$$f_1 = 1.3 - \frac{4.2}{\left(\frac{h}{s_1 + 1.8}\right)^2}, \text{ maximum } 1.0$$

$$f_2 = 0.6 + \frac{0.4}{\frac{h}{s_1}}, \text{ when } \frac{h}{s_1} \leq 1$$

$$1.4 - 0.4 \left(\frac{h}{s_1}\right), \text{ when } 1 \leq \frac{h}{s_1} \leq 1.8$$

$$T_c = 2 \text{ mm}$$

$$R_e = 355 \text{ MPa}$$

3.2.1 1A Super

Required shell plate net thickness on transverse framing area for ice class 1A Super is calculated in table 9.

Table 9. Required shell plating net thickness for ice class 1A Super on transverse framing area

	aft fr 219	bow	mid	stern
f(1)	0.46	0.46	0.46	0.46
s(1)	0.80	0.80	0.80	0.80
h	0.35	0.35	0.35	0.35
R(eH)	355.00	355.00	355.00	355.00
t(c)	2.00	2.00	2.00	2.00
P(PL)	2 816.36	2 380.25	1 414.79	1 061.09
P	3 755.14	3 173.67	1 886.38	1 414.79
t (calculated)	34.28	31.68	24.88	21.81

Required shell plate thickness on longitudinal framing area for ice class 1A Super is calculated in table 10.

Table 10. Required shell plating thickness for ice class 1A Super on longitudinal framing area

	aft fr 219	bow	mid	stern
f(2)	1.51	1.51	1.51	1.51
s(1)	0.80	0.80	0.80	0.80
h	0.35	0.35	0.35	0.35
R(eH)	355.00	355.00	355.00	355.00
t(c)	2.00	2.00	2.00	2.00
P	2 880.06	2 434.10	1 446.79	1 085.09
t (calculated)	41.07	37.92	29.69	25.98

Selected shell plating thickness for ice class 1A Super is shown in table 11.

Table 11. Selected shell plating thickness for ice class 1A Super

	aft fr 219 (transverse framing)	Bow (transverse framing)	Mid (longitudinal framing)	Stern (transverse framing)
t (mm)	35	32	30	22

3.2.2 1A

Shell plate thickness on transverse framing area for ice class 1A is calculated in table 12.

Table 12 Shell plating thickness for ice class 1A on transverse framing area

	aft fr 219	bow	mid	stern
f(1)	0.41	0.41	0.41	0.41
s(1)	0.80	0.80	0.80	0.80
h	0.30	0.30	0.30	0.30
R(eH)	355.00	355.00	355.00	355.00
t(c)	2.00	2.00	2.00	2.00
P(PL)	2 816.36	2 380.25	1 202.57	919.61
P	3 755.14	3 173.67	1 603.42	1 226.15
t (calculated)	32.52	30.06	21.94	19.44

Shell plate thickness on longitudinal framing area for ice class 1A is calculated in table 13.

Table 13 Shell plating thickness for ice class 1A on longitudinal framing area

	aft fr 219	bow	mid	stern
f(2)	1.67	1.67	1.67	1.67
s(1)	0.80	0.80	0.80	0.80
h	0.30	0.30	0.30	0.30
R(eH)	355.00	355.00	355.00	355.00
t(c)	2.00	2.00	2.00	2.00
P	2 880.06	2 434.10	1 229.77	940.41
t (calculated)	39.24	36.23	26.33	23.28

The selected shell plate thickness for ice class 1A is shown in table 14.

Table 14 The selected shell plate thickness for ice class 1A

	aft fr 219 (transverse framing)	Bow (transverse framing)	Mid (longitudinal framing)	Stern (transverse framing)
t (mm)	33	32	28	20

3.2.3 1C

Shell plate thickness on transverse framing area for ice class 1C is calculated in table 15.

Table 15 Shell plating thickness for ice class 1C on transverse framing area

	aft fr 219	bow	mid	stern
f(1)	0.33	0.33	0.33	0.33
s(1)	0.80	0.80	0.80	0.80
h	0.22	0.22	0.22	0.22
R(eH)	355.00	355.00	355.00	355.00
t(c)	2.00	2.00	2.00	2.00
P(PL)	2 816.36	2 380.25	707.39	353.70
P	3 755.14	3 173.67	943.19	471.60
t (calculated)	29.10	26.92	15.58	11.61

Shell plate thickness on longitudinal framing area for ice class 1C is calculated in table 16.

Table 16 Shell plating thickness for ice class 1C on longitudinal framing area

	aft fr 219	bow	mid	stern
f(2)	2.06	2.06	2.06	2.06
s(1)	0.80	0.80	0.80	0.80
h	0.22	0.22	0.22	0.22
R(eH)	355.00	355.00	355.00	355.00
t(c)	2.00	2.00	2.00	2.00
P	2 880.06	2 434.10	723.39	361.70
t (calculated)	35.54	32.83	18.81	13.89

The selected shell plate thickness for ice class 1C is shown in table 17.

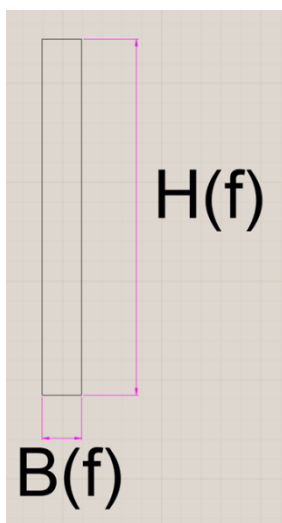
Table 17 The selected shell plate thickness for ice class 1C

	aft fr 219 (transverse framing)	Bow (transverse framing)	Mid (longitudinal framing)	Stern (transverse framing)
t (mm)	30	28	20	12

3.3 Frame transverse

The object of this thesis is a comparison of hull steel weights between different ice classes. Flat bars shall be used along the ship regardless of the ice class. To determine the profile's scantling, the gross section modulus requirement and the effective gross shear area requirement need to be calculated. Gross section modulus is the moment of inertia of the cross-section of the member being bent around its neutral axis divided by the distance from the neutral axis to the outermost edge of the section. It can be used to calculate the magnitude of the positive stress in the bending of the section. When calculating the attended section modulus for flat bars, the attached plate is considered as a flange, which makes flat bars into T-bars, and the attached plate shall be taken into account. The dimension of the flat bars is defined in picture 5.

Picture 6. Dimensions of flat bar



The gross section modulus of a main or intermediate transverse frame, in cm^3 , shall be calculated by equation 4:

$$Z_{gr} = \frac{P * s_1 * h * l_{bdg}}{m_t * R_{eH}} * 10^3$$

Equation 4. Gross section modulus for frame transverse. (DET NORSKE VERITAS AS, 2022a, p.41.)

and the effective gross shear area, in cm², is calculated from equation 5:

$$A_{gr} = \frac{8.7 * f_3 * P * h * s_1}{R_{eH}}$$

Equation 5. Effective gross shear area for frame transverse. (DET NORSKE VERITAS AS, 2022a, p.41.)

Where:

s_1 = ordinary stiffener spacing = 0.8 m

$$m_t = \frac{7m_o}{7 - \frac{5h}{l_{bdg}}}$$

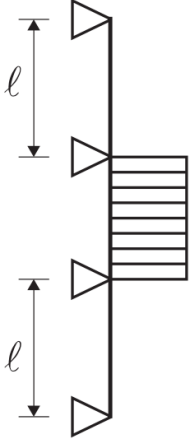
$f_3 = 1.2$

the value of l_{bdg} is defined in table 18.

Table 18 Value of $l(bdg)$

	Stern	Midbody	Bow	Aft fr 219
Span of frame	2.45	2.35	2.8	1.4

$m_o = 5.7$ (the vessel is assumed to have such boundary condition as shown in picture 5.)

Boundary condition	m_o	Example
	5.7	Continuous frames between several decks or stringers

Picture 7 Value of $m(o)$. (DET NORSKE VERITAS AS, 2022a, p.43.)

The effective breadth B_s , in mm, of the attached plating to be considered in the actual net section modulus for the yielding check of stiffeners shall be obtained from equation 6:

Where the plating extends on both sides of the stiffener:

$$B_a = 200 * l, \text{ or}$$

$$B_a = s$$

Equation 6. The effective breadth of the attached plating in calculations for profiles. (DET NORSKE VERITAS AS, 2022b, p.70.)

$$l = l_{bdg}$$

s = frame spacing

Table 19 Gross section modulus of transverse frame for ice class 1A Super

	aft fr 219	Bow	Midbody	stern
P	3 755.14	3 173.67	1 886.38	1 414.79
s(1)	0.80	0.80	0.80	0.80
h	0.35	0.35	0.35	0.35
l(bdg)	1.40	2.80	2.35	2.45
R(eH)	355.00	355.00	355.00	355.00
m(t)	6.94	6.26	6.38	6.35
m(o)	5.70	5.70	5.70	5.70
Z(gr)	597.56	1 119.84	548.15	430.69
f(3)	1.20	1.20	1.20	1.20
A(gr)	30.92	26.13	15.53	11.65
B(f)	1.00	1.00	1.00	1.00
H(f)	32.00	28.00	18.00	12.00
B(s)	60.00	80.00	80.00	80.00
H(s)	3.50	3.20	3.00	2.20
l	1.40	2.80	2.35	2.45
s	0.60	0.80	0.80	0.80
A(f)	32.00	28.00	18.00	12.00
Z(a)	2 854.18	2 609.94	1 125.19	503.03
l(x)	11 693.88	8 190.06	2 512.05	781.29
Y(c)	4.10	3.14	2.23	1.55

Table 20 Gross section modulus of transverse frame for ice class 1A

	aft fr 219	Bow	Midbody	stern
P	3 755.14	3 173.67	1 603.42	1 226.15
s(1)	0.80	0.80	0.80	0.80
h	0.30	0.30	0.30	0.30
l(bdg)	1.40	2.80	2.35	2.45
R(eH)	355.00	355.00	355.00	355.00
m(t)	6.73	6.17	6.27	6.25
m(o)	5.70	5.70	5.70	5.70
Z(gr)	528.10	973.31	406.16	325.14
f(3)	1.20	1.20	1.20	1.20
P	3 755.14	3 173.67	1 603.42	1 226.15
h	0.30	0.30	0.30	0.30
s(1)	0.80	0.80	0.80	0.80
R(eH)	355.00	355.00	355.00	355.00
A(gr)	26.50	22.40	11.32	8.65
B(f)	1.00	1.00	1.00	1.00
H(f)	28.00	24.00	12.00	10.00
B(s)	60.00	80.00	80.00	80.00
H(s)	3.50	3.20	3.00	2.20
l	1.40	2.80	2.35	2.45
s	0.60	0.80	0.80	0.80
A(f)	28.00	24.00	12.00	10.00
Z(a)	2 268.23	1 962.97	520.62	354.64
l(x)	8 172.31	5 429.00	966.86	506.41
Y(c)	3.60	2.77	1.86	1.43

Table 21 Gross section modulus of transverse frame for ice class 1C

	aft fr 219	Bow	Midbody	stern
P	3 755.14	3 173.67	943.19	471.60
s(1)	0.80	0.80	0.80	0.80
h	0.22	0.22	0.22	0.22
l(bdg)	1.40	2.80	2.35	2.45
R(eH)	355.00	355.00	355.00	355.00
m(t)	6.42	6.04	6.11	6.09
m(o)	5.70	5.70	5.70	5.70
Z(gr)	405.94	729.53	179.89	94.05
f(3)	1.20	1.20	1.20	1.20
A(gr)	19.44	16.43	4.88	2.44
B(f)	1.00	1.00	1.00	0.80
H(f)	20.00	18.00	6.00	6.00
B(s)	60.00	80.00	80.00	80.00
H(s)	3.50	3.20	3.00	2.20
l	1.40	2.80	2.35	2.45
s	0.60	0.80	0.80	0.80
A(f)	20.00	18.00	6.00	4.80
Z(a)	1 227.45	1 129.65	196.64	135.61
l(x)	3 402.18	2 594.07	316.54	163.93
Y(c)	2.77	2.30	1.61	1.21

3.4 Frame longitudinal

The gross section modulus of longitudinal frame with and without brackets, in cm³, shall be calculated by equation 7:

$$Z_{gr} = \frac{f_4 * P * h * l_{bdg}^2}{m_1 * R_{eH}} * 10^3$$

Equation 7. Gross section modulus for frame longitudinal. (DET NORSKE VERITAS AS, 2022a, p.44.)

The shear effective gross area of a longitudinal frame, in cm², shall be:

$$A_{gr} = \frac{8.7 * f_4 * f_5 * P * h * l_{shr}}{R_{eH}}$$

Equation 8. Effective gross shear area for frame transverse. (DET NORSKE VERITAS AS, 2022a, p.44.)

(In the calculation of the actual shear area of the frames, the shear area of the brackets is not to be considered.)

Where:

s_1 = ordinary stiffener spacing = 0.8 m

$f_4 = 1 - 0.2h/s_1$

$f_5 = 2.16$

$m_1 = 13.3$ (assuming brackets are used)

$l_{bdg} = 2.52$

$l_{shr} = 2.52$

As the longitudinal frames only exist in the midbody region, the required gross section modulus and the required shear effective gross area of longitudinal frames for different ice classes will also be calculated for the midbody region only.

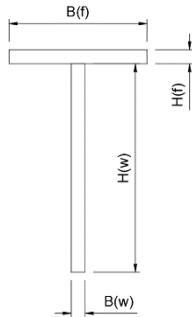
Table 22 Gross section modulus of longitudinal frame for different ice classes

	1A Super	1A	1C
f(4)	0.91	0.93	0.95
s(1)	0.80	0.80	0.80
P	920.46	782.39	460.23
h	0.35	0.30	0.22
l(bdg)	2.52	2.52	2.52
m(1)	13.30	13.30	13.30
R(eH)	355.00	355.00	355.00
Z(gr)	395.39	292.02	128.69
f(4)	0.91	0.93	0.95
s(1)	0.80	0.80	0.80
f(5)	2.16	2.16	2.16
P	920.46	782.39	460.23
h	0.35	0.30	0.22
l(shr)	2.52	2.52	2.52
R(eH)	355.00	355.00	355.00
A(gr)	39.21	28.96	12.76
B(f)	1.50	1.50	1.00
H(f)	28.00	20.00	14.00
B(s)	60.00	80.00	80.00
H(s)	3.50	3.20	3.00
l	1.40	2.80	2.35
s	0.60	0.80	0.80
A(f)	42.00	30.00	14.00
Z(a)	2 660.70	1 715.37	693.12
l(x)	11 640.56	4 831.81	1 364.41
Y(c)	4.38	2.82	1.97

3.5 Ice stringers

The ice stringer starts at frame 101, and the boundary of the bow and midbody region is at fr 109. The ice pressures of the bow region and aft fr 219 applied on stringers will be used in the calculation. Though stringers are usually assumed as T-beams, but the attached plate (usually the shell plate) is considered as

another flange of the T-beam in the calculation of the gross section modulus of web frames, which makes web frames I-beams instead of T-beams. The dimensions of T-beam is shown in picture 7.



Picture 8 Dimensions of T-bar

3.5.1 Stringers within the ice belt

The gross section modulus of a stringer situated within the ice belt, in cm^3 , shall be calculated by equation 9:

$$Z(gr) = \frac{f_6 * f_7 * P * h * l^2}{m_1 * R_{eH}} * 10^3$$

Equation 9. Gross section modulus of stringers within the ice belt. (DET NORSKE VERITAS AS, 2022a, p.45.)

The required gross shear area, in cm^2 , shall be calculated by equation 10:

$$A_{gr} = \frac{8.7 * f_6 * f_7 * f_8 * P * h * l}{R_{eH}}$$

Equation 10. Gross section modulus of stringers within the ice belt. (DET NORSKE VERITAS AS, 2022a, p.45.)

Where:

l = span of stringer

$$f_6 = 0.9$$

$$f_7 = 1.8$$

$$f_8 = 1.2$$

$$m_1 = 13.3 \text{ (assuming brackets are used.)}$$

Ph shall not be taken as less than 150.

Table 23 Gross section modulus of stringer situated within the ice belt

	1A Super	1A	1C
I	2.52	2.52	2.52
f(6)	0.90	0.90	0.90
f(7)	1.80	1.80	1.80
P	1 831.96	1 831.96	1 831.96
h	0.35	0.30	0.22
Ph	641.19	549.59	403.03
R(eH)	355.00	355.00	355.00
m(1)	13.30	13.30	13.30
Z(gr)	1 398.18	1 198.44	878.86
f(6)	0.90	0.90	0.90
f(7)	1.80	1.80	1.80
f(8)	1.20	1.20	1.20
P	1 831.96	1 831.96	1 831.96
h	0.35	0.30	0.22
Ph	641.19	549.59	403.03
I	2.52	2.52	2.52
R(eH)	355.00	355.00	355.00
A(gr)	77.01	66.01	48.41
B(f)	45.00	30.00	20.00
H(f)	0.80	1.00	1.00
B(w)	0.80	1.00	1.00
H(w)	55.00	40.00	30.00
B(s)	59.24	59.24	59.24
H(s)	3.30	3.10	2.60
$I/(S^3)^{0.5}$	0.61	0.61	0.61
S	2.40	2.40	2.40
A(a)	80.00	70.00	50.00
Z(a)	8 029.83	5 072.30	2 960.29
I(x)	110 497.41	50 327.79	20 171.84
Y(c)	13.76	9.92	6.81

3.5.2 Stringers outside the ice belt

The gross section modulus of a stringer situated outside the ice belt but supporting ice-strengthened frames, in cm^3 , shall be calculated by equation 11:

$$Z_{gr} = \frac{f_9 * f_{10} * P * h * l^2}{m_1 * R_{eH}} \left(1 - \frac{h_s}{l_s}\right) * 10^3$$

Equation 11. Gross section modulus of stringers outside the ice belt. (DET NORSKE VERITAS AS, 2022a, p.46.)

The required gross shear area, in cm^2 , shall be calculated by equation 12:

$$A_{gr} = \frac{8.7 * f_9 * f_{10} * f_{11} * P * h * l}{R_{eH}} \left(1 - \frac{h_s}{l_s}\right)$$

Equation 12. Gross shear area of stringers within the ice belt. (DET NORSKE VERITAS AS, 2022a, p.46.)

Where:

l_s = the distance to the adjacent ice stringer, in m

$$l_{s(\text{upper})} = 1.75 \text{ m}$$

$$l_{s(\text{lower})} = 3.1 \text{ m}$$

h_s = the distance to the ice belt, in m

$$h_{s(\text{upper})} = 0.488 \text{ m}$$

$$h_{s(\text{lower})} = 1.162 \text{ m}$$

$$f_9 = 0.8$$

$$f_{10} = 1.8$$

$$f_{11} = 1.2$$

$$m_1 = 13.3 \text{ (assuming brackets are used)}$$

Ph shall not be taken as less than 150

Table 24 Gross section modulus of stringers situated outside the ice belt for different ice classes

	IA Super	IA	IC
f(9)	0.80	0.80	0.80
f(10)	1.80	1.80	1.80
P	1 831.96	1 831.96	1 831.96
h	0.35	0.30	0.22
Ph	641.19	549.59	403.03
I	2.52	2.52	2.52
I(aft fr 219)	2.58	2.58	2.58
m(1)	13.30	13.30	13.30
R(eH)	355.00	355.00	355.00
h(s)(upper)	0.49	0.49	0.49
h(s)(lower)	1.16	1.16	1.16
I(s)(upper)	1.75	1.75	1.75
I(s)(lower)	3.10	3.10	3.10
Z(gr)(upper)	896.26	768.22	563.36
Z(gr)(upper)(aft fr 219)	935.06	801.48	587.75
Z(gr)(lower)	776.97	665.97	488.38
f(11)	1.20	1.20	1.20
A(gr)(upper)	49.36	42.31	31.03
A(gr)(upper)(aft fr 219)	50.42	43.22	31.69
A(gr)(lower)	42.79	36.68	26.90
B(f)(upper)	30.00	25.00	20.00
H(f)(upper)	0.80	0.80	0.80
B(f)(lower)	25.00	22.00	15.00
H(f)(lower)	0.80	0.80	0.80
B(w)(upper)	0.80	0.80	0.80
H(w)(upper)	35.00	30.00	20.00
B(w)(lower)	0.80	0.80	0.80
H(w)(lower)	30.00	25.00	20.00
B(s)	59.24	59.24	59.24
H(s)	3.30	3.10	2.60
I/(S*3 ^{0.5})	0.00	0.00	0.00
S	2.40	2.40	2.40
A(a)(upper)	52.00	44.00	32.00
A(a)(lower)	44.00	37.60	28.00
Z(a)(upper)	4 184.76	3 166.54	1 585.72
I(x)(upper)	31 006.48	19 321.72	6 562.24
Y(c)(upper)	7.41	6.10	4.14
Z(a)(lower)	3 229.00	2 352.27	1 453.50
I(x)(lower)	19 357.95	11 676.58	5 412.64
Y(c)(lower)	6.00	4.96	3.72

Table 25 The required gross shear area for different ice classes

	IA Super	IA	IC
f(9)	0.80	0.80	0.80
f(10)	1.80	1.80	1.80
f(11)	1.20	1.20	1.20
P	1 831.96	1 831.96	1 831.96
h	0.35	0.30	0.22
Ph	641.19	549.59	403.03
I	2.52	2.52	2.52
l(aft fr 219)	2.58	2.58	2.58
R(eH)	355.00	355.00	355.00
h(s)(upper)	0.49	0.49	0.49
h(s)(lower)	1.16	1.16	1.16
l(s)(upper)	1.75	1.75	1.75
l(s)(lower)	3.10	3.10	3.10
A(gr)(upper)	49.36	42.31	31.03
A(gr)(upper)(aft fr 219)	50.42	43.22	31.69
A(gr)(lower)	42.79	36.68	26.90

3.6 Web frame

As the web frame supports three ice stringers, one within the ice belt and two outside, the design ice load will be calculated with the most pressured ice stringer. It is indicated in DNV rules that in case the supported stringer is outside the ice belt, the load F may be multiplied by factor: $(1 - \frac{h_s}{l_s})$, and the value of h_s is always less than l_s , which makes the factor smaller than 1 and such case will not be considered in this thesis. As web frames are T-bars, the attached plate is also considered a flange, as in stringers' attained section modulus calculation. The dimension of web frames is shown in picture 5.

The design ice load transferred to a web frame from an ice stringer or longitudinal framing, in kN, shall be calculated by equation 13:

$$F = f_{12} * P * h * S$$

Equation 13. design ice load for web frame. (DET NORSKE VERITAS AS, 2022a, p.47.)

The gross shear area of a web frame, in cm², is given by:

$$A_{gr} = \frac{17.3 * a * f_{13} * Q}{R_{eH}}$$

Equation 14. The gross shear area of a web frame. (DET NORSKE VERITAS AS, 2022a, p.47.)

The required gross section modulus, in cm³, is given by:

$$Z_{gr} = \frac{M}{R_{eH}} \sqrt{\frac{1}{1 - \left(\gamma \frac{A}{A_a}\right)^2}} * 10^3$$

Equation 15. The required gross section modulus for web frames. (DET NORSKE VERITAS AS, 2022a, p.47.)

The effective breadth of attached plating, in m, for calculating the modulus and/or moment of inertia of a primary supporting member with uniform load shall be taken as:

$$B_s = S * \min \left[\frac{1.12}{1 + \frac{1.75}{\left(\frac{l_{bdg}}{S\sqrt{3}}\right)^{1.6}}}; 1.0 \right] \text{ for } \frac{l_{bdg}}{S\sqrt{3}} \geq 1.0$$

$$B_s = 0.407 \left(\frac{l_{bdg}}{\sqrt{3}}\right) \text{ for } \frac{l_{bdg}}{S\sqrt{3}} < 1.0$$

Equation 16. The effective breadth of attached plating. (DET NORSKE VERITAS AS, 2022b, p.71.)

Where:

S = web frame spacing, in m

f₁₂ = 1.8

$$M = 0.193 \cdot F \cdot l$$

$$l = l_{bdg} = \text{span of web frame}$$

$$A = A_{gr}$$

$$A_a = \text{actual gross sectional area of web frame, in cm}^2 (A_f + A_w).$$

$$Q = F$$

$$f_{13} = 1.3$$

$$A_f = \text{area of the flange}$$

$$A_w = \text{area of web plate}$$

$$H_s = \text{Shell plating net thickness}$$

Table 26 Value of a and γ . (DET NORSKE VERITAS AS, 2022a, p.48.)

A_f/A_w	0.0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
a	1.5	1.23	1.16	1.11	1.09	1.07	1.06	1.05	1.05	1.04	1.04
γ	0	0.44	0.62	0.71	0.76	0.80	0.83	0.85	0.87	0.88	0.89

Table 27 Web frame scantling for ice class 1A Super

	aft fr 219	Bow	Midbody	Stern
F	1 469.26	2 433.84	1 222.63	916.97
P	1 295.65	1 533.03	770.11	577.58
h	0.35	0.35	0.35	0.35
S	1.80	2.52	2.52	2.52
f(12)	1.80	1.80	1.80	1.80
A(gr)	118.14	139.60	71.44	53.58
a	1.50	1.07	1.09	1.09
f(13)	1.10	1.10	1.10	1.10
Q	1 469.26	2 433.84	1 222.63	916.97
R(eH)	355.00	355.00	355.00	355.00
Z(gr)	1 158.23	9 089.75	4 483.32	2 076.53
M	411.17	2 188.95	1 045.34	495.53
I	1.45	4.66	4.43	2.80
Y	0.00	0.80	0.76	0.76
A(a)	120.00	152.00	72.00	55.00
A(f)	0.00	80.00	32.00	25.00
A(w)	120.00	72.00	40.00	30.00
B(f)	0.00	40.00	32.00	25.00
H(f)	0.00	2.00	1.00	1.00
B(w)	0.60	1.20	1.00	1.00
H(w)	200.00	60.00	40.00	30.00
B(s)	34.07	56.81	54.55	65.79
H(s)	3.50	3.20	3.00	2.20
$I/(S \cdot 3^{0.5})$	0.47	1.07	1.01	0.64
Z(a)	18 530.67	9 576.77	4 711.18	3 090.21
I(x)	978 119.46	224 284.57	51 131.05	23 093.18
Y(c)	52.78	23.42	10.85	7.47

Table 28 Web frame scantling for ice class 1A

	aft fr 219	Bow	Midbody	Stern
F	1 259.37	2 086.15	890.77	681.18
P	1 295.65	1 533.03	654.59	500.57
h	0.30	0.30	0.30	0.30
S	1.80	2.52	2.52	2.52
f(12)	1.80	1.80	1.80	1.80
A(gr)	101.26	119.66	55.39	39.07
a	1.50	1.07	1.16	1.07
f(13)	1.10	1.10	1.10	1.10
Q	1 259.37	2 086.15	890.77	681.18
R(eH)	355.00	355.00	355.00	355.00
Z(gr)	992.77	7 650.33	2 688.00	1 661.73
M	352.43	1 876.24	761.60	368.11
I	1.45	4.66	4.43	2.80
Y	0.00	0.80	0.62	0.80
A(a)	120.00	132.40	57.00	40.00
A(f)	0.00	70.00	20.00	20.00
A(w)	120.00	62.40	37.00	20.00
B(f)	0.00	35.00	20.00	20.00
H(f)	0.00	2.00	1.00	1.00
B(w)	0.60	1.20	1.00	1.00
H(w)	200.00	52.00	37.00	20.00
B(s)	34.07	56.81	54.55	65.79
H(s)	3.30	3.20	2.80	2.00
$I/(S \cdot 3^{0.5})$	0.47	1.07	1.01	0.64
Z(a)	17 775.61	7 965.14	3 768.36	1 679.85
I(x)	962 164.39	153 297.73	32 483.73	8 043.31
Y(c)	54.13	19.25	8.62	4.79

Table 29 Web frame scantling for ice class 1C

	aft fr 219	Bow	Midbody	Stern
F	1 092.74	1 292.95	384.25	192.13
P	1 533.03	1 295.65	385.06	192.53
h	0.22	0.22	0.22	0.22
S	1.80	2.52	2.52	2.52
f(12)	1.80	1.80	1.80	1.80
A(gr)	87.87	74.16	23.89	11.43
a	1.50	1.07	1.16	1.11
f(13)	1.10	1.10	1.10	1.10
Q	1 092.74	1 292.95	384.25	192.13
R(eH)	355.00	355.00	355.00	355.00
Z(gr)	861.42	4 882.98	1 064.26	309.22
M	305.80	1 162.85	328.53	103.83
I	1.45	4.66	4.43	2.80
Y	0.00	0.80	0.62	0.71
A(a)	120.00	80.00	30.00	25.00
A(f)	0.00	40.00	10.00	10.00
A(w)	120.00	40.00	20.00	15.00
B(f)	0.00	20.00	10.00	10.00
H(f)	0.00	2.00	1.00	1.00
B(w)	0.60	1.00	1.00	1.00
H(w)	200.00	40.00	20.00	15.00
B(s)	34.07	56.81	54.55	65.79
H(s)	3.00	2.80	2.00	1.20
$I/(S*3^{0.5})$	0.47	1.07	1.01	0.64
Z(a)	16 624.33	4 924.14	1 238.11	788.93
I(x)	936 137.67	59 458.19	5 110.10	2 617.30
Y(c)	56.31	12.07	4.13	3.32

4 Weight calculation

As the affected area of plates and length of frames are already defined in chapter 2, the weight calculation will be done by multiplying the density of high-strength steel with the selected thickness and area of the plates, the selected thickness of frames and the length of frames and the area of the plates and the length of the frames.

$$m = A_f * l * \rho, \text{ or}$$

$$m = A_p * h * \rho$$

Where:

A_f = scantling of stiffener

L = length of stiffener

A_p = area of the plate

h = thickness of the plate

ρ = density of high strength steel = 7.85 t/m³

The total weight of the hatched area in picture 1 and the structures in picture 2 for ice class 1A Super is calculated in table 30, for ice class 1A is calculated in table 31 and for ice class 1C is calculated in table 32.

Table 30 Weight calculation of ice-strengthened structures for ice class 1A Super.

	scantling	length(area)	density	weight
shell plate				
Aft fr 219	35.00 mm	118.36 m ²	7.85 t/m ³	32.52 t
Bow	32.00 mm	756.97 m ²	7.85 t/m ³	190.15 t
Midbody	30.00 mm	680.88 m ²	7.85 t/m ³	160.35 t
Stern	22.00 mm	427.58 m ²	7.85 t/m ³	73.84 t
transverse frame				
Aft fr 219	32.00 cm ²	990.31 m	7.85 t/m ³	24.88 t
Bow	28.00 cm ²	7 272.77 m	7.85 t/m ³	159.86 t
Stern	12.00 cm ²	1 292.62 m	7.85 t/m ³	12.18 t
longitudinal frame				
midbody	42.00 cm ²	3 837.05 m	7.85 t/m ³	126.51 t
ice stringer				
Within ice belt	8.00 mm	426.15 m ²	7.85 t/m ³	26.76 t
Outside ice belt upper	5.20 mm	410.00 m ²	7.85 t/m ³	16.74 t
Outside ice belt lower	4.40 mm	390.00 m ²	7.85 t/m ³	13.47 t
Web frame				
Aft fr 219	12.00 mm	120.00 m ²	7.85 t/m ³	11.30 t
Bow	15.20 mm	934.57 m ²	7.85 t/m ³	111.51 t
Midbody	7.20 mm	996.20 m ²	7.85 t/m ³	56.31 t
Stern	5.50 mm	352.17 m ²	7.85 t/m ³	15.20 t
weight sum				1031.57 t

Table 31 Weight calculation of ice-strengthened structures for ice class 1A

	scantling	length(area)	density	weight
shell plate				
Aft fr 219	33.00 mm	118.36 m ²	7.85 t/m ³	30.66 t
Bow	32.00 mm	756.97 m ²	7.85 t/m ³	190.15 t
Midbody	28.00 mm	680.88 m ²	7.85 t/m ³	149.66 t
Stern	20.00 mm	427.58 m ²	7.85 t/m ³	67.13 t
transverse frame				
Aft fr 219	28.00 cm ²	990.31 m	7.85 t/m ³	21.77 t
Bow	24.00 cm ²	7 272.77 m	7.85 t/m ³	137.02 t
Stern	10.00 cm ²	1 292.62 m	7.85 t/m ³	10.15 t
longitudinal frame				
midbody	30.00 cm ²	3 837.05 m	7.85 t/m ³	90.36 t
ice stringer				
Within ice belt	7.00 mm	426.15 m ²	7.85 t/m ³	23.42 t
Outside ice belt upper	4.40 mm	410.00 m ²	7.85 t/m ³	14.16 t
Outside ice belt lower	3.76 mm	390.00 m ²	7.85 t/m ³	11.51 t
Web frame				
Aft fr 219	12.00 mm	120.00 m ²	7.85 t/m ³	11.30 t
Bow	13.24 mm	934.57 m ²	7.85 t/m ³	97.13 t
Midbody	5.70 mm	996.20 m ²	7.85 t/m ³	44.57 t
Stern	4.00 mm	352.17 m ²	7.85 t/m ³	11.06 t
weight sum				910.06 t

Table 32 Weight calculation of ice-strengthened structures for ice class 1C.

	scantling	length(area)	density	weight
shell plate				
Aft fr 219	30.00 mm	118.36 m ²	7.85 t/m ³	27.87 t
Bow	28.00 mm	756.97 m ²	7.85 t/m ³	166.38 t
Midbody	20.00 mm	680.88 m ²	7.85 t/m ³	106.90 t
Stern	12.00 mm	427.58 m ²	7.85 t/m ³	40.28 t
transverse frame				
Aft fr 219	20.00 cm ²	990.31 m	7.85 t/m ³	15.55 t
Bow	18.00 cm ²	7 272.77 m	7.85 t/m ³	102.76 t
Stern	4.80 cm ²	1 292.62 m	7.85 t/m ³	4.87 t
longitudinal frame				
midbody	14.00 cm ²	3 837.05 m	7.85 t/m ³	42.17 t
ice stringer				
Within ice belt	5.00 mm	426.15 m ²	7.85 t/m ³	16.73 t
Outside ice belt upper	3.20 mm	410.00 m ²	7.85 t/m ³	10.30 t
Outside ice belt lower	2.80 mm	390.00 m ²	7.85 t/m ³	8.57 t
Web frame				
Aft fr 219	12.00 mm	120.00 m ²	7.85 t/m ³	11.30 t
Bow	8.00 mm	934.57 m ²	7.85 t/m ³	58.69 t
Midbody	3.00 mm	996.20 m ²	7.85 t/m ³	23.46 t
Stern	2.50 mm	352.17 m ²	7.85 t/m ³	6.91 t
weight sum				642.75 t

5 Conclusions

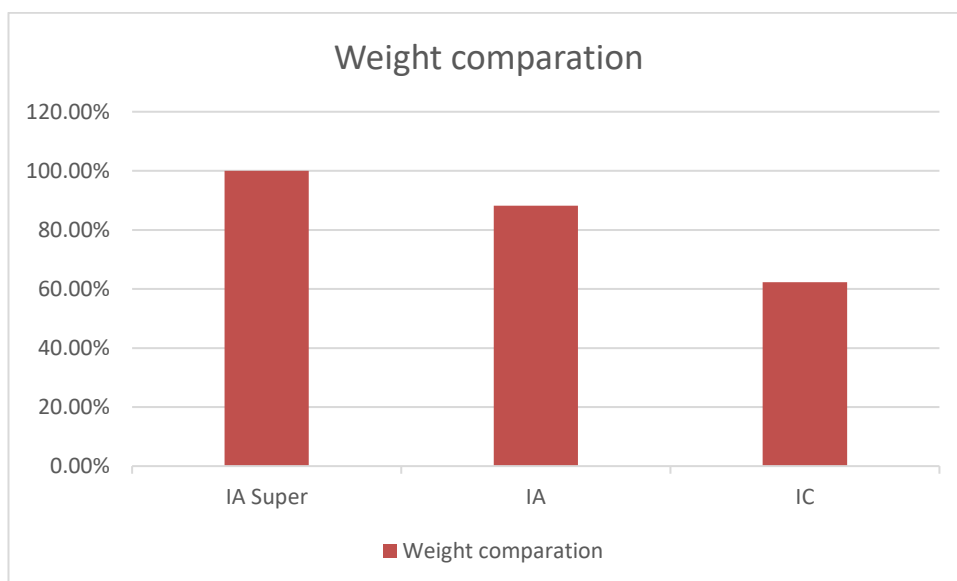
As shown in table 33 and Figure 1, Ice class 1A is about 12%, and Ice class 1C is about 38% lighter than Ice class 1A Super on the weight of Ice class affected hull steel structures. The price of Ah36 ASTM A131 Shipbuilding Steel Plate is 750 – 990 US\$/t (www.sambhavpipes.com. (2022)). The ice class 1A is about 100,000 \$ cheaper than Ice class 1A Super on the cost of building materials of the ice class affected area, and for ice class 1C, it's about 340,000 \$ cheaper, assuming the steel price is 870 \$/t.

A better ice class brings more lightship weight, less payload, more building cost, and labour cost but less fairway dues. The selection of ice class is usually based on the operation region and the availability of ice breakers.

Table 33. Weight Comparison

	IA Super	IA	IC
Weight	1 032 t	910 t	643 t
Weight comparison	100.00%	88.22%	62.31%
Price comparison (870 \$/t)	0 \$	-105 714 \$	-338 273 \$

Figure 1. Weight comparison



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