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PREEDICT –EEDI POWER CORRECTION FACTORS FJ FOR ICE CLASS SHIPS

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FOREWORD

In this report no 105, the Winter Navigation Research Board presents the results of the study on new ice class correction factors for power. As the stricter EEDI regulations will be applied in phases 2 and 3, the effectiveness of the current ice class correction factors will decrease.

The new ice class correction factors are developed by analysing the difference in engine power of open water ships and ships build in accordance with the Finnish-Swedish Ice Class Rules.

The Winter Navigation Research Board warmly thanks Mr. Tom Mattsson for this report.

Helsinki and Norrköping

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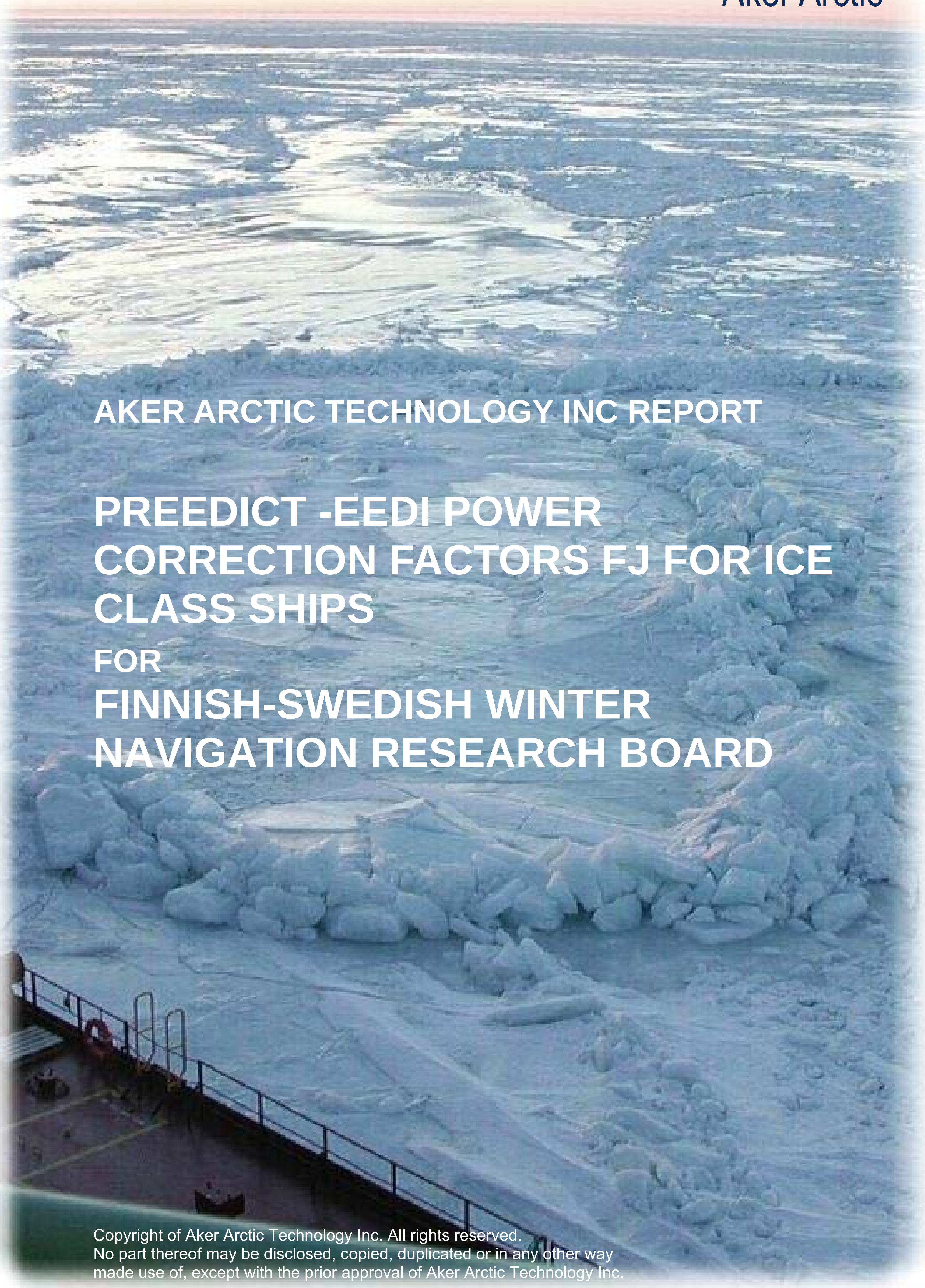

AKER ARCTIC TECHNOLOGY INC REPORT

PREEDICT -EEDI POWER CORRECTION FACTORS FJ FOR ICE CLASS SHIPS

FOR

FINNISH-SWEDISH WINTER NAVIGATION RESEARCH BOARD

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Summary: EEDI (Energy Efficiency Design Index) regulations – adopted by the IMO at the MEPC 62 Meeting in July 2011 and came into force 1 January 2013 – affect the world shipping and especially the transport regime in the Baltic Sea, where high ice classes are the basis of year-round regular maritime transport. In order to take into account the special design features of ships having an ice class compared to ships sailing in open water only, ice class correction factors have been adopted in the 2014 Guidelines on the method of calculation of the attained Energy Efficiency Design Index (EEDI) for new ships (Resolution MEPC.245(66), as amended by resolution MEPC.281(70)). The stricter requirements of the EEDI in phases 2 and 3 will decrease the effectiveness of the current ice class correction factors for ice-classed ships in the 2014 Guidelines. The experience gained from applying the current ice class correction factors also indicates that certain improvements are needed in the calculation of the current factors. For these reasons, in 2017 Finland and Sweden submitted a proposal for new ice class correction factors for capacity to the MEPC 71 Meeting. The purpose of this research project is to develop a proposal for new ice class correction factors for power. The new ice class correction factors for power are developed by analysing the difference in engine power of open water ships and ships built in accordance with the Finnish-Swedish Ice Class Rules. The new suggested power correction factors are described in Chapter 4. Chapter 5 presents the effect of the new ice class correction factors on the attained EEDI of ships with an ice class.			
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1 BACKGROUND

EEDI (Energy Efficiency Design Index) regulations – adopted by the IMO at the MEPC 62 Meeting in July 2011 and came into force 1 January 2013 – affect the world shipping and especially the transport regime in the Baltic Sea, where high ice classes are the basis of year-round regular maritime transport. In order to take into account the special design features of ships having an ice class compared to ships sailing in open water only, ice class correction factors for capacity and power have been adopted in the 2014 Guidelines on the method of calculation of the attained Energy Efficiency Design Index (EEDI) for new ships (Resolution MEPC.245(66), as amended by resolution MEPC.281(70)).

The stricter requirements of EEDI in phases 2 and 3 will decrease the effectiveness of the current ice class correction factors for ice-classed ships given in the 2014 Guidelines. The experience gained from applying the current ice class correction factors also indicates that certain improvements are needed in the calculation of the current factors. For these reasons, in 2017 Finland and Sweden submitted a proposal for new ice class correction factors for capacity to the MEPC 71 Meeting. The purpose of this research project is to develop a proposal for new ice class correction factors for power.

The aim of this project, submitted to Aker Arctic Technology Inc. (AAT), funded by the Finnish and Swedish Maritime Administrations, and addressing the special research topic for 2017 of the Winter Navigation Research Board, was to develop a proposal for new ice class correction factors for power and to provide the supporting information and calculations on the effect of the proposed new ice class correction factors of EEDI on the design of ships with a Finnish-Swedish ice class sailing in the Baltic Sea area.

1.1 ABBREVIATIONS

EEDI: Energy Efficiency Design Index, as specified in resolution MEPC.245 (66), 2014 Guidelines on the Method of Calculation of the Attained Energy Efficiency Design Index for New Ships; see the link for details on the resolution: http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/245(66).pdf

FSICR: Finnish-Swedish Ice Class Rules (2017); see www.trafi.fi

IMO: International Maritime Organisation, a specialised agency of the United Nations responsible for regulating shipping.

MEPC: Marine Environment Protection Committee of the IMO.

2 SCOPE OF WORK

The original scope of work was to divide the work into four Work Packages (WP) with the following contents and aims:

WP1: Data of ice classed (Finnish-Swedish Ice Class Rules (FSICR), ice classes IA Super, IA, IB and IC) ships ordered with EEDI Phase 1 criteria is collected from Maritime IHS database, a ship database. Information is supplemented where needed with information requested from ship owners. The data is analysed against EEDI Phase 2 and 3 requirements and required FSICR power levels.

WP2: The target of WP2 is to develop various scenarios on the effect of the implementation of current EEDI Phase 2 and Phase 3 levels and to evaluate the implications for shipping in the Baltic Sea in wintertime. Part of the scenario study includes a workshop planned in April 2017, where selected specialists will share their vision on the effects of the EEDI.

WP3: The installed power difference will be evaluated from a selected set of ships. The viability of this work depends on the number of ships that have been ordered and on the analyses and results of WP1.

WP4: Evaluation of the influence of the required EEDI in Phase 3 for open water ships compared to the required engine power of ice class ships. A proposal for new ice class correction factors for power will be developed.

Due to changes in the IMO process, the original target of the study has changed both in schedule and in content. The main changes were in the schedule and in the content.

- The aim of this project is to develop a proposal for new ice class correction factors for power and to provide the supporting information and calculations on the effect of the proposed new ice class correction factors of EEDI on the design of ships with an ice class sailing in the Baltic Sea area.

3 ANALYSIS METHODS

In the first phase, a statistical analysis was made for the various ship types. The statistical analysis is based on available ship data in the Maritime IHS database (for a ship's keel laid between 2000 and 2017). The average engine power level of the ships was determined by using regression analysis for open water ships and ice class ships.

The engine power levels of open water ships were compared to the engine power of ships having an ice class for the selected ship types. To compare the power levels achieved via regression analysis, the required engine power was calculated using the formula (3.1 and 3.2) in section 3.2 of the Finnish-Swedish Ice Class Rules (FSICR). The calculations were made to determine if differences can be found between the installed power of existing ships and their required power.

The minimum required engine power according to the FSICR was defined for each ship type for some chosen sizes of ships. The minimum engine power requirement depends on the ship hull shape. As there was no possibility to obtain the line drawings of the selected ships, the required engine power for sailing in ice was determined by using a generic hull form.

The used generic hull form represents a typical bulbous bow shape for each ship type. The calculations were done by assuming a typical propeller arrangement and number of propellers for each ship type. The achieved power levels can, in that respect, be seen as an average value for each ship size and type, but not as absolute values. The generic hull shape was developed by using general arrangements and other sources.

Figure 1: Typical tanker/bulk carrier hull type used in the FSICR calculations.

4 DEVELOPMENT OF THE POWER CORRECTION FACTOR F_J

4.1 GENERAL

This study is done for the selected ship types, differing in hull shape and in-service speed range.

In the 2014 Guidelines, correction factors for power are defined for the following ship types: tankers, bulk carriers, general cargo ships and refrigerated cargo ships. The following ship types were included in the study:

1. Tankers
   - The hull form is usually very blunt, with block coefficients ranging from 0.8 to over 0.85. The service speed of the ships is mainly below 16 knots, on average about 15 knots.

2. Bulk carriers
   - The hull form of bulk carriers is quite similar to that of tankers. Usually, the block coefficient is slightly higher than for tankers. The service speeds are slightly lower than the service speeds of tankers, being around 14–14.5 knots.

3. General Cargo ships
   - The bow form of general cargo ships is often somewhat slimmer (half the entrance angle of the waterline is smaller) than for tankers and bulk carriers. The service speed can vary from 10 knots for small ships up to 19 knots in some cases.

4. Container ships
   - The hull form of container ships differs from the three ship types mentioned above, with it being much slenderer. The block coefficient is rarely above 0.75 and mainly around 0.7. The service speeds are around 20 knots, but they can be as high as 25-26 knots.

5. Ro-Ro ship
   - The hull shape of Ro-Ro ships is even more slender than the hull of container ships. The block coefficient can be as low as 0.5 and, on average, about 0.62. The service speeds of Ro-Ro ships vary from about 16 to 22 knots.

6. Gas carriers (LNG carrier)
   - LNG carriers have a smaller block coefficient than tankers. The block coefficient is usually around 0.75. The service speeds for smaller size ships are 15–16 knots, and for large LNG carriers about 19–20 knots.

The most interesting ship types in this study are the types with relatively low service speed (15 knots or less), as ships with higher service speeds usually have enough engine power to meet the requirements given in the FSICR due to their high speed in open water.

The data for each studied ship type was obtained from the Maritime IHS database. Ships built on or after 1 January 2000 were included in this study. The data was then divided into five data sets, with the first set consisting of ships with no ice class (the parameter “ice capable” in the database receives the value “no” or else the ice class of the ship is “FS Ice Class II”). In Finland, the fairway dues depend on the ice class of the vessel, and for this reason “ice classes” II and III are used. Ships belonging to ice classes II and III are not strengthened for navigation in ice. Ships belonging to ice class II are ships that have a steel hull and are structurally fit for navigation in the open sea and that, despite not being strengthened for navigation in ice, are capable of navigating in very light ice conditions using their own propulsion machinery. Ships belonging to ice class III comprise the rest of the ships, which do not belong to higher ice classes, e.g. barges, ships with a wooden hull, etc.

The other separate sets of data consist of ships that have Finnish-Swedish ice classes IC, IB, IA and IA Super. The selected ships had their keel laid or ordered on or after 2000.

Some of the data found in the Maritime IHS database was excluded from the study due to missing information on a relevant parameter. Open water ships that are larger in deadweight than existing ships with an ice class have also been excluded from this study. Also, ships with a higher ice class than defined by the FSICR as well as ships with diesel-electric propulsion have been excluded from the analysis.

For each ship type, a regression analysis was done to determine the typical average engine power level of that ship type. Regression analysis was done for open water ships and for ships having an ice class, though separately for each ice class (Finnish-Swedish ice classes IC, IB, IA and IAS).

Different approaches were made at the beginning of the study, where engine power versus different ship parameters were analysed. These results were then compared in order to determine which parameter has the best correlation. The results showed that the main engine power versus deadweight gave the best result. It is also convenient to choose deadweight for the parameter, because in the new proposal for ice class correction factors for capacity (see MEPC 71/5/6), deadweight was also used as the main parameter. Deadweight is also the parameter in reference lines in the EEDI regulations. Therefore, the deadweight was chosen to be the base for the new suggested power correction factor f_j. The regression analyses are then based on engine power and deadweight.

4.2 TANKERS

4.2.1 REGRESSION ANALYSIS

For this study, ship data was obtained for tankers with a deadweight of 4000 tonnes or more, which is the minimum deadweight for the required EEDI in the EEDI regulations.

The available data on tankers included a total of 2594 ships, of which the division between open water and different ice classes was as given in Table 1.

Table 1: Number of tankers built on or after 1 January 2000 designed for sailing in open water only and having an ice class included in the study.

Open water tankers	1740
Ice class IC	204
Ice class IB	190
Ice class IA	429
Ice class IAS	31

The correlation between the deadweight and propulsion power for ships without an ice class and ships with various ice classes is determined by using regression analysis.

Figure 2 shows the regression curves for engine power for open water ships and various ice class ships; the results of the regression analysis are given in Table 2.

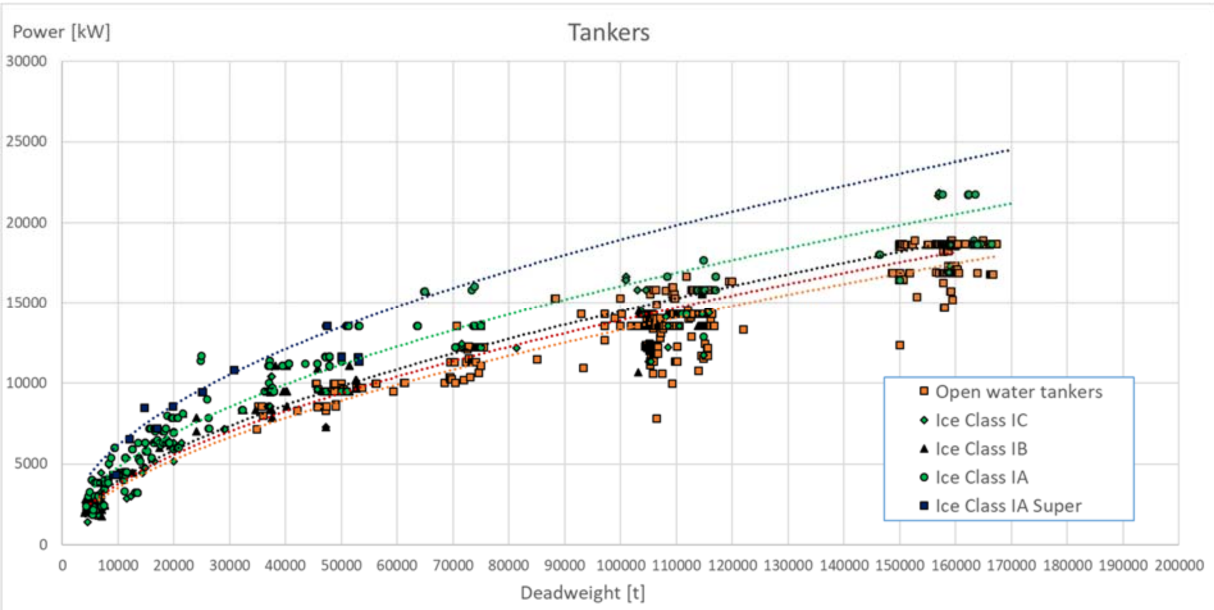


Figure 2: Average engine power of existing tankers with and without an ice class.

Note: Dots and corresponding regression line are in the same colours.

Table 2: The power regression for the studied tankers.

Open water/ice class	Average engine power [kW]	R^2
Open water	$17.444 * dwt^{0,5766}$	0.8369
IC	$19.957 * dwt^{0,5687}$	0.9577
IB	$22.412 * dwt^{0,5621}$	0.9186
IA	$38.414 * dwt^{0,5242}$	0.9211
IA Super	$70.111 * dwt^{0,4863}$	0.8730

Tankers with a low FSICR ice class (IC and IB) have only slightly higher installed power than open water tankers. The engine power of tankers with higher ice classes (IA or IAS) already differs more from the engine power of open water ships. Based on the information given in Table 2, the difference in average engine power (MCR) of tankers having an ice class compared to open water tankers can be defined. The difference in average engine power (delta power) is presented in Figure 3.

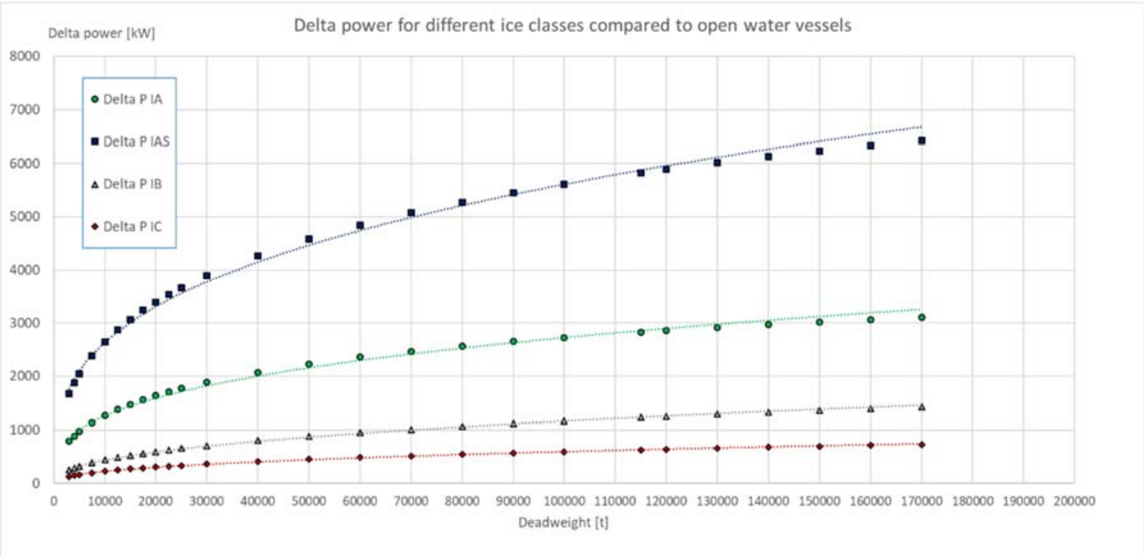


Figure 3: Difference in average engine power (MCR) of tankers having an ice class compared to open water tankers.

When comparing the installed engine power of ice-classed ships to open water tankers, the installed engine power of an AFRAMAX size (115000 DWT) tanker in ice class IA is approximately 20% higher than the installed power of an open water tanker. For AFRAMAX tankers with ice class IAS, the difference is almost 40%. With smaller tankers, the differences are even higher, being up to 70-80% higher than for open water tankers.

One method for determining the propulsion power required for an ice class is to use ice model tests. Based on the ice model test, Aker Arctic has developed a method for estimating the required power for wide ships. The method is based on a database of model scale tests for FSICR channel resistance tests run at the Aker Arctic model basin. This method gives similar required engine power levels as on built ships.

Note that for most of the large tankers (AFRAMAX size) with ice class IA or IAS, the required engine power has been determined via ice model tests.

Table 3: Relative power increase for ice class tankers based on regressions analysis.

Ship type	DWT	Regression of Open Water Tankers	Regression of Ice Class IC Tankers	Regression of Ice Class IB Tankers	Regression of Ice Class IA Tankers	Regression of Ice Class IAS Tankers
		[kW]				
Tanker	10000	~3500	106%	112%	136%	175%
Tanker	25000	~6000	106%	111%	130%	161%
Tanker	50000	~8950	105%	110%	125%	151%
Tanker	115000	~14450	104%	109%	120%	140%

4.2.2 REQUIRED ENGINE POWER ACCORDING TO THE FSICR FORMULA

The required engine power according to the FSICR formula was determined by using a generic hull form defined for this purpose. This method was used only for checking if the formula showed any difference for existing ships. The used generic hull form represents a typical bulbous bow shape for each ship type (see Figure 1). The calculations were done by assuming a typical propeller arrangement (propeller type and number of propellers) for this ship type.

The FSICR formula resulted in higher power requirements, especially for large ships in ice classes IA and IAS, than has been installed in existing tankers. The reason for this is that for ice classes IA and IAS, the engine power has in most cases been determined based on the results from ice model tests, which generally give a lower level of ice resistance than the FSICR formula.

Table 4: Average engine power for four sizes of tankers designed for open water only compared to the calculated required minimum engine power of Finnish-Swedish ice classes IC, IB, IA and IA Super.

Ship type	DWT	Regression of open water tankers	FSICR formula Ice Class IC	FSICR formula Ice Class IB	FSICR formula Ice Class IA	FSICR formula Ice Class IAS
		[kW]	[kW]	[kW]	[kW]	[kW]
Tanker	10000	~3500	~2050	~3150	~4490	~6160
Tanker	25000	~6000	~3200	~4680	~6470	~9320
Tanker	50000	~8950	~4900	~7820	~11420	~16130
Tanker	115000	~14450	~9100	~14600	~21340	~28340

The difference in engine power between an open water and an ice class ship will probably increase when the forthcoming EEDI phases enter into force, due to the fact that the ship will naturally need more installed power to have some ice-going capability, at least according to the minimum FSICR requirements for brash ice channel conditions. This will certainly be the case if more stringent EEDI requirements result in lower levels of engine power for ships designed for open water.

It must be noted that for ice class IC, the installed power is higher in existing ships than that required by the FSICR formula because the higher installed power is usually determined by open water requirements, such as speed and manoeuvrability in open water.

4.2.3 PROPOSED NEW POWER CORRECTION FACTOR F_J FOR TANKERS

The study has focused on determining a new way to define the power correction factor, f_j, for ice class ships. The old correction factor was based on the length of the ship (L_{pp}), whereas the new suggested correction factor will be based on the deadweight tonnage (*DWT*) of the ship.

The correction factor for power, f_j, for ice-classed ships is calculated using the same method as in the 2014 Guidelines (Resolution MEPC.245(66)):

The coefficients f_{j0} and $f_{j,\,min}$ in the present study are defined differently than in the 2014 Guidelines. The essential difference is that the applied average engine powers in the present study are defined as a function of DWT, while they were defined as a function of ship length in the 2014 Guidelines. Otherwise, the principles of defining f_{j0} and $f_{j,\,min}$ in the present study are similar to those in the 2014 Guidelines; see EE-WG 2/2/9 for details.

The basic form of the present correction factor for power, f_j, is the average engine power of ships designed for open water ($P_{OW,\,ave}$) divided by the actual engine power (MCR 100%) of the ship with an ice class:

$$f_{j0} = \frac{P_{OW,ave}(dwt)}{actual\ power}.$$

The average power versus DWT is achieved via regression analysis using the Maritime IHS database for tankers. The obtained equations are given in Table 5 for open water and ice class tankers.

Table 5: Regression formula on average engine power for the studied tankers.

Open water/ice class	Average engine power [kW]
Open water	$17.444 * dwt^{0.5766}$
IC	$19.957 * dwt^{0.5687}$
IB	$22.412 * dwt^{0.5621}$
IA	$38.414 * dwt^{0.5242}$
IA Super	$70.111 * dwt^{0.4863}$

The minimum value of the correction factor, f_j, is limited by the fact that the correction should not result in a power greater than the minimum engine power required by the ice class in question. This is expressed with the lower limit of $f_{j,min}$, which can be defined as the average engine power of ships designed for open water ($P_{OW,ave}$) divided by the average engine power of ships with an ice class ($P_{ice\ class,\ ave}$) in question:

$$f_{j,min} = \frac{P_{OW,ave}(dwt)}{P_{ice\ class,ave}(dwt)}.$$

Thus, the present definitions of f_{j0} and $f_{j,\ min}$ are as follows:

$$f_{j0} = \frac{17{,}444 \cdot dwt^{0{,}5766}}{actual\ power\ MCR\ 100\ \%}.$$

Based on the regression analysis equations, the suggested correction factors ($f_{j,\ min}$) are as follows:

Ice class IC: $f_{j,min} = 0{,}8741 * dwt^{0{,}0079}$

Ice class IB: $f_{j,min} = 0{,}7783 * dwt^{0{,}0145}$

Ice class IA: $f_{j,min} = 0{,}4541 * dwt^{0{,}0524}$

Ice class IAS: $f_{j,min} = 0{,}2488 * dwt^{0{,}0903}$

4.2.4 COMPARISON OF THE NEW CORRECTION FACTORS TO THE CURRENT CORRECTION FACTORS

In this section, the new suggested correction factors for power (f_{jo} and $f_{j,\,min}$) are compared to the current correction factors. This has been done for some existing ships from several of the more interesting ice classes (IA and IAS). The sample tankers have been selected as typical sizes for Baltic Sea traffic.

Table 6: Comparison of installed engine power for sample ships.

	Ice class	DWT	L_{pp}	Service speed	$P_{inst.}$	$P_{owreg.}$	$P_{icereg.}$	P_{FSICR}
		tonnes	m	Knots	kW	kW	kW	kW
Ship 1	IAS	14700	132.2	15.3	8450	4463	7453	7247
Ship 2	IAS	25100	159.12	14.5	9450	5991	9668	8605
Ship 3	IA	115000	242	15.2	17647	14443	17271	21344

$P_{inst.}$ = The installed main engine power (100% of MCR).

$P_{owreg.}$ = Average power level according to the regression of open water ships.

$P_{icereg.}$ = Average power level according to ice class regression.

P_{FSICR} = Estimated power according to the FSICR formula.

The power correction factors are calculated using the newly purposed equations and restrictions presented in section 4.2.3 (see Table 7).

Table 7: Comparison of current and new power correction factors.

	Ice class	DWT tonnes	Current correction factors			Purposed new correction factors		
			f_{j0}	f_{jmin}	f_j	f_{j0}	$f_{j,min}$	f_j
Ship 1	IAS	14700	0.575	0.649	**0.649**	0.522	0.592	**0.592**
Ship 2	IAS	25100	0.733	0.686	**0.733**	0.635	0.621	**0.635**
Ship 3	IA	115000	0.879	0.855	**0.879**	0.818	0.836	**0.836**

4.3 BULK CARRIERS

4.3.1 REGRESSION ANALYSIS

For this study, ship data was obtained for bulk carriers built on or after 1 January 2000 with a DWT of 10000 tonnes, which is the minimum deadweight for the required EEDI in the EEDI regulations.

The available data on bulk carriers included a total of 6958 ships, of which the division between open water and different ice classes was as given in Table 8.

Table 8: Number of bulk carriers built on or after 1 January 2000 designed for sailing in open water only and having an ice class included in the study.

Open water bulk carriers	6692
Ice class IC	244
Ice class IB	7
Ice class IA	14
Ice class IAS	1

The database for ice class bulk carriers is much smaller than that for tankers, and especially data on large ships are still lacking. However, the same analysis was done for bulk carriers as for tankers. The same assumptions were made for large bulk carriers as for tankers due to the similarities in hull forms and service speeds. Only one ship could be found in ice class IAS, with the power analysis in this case being based on calculations using the Aker Arctic estimation method. Then, the calculated power levels were compared to the regression analysis done for tankers. Due to the similarities in hull forms and the calculated regression for ice class IAS, this method could be justified.

The assumption was made that the regression follows the same form as for tankers. The regression was seemingly quite similar as for tankers.

The correlation between the DWT and propulsion power for ships without an ice class and ships with various ice classes is determined by using regression analysis.

Figure 4 shows the regression curves for engine power for open water ships and various ice class ships and the results of the regression analysis are given in Table 9.

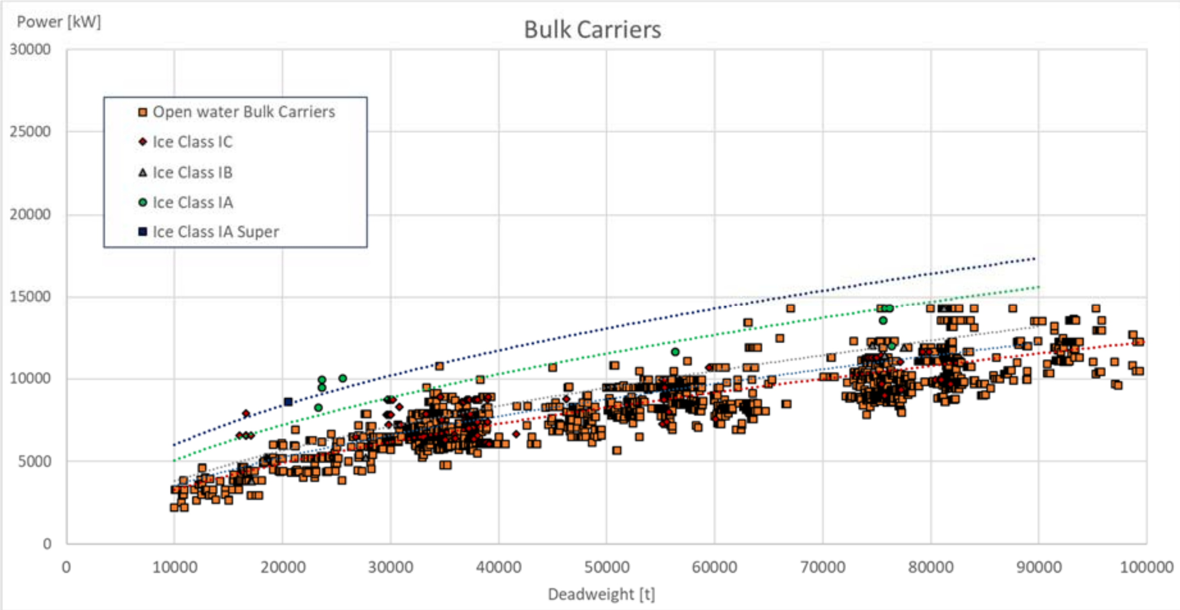


Figure 4: Average engine power of existing bulk carriers with and without an ice class.

Note: Dots and corresponding regression line are in the same colours

Table 9: The power regression for the studied bulk carriers.

Open water/ice class	Average engine power [kW]	R^2
Open water	$17.207 * dwt^{0.5705}$	0.9276
IC	$20.070 * dwt^{0.5618}$	0.4412
IB	$21.308 * dwt^{0.5634}$	0.8476
IA	$43.918 * dwt^{0.5149}$	0.7134
IA Super	$68.431 * dwt^{0,4854}$	–

Just as with tankers, bulk carriers with a low Finnish-Swedish ice class (IC and IB) have only slightly higher installed power than open water ships. Bulk carriers with higher ice classes (IA or IAS) differ already more from open water ships.

Based on the information given in Table 9, the difference in the MCR of tankers having an ice class compared to open water tankers can be defined. The difference in average engine power (Delta power) is presented in Figure 5.

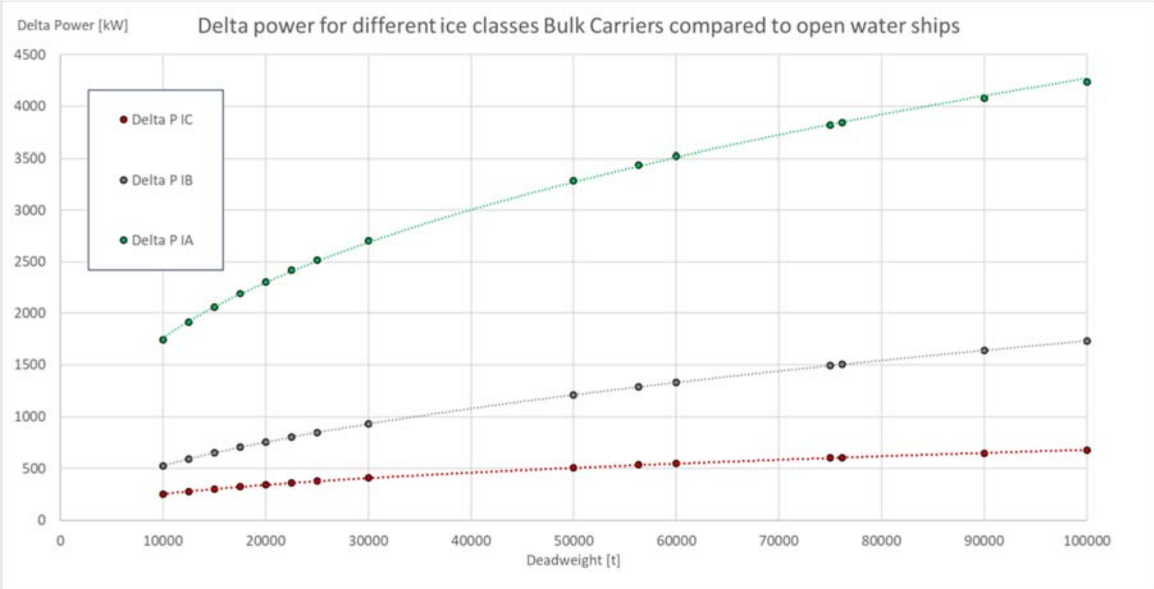


Figure 5: Difference in average engine power of bulk carriers having an ice class compared to open water bulk carriers.

The installed higher power of ice class IA bulk carriers with a DWT of 25000 tonnes is approximately 45% higher than for open water ships. For a bulk carrier of the same size but with ice class IAS, the increase in power is more than 60%.

One method to determine the propulsion power required for an ice class is by using ice model tests. Based on the ice model test, Aker Arctic has developed a method for estimating the required power for wide ships. The method is based on a database of model scale tests for FSICR brash ice channel resistance tests run at an Aker Arctic model basin. This method gives similar required power levels as on built ships.

Therefore, it can be supposed that the Delta power achieved via regression analyses also in this case represents the power level at which a ship might achieve a Finnish-Swedish ice class, by ice model testing, especially for higher ice classes and large ships. The following table presents the installed power for bulk carriers achieved via regression analysis.

Table 10: Relative engine power difference for ice class bulk carriers compared to bulk carriers designed for open water only based on regression analysis.

Ship type	DWT	Regression of open water bulk carriers	Regression of Ice Class IC	Regression of Ice Class IB	Regression of Ice Class IA	Regression of Ice Class IAS
		[kW]				
Bulk carrier	10000	~3300	93%	116%	153%	182%
Bulk carrier	25000	~5550	94%	115%	145%	168%
Bulk carrier	50000	~8250	94%	115%	140%	158%
Bulk carrier	75000	~10400	95%	114%	137%	153%

Just as with tankers, bulk carriers have a difference in power than open water and ice class ships due to the fact that a ship needs higher installed power to be able to fulfil at least the required speed and brash ice channel condition defined by the FSCIR.

4.3.2 REQUIRED POWER ACCORDING TO FSICR FORMULA

The required engine power with the FSICR formula was determined by using a generic hull form defined for this purpose. This method was used only for checking if the formula yielded different results compared to engine power in existing ships. The used generic hull form represents a typical bulbous bow shape for each ship type (see Figure 1). The calculations were done by assuming a typical propeller arrangement (propeller type and number of propellers) for this ship type.

The FSICR formula result in higher power requirements especially for large ships in ice classes IA and IAS than has been installed in existing tankers. The reason for this is that for ice classes IA and IAS, the engine power has in most cases been determined by the results from ice model tests, which generally give lower level of ice resistance than the FSICR formula.

Table 11: Average engine power for four sizes of bulk carriers designed for open water only compared to the calculated required minimum engine power of Finnish-Swedish ice classes IC, IB, IA and IA Super.

Ship type	DWT	Regression of open water bulk carriers	FSICR formula Ice Class IC	FSICR formula Ice Class IB	FSICR formula Ice Class IA	FSICR formula Ice Class IAS
		kW	kW	kW	kW	kW
Bulk carriers	10000	~3300	~1900	~3060	~4330	~6910
Bulk carriers	25000	~5550	~2760	~4220	~6230	~9690
Bulk carriers	50000	~8250	~4190	~6120	~9210	~14030
Bulk carriers	75000	~10400	~5590	~7980	~11930	~18000

The difference in power between open water and ice class ships will probably increase when the forthcoming EEDI phases enter into force due the fact to that a ship will naturally need more installed power to have some ice-going capabilities, at least with respect to what the FSICR require as the minimum level of power for brash ice channel conditions. It must be noted that for ice classes IC or IB, the installed power is higher than that required by the FSICR formula because the higher installed power is usually dependent upon open water requirements, such as speed and manoeuvrability in open water.

4.3.3 PROPOSED NEW POWER CORRECTION FACTOR F_J FOR BULK CARRIERS

The correction factor for power f_j for ice-classed ships is calculated in same way as described in section 4.2.3.

The basic form of the present correction factor for power f_j requires using an MCR of 100%:

$$f_{j0} = \frac{P_{OW,ave}(dwt)}{actual\ power}.$$

The average power versus DWT is achieved via regression analysis using the Maritime IHS database for bulk carriers. The obtained equations are then used for open water and ice class ships:

Table 12: The power regression for the studied bulk carriers.

Open water/ice class	Average engine power [kW]
Open water	$17.207 * dwt^{0.5705}$
IC	$20.070 * dwt^{0.5618}$
IB	$21.308 * dwt^{0.5634}$
IA	$43.918 * dwt^{0,5149}$
IA Super	$68.431 * dwt^{0,4854}$

The minimum value of correction factor f_j is limited by the fact that the correction should not result in a power greater than the minimum power required by the different ice class. This is expressed via the lower limit of $f_{j,min}$, which can be defined as follows:

$$f_{j,min} = \frac{P_{OW,ave}(dwt)}{P_{ice\ class,ave}(dwt)}.$$

Thus, the present definitions for f_{j0} and $f_{j,\ min}$ are as follows:

$$f_{j0} = \frac{17{,}207 \cdot dwt^{0{,}5705}}{actual\ power\ MCR\ 100\ \%}.$$

Based on the regressions analysis equations, the suggested correction factors ($f_{j,\ min}$) are then as follows:

Ice class IC: $f_{j,min} = 0{,}8573 * dwt^{0{,}0087}$

Ice class IB: $f_{j,min} = 0{,}8075 * dwt^{0{,}0071}$

Ice class IA: $f_{j,min} = 0{,}3918 * dwt^{0{,}0556}$

Ice class IAS: $f_{j,min} = 0{,}2515 * dwt^{0{,}0851}$

4.3.4 COMPARISON OF THE NEW CORRECTION FACTORS TO THE CURRENT CORRECTION FACTORS

In this section, the new suggested power correction factors f_{jo} and $f_{j,\ min}$) are compared to the current power correction factors. This has been done for some existing ships of the most interesting ice classes (IA and IAS). The sample bulk carriers have been selected as typical sizes for Baltic Sea traffic.

Table 13: Comparison of installed power for sample bulk carriers.

	Ice class	DWT	Lpp	Service speed	P_{inst}	P_{owreg}	P_{icereg}	P_{FSICR}
		tonnes	m	Knots	kW	kW	kW	kW
Ship 1	IAS	20499	146	13.0	8580	4961	8476	7247
Ship 2	IA	56348	189.04	14.5	11620	8832	12271	8605
Ship 3	IA	76180	220	14.5	14280	10490	14332	21344

$P_{inst.}$ = The installed main engine power (100% of MCR).

$P_{owreg.}$ = Average power level according to the regression of open water ships.

$P_{icereg.}$ = Average power level according to ice class regression.

P_{FSICR} = Estimated power according to the FSICR formula.

The power correction factors are calculated using the new suggested formula and restrictions presented in section 4.3.3.

Table 14: Comparison of current and new power correction factor.

	Ice class	DWT tonnes	Current correction factors			Purposed new correction factors		
			f_{j0}	f_{jmin}	f_j	f_{j0}	$f_{j,min}$	f_j
Ship 1	IAS	20499	0.621	0.736	**0.736**	0.578	0.592	**0.592**
Ship 2	IA	56348	0.722	0.837	**0.837**	0.760	0.720	**0.760**
Ship 3	IA	76180	0.766	0.846	**0.846**	0.735	0.732	**0.735**

4.4 GENERAL CARGO SHIPS

4.4.1 REGRESSION ANALYSIS

For this study, ship data was obtained for general cargo ships built on or after 1 January 2000 with a DWT of 3000 tonnes, which is the minimum deadweight for the required EEDI in the EEDI regulations. The available data on general cargo ships included a total of 3463 ships, of which the division between open water and different ice classes was as given in Table 15.

Table 15: Number of general cargo ships built on or after 2000 designed for sailing in open water only and having an ice class included in the study.

Open water general cargo ships	2590
Ice class IC	191
Ice class IB	111
Ice class IA	564
Ice class IAS	7

The correlation between the DWT and propulsion power for ships without an ice class and ships with various ice classes is determined by using regression analysis.

Figure 6 shows the regression curves for engine power for open water ships and various ice class ships; the results of the regression analysis are given in Table 16.

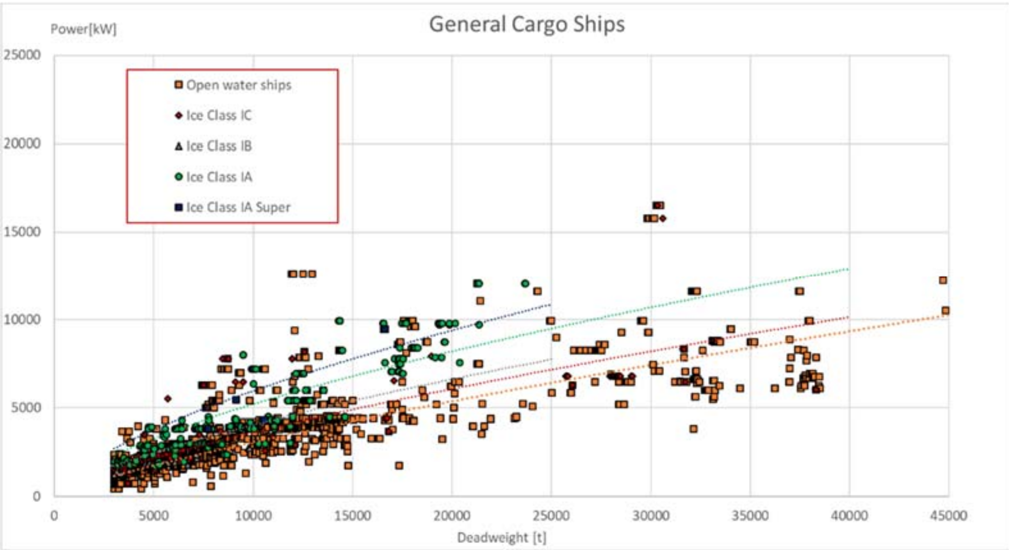


Figure 6: Average engine power of existing general cargo ships with and without an ice class.

Note: Dots and corresponding regression line are in the same colours.

Table 16: The power regression for the studied general cargo ships.

Open water/ice class	Average engine power [kW]	R^2
Open water	$1.974 * dwt^{0.7987}$	0.7898
IC	$3.975 * dwt^{0.7404}$	0.7851
IB	$6.063 * dwt^{0.7065}$	0.6757
IA	$12.546 * dwt^{0.6547}$	0.8506
IA Super	$14.293 * dwt^{0.6552}$	0.7973

The table above presents the power regression for the studied general cargo ships.

Just as with the tankers and bulk carriers, general cargo ships with lower Finnish-Swedish ice classes (IC and IB) have only slightly higher installed power than open water ships. General cargo ships with higher ice classes (IA or IAS) already differ more from pure open water ships.

Based on the information given in Table 16, the difference in average engine power (MCR) of general cargo ships having an ice class compared to open water tankers can be defined. The difference in average engine power (delta power) is presented in Figure 7.

Figure 7: Difference in engine power of general cargo ships having an ice class compared to open water general cargo ships.

The installed higher power of ice class IA general cargo ships with a DWT of 20000 tonnes is approximately 45% higher than for open water ships. For a ship of the same size, but with ice class IAS, the increase in power is approximately 55%.

Therefore, it can be assumed that the delta power achieved via regression analyses in this case also represents the power level at which the ship might achieve a Finnish-Swedish ice class, by ice model testing, especially for higher ice classes and large ships.

The following table presents the installed power for general cargo ships determined via regression analysis.

Table 17: Relative power increase for ice class general cargo ships based on regression analysis.

Ship type	DWT	Regression of Open water general cargo	Regression of Ice Class IC	Regression of Ice Class IB	Regression of Ice Class IA	Regression of Ice Class IAS
		[kW]				
General cargo	5000	~1780	123%	140%	186%	213%
General cargo	10000	~3100	118%	131%	169%	193%
General cargo	20000	~5400	113%	123%	153%	175%
General cargo	40000	~9400	109%	116%	138%	158%

Just as with tankers and bulk carriers with lower Finnish-Swedish ice classes (IC and IB), general cargo ships have only a slightly higher installed power than open water ships, varying from 400 to 800 kW for ice class IC and being approximately 1500 kW with a DWT of 45000 tonnes for ice class IB. Engine power in general cargo ships with higher ice classes (IA or IAS) differs already more from open water ships.

General cargo ships have a difference in power than open water and ice class ships due to the fact that a ship needs higher installed power to be able to fulfil at least the required speed and brash ice channel condition defined by the FSCIR.

4.4.2 REQUIRED ENGINE POWER ACCORDING TO THE FSICR FORMULA

The required power according to the FSICR formula can be determined by using a generic hull developed for this purpose, though this method only shows the difference the formula gives for existing ships. The required power has been calculated by using the FSICR formula (3.1 and 3.2 in section 3.2). The formula gives a relatively high power compared to built ships. The required engine output for ice classes IA Super, IA, IB and IC will therefore have a greater difference than pure open water ships, which might lead to large correction factors for wide ships.

The required power according to the FSICR formula can be determined by using a generic hull developed for this purpose, though this method is only for showing the difference the formula gives for existing ships.

The required power according to the FSICR formula is given in Table 18 for four sizes of general cargo ships.

Table 18: *: Average engine power for four sizes of general cargo ships designed for open water only compared to the calculated required minimum engine power of Finnish-Swedish ice classes IC, IB, IA and IA Super.*

Ship type	DWT	Regression of open water general cargo	FSICR formula Ice Class IC	FSICR formula Ice Class IB	FSICR formula Ice Class IA	FSICR formula Ice Class IAS
		[kW]	[kW]	[kW]	[kW]	[kW]
General cargo	5000	~1780	~1560	~2360	~3390	~4770
General cargo	10000	~3100	~2150	~3390	~5080	~7100
General cargo	20000	~5400	~3200	~5150	~7860	~11020
General cargo	40000	~9400	~4680	~7470	~11000	~15870

The difference in engine power between an open water and an ice class ship will most likely increase when the forthcoming EEDI phases enter into force due to the fact that a ship will naturally need more installed power in order to have some ice-going capability, at least according to the minimum FSICR requirements for brash ice channel conditions. This will certainly be the case if more stringent EEDI requirements result in lower levels of engine power for ships designed for open water.

It must be noted that for ice class IC, the installed power is higher than required by the FSICR formula because the higher installed power is usually dependent upon open water requirements, such as speed and manoeuvrability in open water.

4.4.3 PROPOSED NEW POWER CORRECTION FACTOR F_J FOR GENERAL CARGO SHIPS

The correction factor for power, f_j, for ice-classed ships is calculated in the same way as described in section 4.2.3

The basic form of the present correction factor for an MCR of 100% power, f_j, is as follows:

$$f_{j0} = \frac{P_{OW,ave}(dwt)}{actual\ power}.$$

The average power versus DWT is determined via regression analysis using the Maritime IHS database for general cargo ships. The obtained equations are then used for open water and ice class ships:

Table 19: The power regression for the studied general cargo ships.

Open water/ice class	Average engine power [kW]
Open water	$1.974 * dwt^{0.7987}$
IC	$3.975 * dwt^{0.7404}$
IB	$6.063 * dwt^{0.7065}$
IA	$12.546 * dwt^{0.6547}$
IA Super	$14.293 * dwt^{0.6552}$

The minimum value of correction factor f_j is limited by the fact that the correction should not result in a power greater than the minimum power required by the different ice class. This is expressed via the lower limit of $f_{j,min}$, which can be defined as follows:

$$f_{j,min} = \frac{P_{OW,ave}(dwt)}{P_{ice\ class,ave}(dwt)}.$$

Thus, the present definitions for f_{j0} and $f_{j,\ min}$ are

$$f_{j0} = \frac{1{,}974 \cdot dwt^{0.7987}}{actual\ power\ MCR\ 100\ \%}.$$

Based on the regressions analysis equations, the suggested correction factors ($f_{j,\ min}$) are the following:

Ice class IC: $f_{j,min} = 0.4966 * dwt^{0,0583}$

Ice class IB: $f_{j,min} = 0.3256 * dwt^{0,0922}$

Ice class IA: $f_{j,min} = 0.1574 * dwt^{0,144}$

Ice class IAS: $f_{j,min} = 0.1381 * dwt^{0,1435}$

4.4.4 COMPARISON OF THE NEW CORRECTION FACTORS TO THE CURRENT CORRECTION FACTORS

In this section, the new suggested power correction factors (f_{jo} and $f_{j,\ min}$) are compared to the current power correction factors. This has been done for some existing ships of the most interesting ice classes (IA and IAS). The sample general cargo ships have been selected as typical sizes for Baltic Sea traffic.

Table 20: Comparison of installed power for sample general cargo ships.

	Ice class	DWT	Lpp	Service speed	P_{inst}	P_{owreg}	P_{icereg}	P_{FSICR}
		tonnes	m	Knots	kW	kW	kW	kW
Ship 1	IA	3724	84.56	12.5	1880	1430	2732	2155
Ship 2	IA	7868	111.85	14.0	3840	2552	4457	3614
Ship 3	IAS	16615	165.7	15.5	9480	4273	8325	9720
Ship 4	IA	20170	155.79	17.0	9800	5414	8256	11497

$P_{inst.}$ = The installed main engine power (100% of MCR).

$P_{owreg.}$ = Average power level according to the regression of open water ships.

$P_{icereg.}$ = Average power level according to ice class regression.

P_{FSICR} = Estimated power according to the FSICR formula.

The power correction factors are calculated using the new suggested equations and restrictions presented in section 4.4.3.

Table 21: Comparison of current and new power correction factor.

	Ice class	DWT tonnes	Current correction factors			Purposed new correction factors		
			f_{j0}	f_{jmin}	f_j	f_{j0}	$f_{j,min}$	f_j
Ship 1	IA	3724	0.982	0.732	**0.982**	0.926	0.592	**0.926**
Ship 2	IA	7868	0.962	0.757	**0.962**	0.821	0.641	**0.821**
Ship 3	IAS	16615	1.035	0.702	**1.000**	0.642	0.647	**0.647**
Ship 4	IA	20170	0.859	0.788	**0.859**	0.718	0.759	**0.759**

4.5 CONTAINER SHIPS

4.5.1 REGRESSION ANALYSIS

The installed power of container ships was studied in the same way as with the ship types presented in earlier sections. Only ships with a DWT larger than 10 000 tonnes are included, but also ships with a DWT larger than 50000 tonnes were left out due to the fact that no ice class ships of that size have been built or ordered.

Available data for tankers included a total of 2594 ships, of which the division between open water and different ice classes was as given in Table 22.

Table 22: Number of container ships designed for sailing in open water only and having an ice class included in the study.

Open water container ships	1344
Ice class IC	40
Ice class IB	1
Ice class IA	155
Ice class IAS	22

Figure 8 shows the regression curves for the engine power of open water ships and various ice class ships; the results of the regression analysis are given in Table 23.

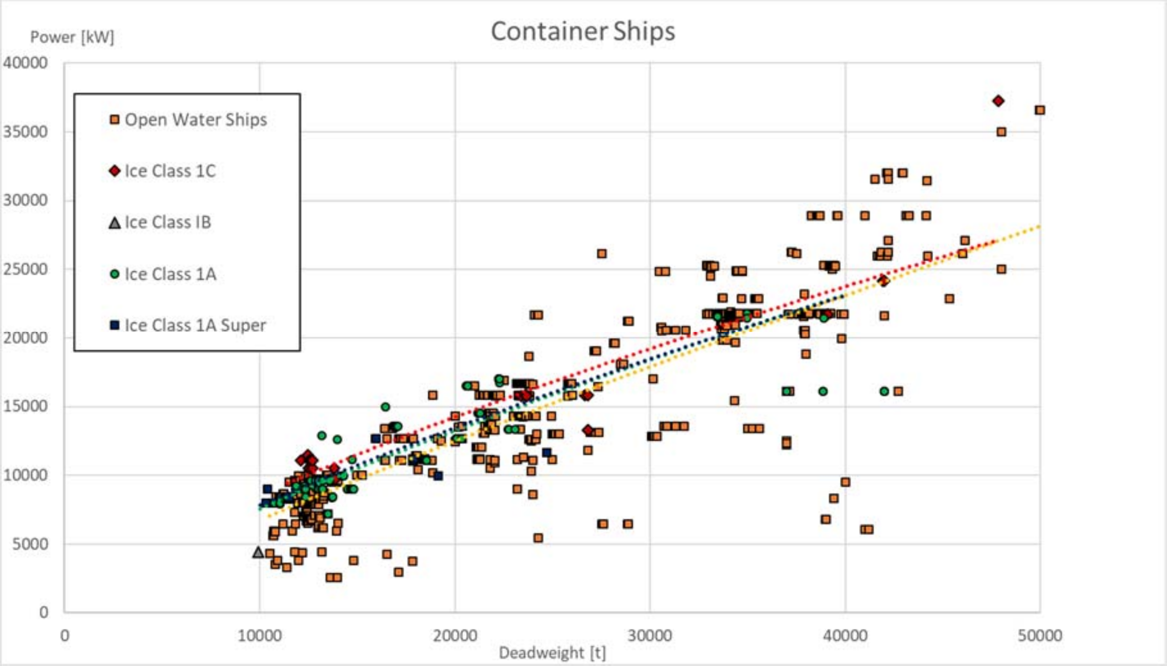


Figure 8. Average engine power of existing container ships with and without an ice class.

Note: Dots and corresponding regression lines are presented in the same colours.

No clear regression for ice class container ships could be determined because no clear differences could be determined between open water and ice class ships.

Table 23: Regression formula for average engine power of the studied container ships.

Open water/ice class	Average engine power [kW]	R^2
Open water	$1.919 * dwt^{0.8867}$	0.7433
IC	$9.337 * dwt^{0.8640}$	0.8640
IB	*No ships in the database*	
IA	$4.459 * dwt^{0.8074}$	0.8072
IA Super	$5.864 * dwt^{0.7813}$	0.3944

The DWT vs. installed power might not be the final way to define the correction factors due to the fact that ship type is volume based and usually the capacity is defined as number of containers (TEU). The installed power is also more dependent on service speed in open water than on the power needed in ice.

Due to the relatively high open water speed and the high power of open water container ships, the installed power in container ships is seemingly almost the same for open water ships and for ships with an ice class. It is worth noting that ships with ice class IC seemingly have the highest installed power. The installed power in ice classes IA and IAS is only marginally higher on smaller ships and equal on large ships. Unfortunately, only one ship with ice class IB was found, and no statistical analysis of engine power could be done for that ice class.

Table 24: Relative power increase for ice class container ships based on regression analysis.

Ship type	DWT	Regression of open water container ships	Regression of Ice Class IC	Regression of Ice Class IB	Regression of Ice Class IA	Regression of Ice Class IAS
		[kW]				
Container ship	10000	~6800	126% *)	**)	112% *)	116% *)
Container ship	15000	~8250	119% *)	**)	108% *)	111% *)
Container ship	25000	~9700	110% *)	**)	104% *)	105% *)
Container ship	40000	~11100	103% *)	**)	100% *)	100% ***)

*) No regression possible, estimated power average for ship with similar DWT.
**) Only one ship in ice class IB.
***) No ships in that size, estimated via extrapolation.

4.5.2 REQUIRED POWER ACCORDING TO THE FSICR FORMULA

The required power according to the FSICR formula can be determined by using a generic hull constructed for this purpose. The required power for container ships was calculated using the FSICR formula (3.1 and 3.2 in section 3.2.). This method only shows the difference that the formula gives for existing ships.

Table 25: Average engine power for four sizes of container ships designed for open water only compared to the calculated required minimum engine power of Finnish-Swedish ice classes IC, IB, IA and IA Super.

Ship type	DWT	Regression of open water container ships	FSICR formula Ice Class IC	FSICR formula Ice Class IB	FSICR formula Ice Class IA	FSICR formula Ice Class IAS
		[kW]	[kW]	[kW]	[kW]	[kW]
Container ship	10000	~6800	~2830	~4470	~6610	~8650
Container ship	15000	~8250	~3440	~5280	~7660	~9940
Container ship	25000	~9700	~4360	~6470	~9310	~11930
Container ship	40000	~11100	~5000	~7120	~10670	~13400

The installed engine power for open water container ships is, in general, on the same level or higher than that required by the ice class. In this respect, it seems that the minimum engine power requirements of the FSICR can be achieved even when the phase 3 requirements of the EEDI will enter into force.

4.5.3 CONSIDERATION OF THE NEED FOR POWER CORRECTION FACTORS FOR CONTAINER SHIPS

The regression analysis based on DWT indicates that there are no real differences in the powering of ice classed and open water ships. As a result, ice class IC seems to have the highest installed power of the studied container ships, while ships with ice class IA and IAS have about same power level, which is only marginally higher than for open water ships.

The calculated power levels required by the FSICR for the different ice classes are usually lower than those installed on open water ships.

In this respect, it seems that there is no need to introduce power correction factors, f_j, for container ships at this moment.

If the power levels of container ships will be reduced in the future, the same method as described above for tankers, bulk carriers and general cargo ships can be used. If regression analysis cannot determine the power correction factors, f_j, they could then be based on the power regression analysis of the engine power required by open water ships and calculated based on the required power for the ice class in question. Alternatively, further studies could be done to determine another way to develop ice class correction factors for power, for example based on the container capacity.

4.6 RO-RO SHIPS

4.6.1 REGRESSION ANALYSIS

The installed engine power of ro-ro ships was studied in the same way as for the ship types presented in the previous sections. For this study, ship data was obtained for ro-ro ships with a DWT of more than 2000 tonnes, which is the minimum deadweight for the required EEDI in the EEDI regulations.

Available data on ro-ro ships included a total of 147 ships, of which the division between open water and different ice classes was as given in Table 26.

Table 26: Number of ro-ro ships designed for sailing in open water only and having an ice class included in the study.

Open water ro-ro ships	75
Ice class IC	11
Ice class IB	8
Ice class IA	36
Ice class IAS	17

Figure 9 shows the results of regression analysis with respect to the average engine power for ro-ro ships without an ice class. Data on ice-classed ships are presented in the same figure as dots.

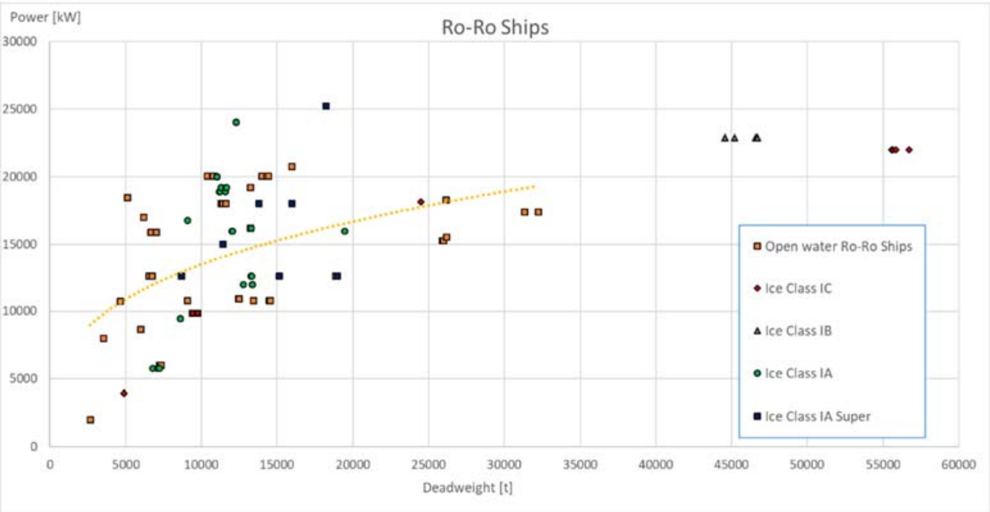


Figure 9: Average engine power of existing ro-ro ships with and without an ice class.

Only one ship series has been built in ice class IB and statistical analysis is therefore not possible for this ice class.

Table 27: Power regression for open water ro-ro ships.

Open water/ice class	Average engine power [kW]	R^2
Open water	$790.42 * dwt^{0.3080}$	0.1726

As for container ships, the installed engine power is more dependent on service speed in open water than on the required minimum engine power of the ice classes. The DWT/Installed power might not be the ultimate way to define the correction factors due to the fact that ship type is volume based and the capacity is often defined as line metres for ro-ro ships.

The installed power in ro-ro ships varies a great deal and one regression might not represent all ships. No clear tendency on differences in the powering of open water ships compared to ice class ships could be found. Similar to container ships, no regression formula on correction factors for the power of ice class ro-ro ships could be determined because of the fact that no clear differences in engine power could be determined between open water and ice class ships for ice classes IC and IA. The engine power levels are seemingly the same for those ice classes and for open water ships, which indicates that the high engine power levels resulting from the need for high speed is also sufficient for ships with an ice class. Only for ice class IAS did the power levels seem to be slightly higher than for open water ships.

Table 28: Relative difference in engine power for ice class ro-ro ships compared to four sizes of ro-ro ships designed for open water only.

Ship type	DWT	Regression of open water ro-ro ships	Regression of Ice Class IC	Regression of Ice Class IB	Regression of Ice Class IA	Regression of Ice Class IAS
		[kW]				
Ro-Ro ship	5000	~10900	65% *)	**)	63%	109% *)
Ro-Ro ship	10000	~13500	78% *)	**)	81%	111% *)
Ro-Ro ship	15000	~17000	80% *)	**)	87%	103% *)
Ro-Ro ship	25000	~18000	100% *)	**)	115%	***)

*) No regression possible, estimated power average for ships with approximately the same DWT.
**) Only one ship series in ice class IB.
***) No ships in that size.

4.6.2 REQUIRED ENGINE POWER ACCORDING TO THE FSICR FORMULA

The required minimum engine power according to the FSICR formula can be determined by using a generic hull developed for this purpose. The required power for ro-ro ships was calculated using the FSICR formula (3.1 and 3.2 in section 3.2.). This method only shows the difference that the formula gives for existing ships.

Table 29: Average engine power for four sizes of ro-ro ships designed for open water only compared to the calculated required minimum engine power of Finnish-Swedish ice classes IC, IB, IA and IA Super.

Ship type	DWT	Regression of Open Water ro-ro ship	FSICR formula Ice Class IC	FSICR formula Ice Class IB	FSICR formula Ice Class IA	FSICR formula Ice Class IAS
		[kW]	[kW]	[kW]	[kW]	[kW]
Ro-Ro ship	5000	~10900	~2180	~3550	~5260	~7550
Ro-Ro ship	10000	~13500	~2970	~4800	~7080	~10100
Ro-Ro ship	15000	~17000	~3560	~5740	~8430	~12000
Ro-Ro ship	25000	~18000	~4480	~7180	~10500	~14900

The installed engine power for ro-ro ships is usually higher than required by the FSCIR. In this respect, it seems that the required minimum engine power for ships with an ice class can in the future even be achieved for ro-ro ships that comply with the EEDI regulations.

4.6.3 CONSIDERATION OF THE NEED FOR POWER CORRECTION FACTORS FOR RO-RO SHIPS

The regression analysis based on the DWT indicates that there are no real differences in the engine power of ice-classed and open water ships. The calculated power levels required by the FSICR for the different ice classes are usually lower than the installed engine power on open water ships. In this respect, it seems that there is no need to introduce the power correction factors, *fj*, for ro-ro ships at this moment.

If the power levels of ro-ro ships will be reduced in the future, the same method as described above for tankers, bulk carriers and general cargo ships can be used. If regression analysis cannot determine the power correction factor, *fj*, it could then be based on regression analysis of the engine power required by open water ships and the calculated based on the required minimum engine power for the ice class in question.

Alternatively, further studies could be done to determine another way to develop ice class correction factors for power, for example based on line metres of ro-ro ships.

4.7 LNG CARRIERS

4.7.1 REGRESSION ANALYSIS

The installed engine power of LNG carriers was studied in the same way as for the ship types presented in the previous sections. For LNG carriers, ship data was obtained for ships with a DWT of more than 2000 tonnes, which is the minimum deadweight for the required EEDI in the EEDI regulations.

The number of LNG carriers with an ice class is quite small compared to the other studied ship types, e.g. no ships with ice class IC and IAS were found.

Data on only three ships was available for ice class IB. Only 12 ships have been built that fit ice class IA. This means that no statistical analysis is possible for LNG carriers with an ice class.

Available data on LNG carriers built on or after 1 January 2000 included a total of 418 ships, of which the division between open water and different ice classes was as given in Table 30.

Table 30: Number of LNG carriers built on or after 2000 designed for sailing in open water only and having an ice class included in the study.

Open water LNG carriers	403
Ice class IC	-
Ice class IB	3
Ice class IA	12
Ice class IAS	-

As Figure 10 shows, all of the ships with an ice class differ very little from the engine power of open water LNG carriers. Figure 9 shows the results of the regression analysis for LNG carriers without an ice class. Ships with an ice class are presented in same figure as dots.

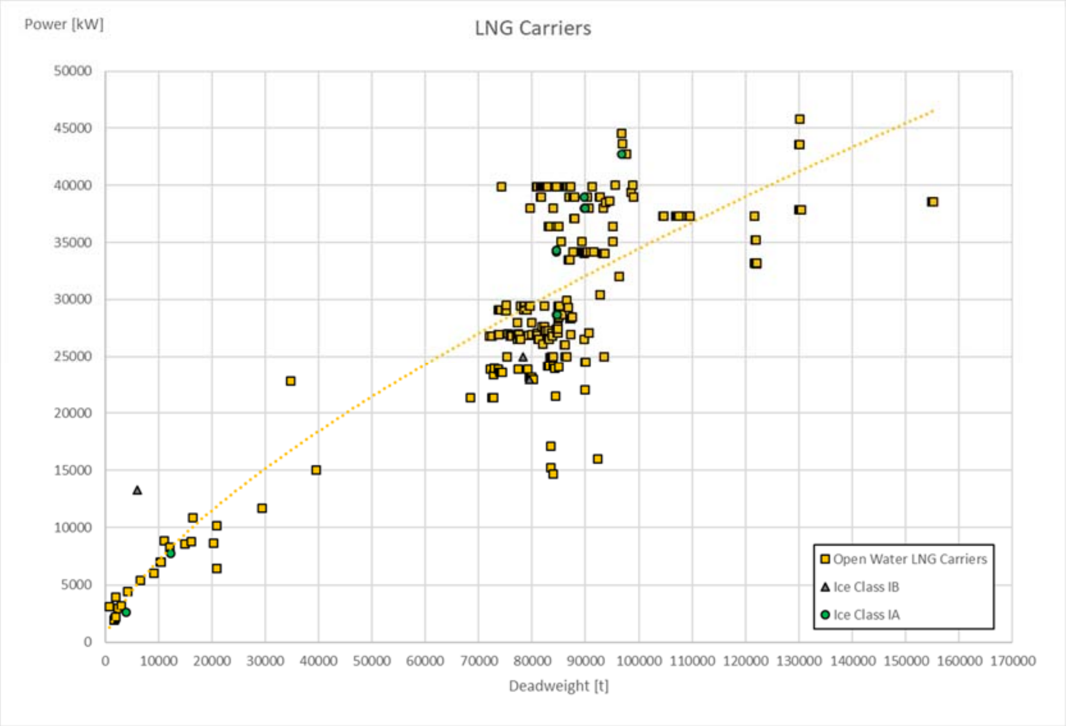


Figure 10: Average engine power of existing LNG carriers with and without an ice class.

Table 31: Power regression for open water LNG carriers.

Open water/ice class	Average engine power [kW]	R^2
Open water	$8.524 * dwt^{0.7220}$	0.7828

The table presents the results of the regression analysis of LNG carriers designed for sailing in open water only.

The installed engine power in LNG carriers is seemingly almost the same for open water ships and for ships with an ice class. Unfortunately, only ships with ice class IB and IA were found, and no regression analysis for engine power could be done for the other ice classes.

As for container and ro-ro ships, the installed power is more dependent on the service speed, which is higher than 15 knots and usually around 19–20 knots in open water. This open-water speed typically requires higher installed power than what is required for an ice class.

The DWT/Installed power might not be the ultimate way to define the correction factors because this ship type is volume based and usually the capacity is defined in cubic metres.

Table 32: *Relative difference in engine power for ice class LNG carriers compared to four sizes of LNG carriers designed for open water only.*

Ship type	DWT	Regression of open water ships	Regression of Ice Class IC	Regression of Ice Class IB	Regression of Ice Class IA	Regression of Ice Class IAS
		[kW]				
LNG Carrier	2000	~2100	**)	120% *)	76% *)	**)
LNG Carrier	10000	~6600	**)	108% *)	89% *)	**)
LNG Carrier	40000	~17900	**)	98% *)	103% *)	**)
LNG Carrier	80000	~30000	**)	93% *)	111% *)	**)

*) No regression possible, estimated average engine power is determined for ships having approximately the same DWT.
**) No ships with an ice class.

4.7.2 REQUIRED ENGINE POWER ACCORDING TO THE FSICR FORMULA

The required engine power according to the FSICR formula can be determined by using a generic hull developed for this purpose. The required engine power for LNG carriers was calculated using the FSICR formula (3.1 and 3.2 in section 3.2. of the FSICR). This method only shows the difference in engine power that the formula gives for existing ships.

Table 33: Average engine power for four sizes of LNG carriers designed for open water only compared to the calculated required minimum engine power of Finnish-Swedish ice classes IC, IB, IA and IA Super.

Ship type	DWT	Regression of open water LNG carriers	FSICR formula Ice Class IC	FSICR formula Ice Class IB	FSICR formula Ice Class IA	FSICR formula Ice Class IAS
		[kW]	[kW]	[kW]	[kW]	[kW]
LNG Carrier	5000	~4000	~1780	~2840	~4130	~5860
LNG Carrier	10000	~6600	~2250	~3540	~5140	~7210
LNG Carrier	40000	~17900	~4910	~7950	~11600	~16260
LNG Carrier	80000	~30000	~8180	~14400	~23040	~31200

The installed engine power for LNG carriers is about the same for ships designed for open water as for ice class ships. Only for ice class IAS is the installed engine power slightly higher than for open water ships. In this respect, it seems that there is no need to introduce the power correction factors, *fj*, for LNG carriers at this moment.

4.7.3 CONSIDERATION OF THE NEED FOR POWER CORRECTION FACTORS FOR LNG CARRIERS

The installed engine power in LNG carriers is generally higher than the required minimum engine power given in the FSICR for ice classes. As a conclusion, there is no need to introduce power correction factors, f_j, for LNG carriers at this time. If the power levels of LNG carriers are reduced in the future, then the same method as described above for tankers, bulk carriers and general cargo ships can be used. If regression analysis is not possible, the power correction factor, f_j, could be based on the regression analysis of engine power required by open water ships and the calculated based on the required minimum engine power for the ice class in question.

Alternatively, further studies could be done to determine another way to develop ice class correction factors for power, for example based on the carrying capacity in cubic metres of LNG carriers.

5 ENERGY EFFICIENCY DESIGN INDEX

5.1 GENERAL

In this section, the Energy Efficiency Design Index (EEDI) has been calculated using the proposed new capacity correction factors, f_i, and the power correction factors, f_j. The calculations were only made for the most important ship types: tankers, bulk carriers and general cargo ships. The three other ship types were left out since the results of the analysis have already been given in the previous sections of this report. The basis for the new correction factors will be briefly described in the next sections.

5.2 CAPACITY CORRECTION FACTOR F_I

5.2.1 BACKGROUND OF THE ICE CLASS CORRECTION FACTORS FOR CAPACITY

The current ice class correction factors for capacity for tankers, bulk carriers, general cargo ships, containerships and gas carriers having a Finnish–Swedish ice class of IC, IB, IA or IA Super are based on a proposal by Finland (see EE-WG 2/2/9). The existing ice class correction factors for capacity can be found in section 2.11.1 of the 2014 Guidelines.

The existing ice class correction factors for capacity were statistically determined based on data on existing ships, as is explained in detail in EE-WG 2/2/9. The purpose of the capacity correction factor is to take into account the decrease in the DWT of an ice-strengthened ship due to the additional steel and machinery weight necessary for ice strengthening compared to a ship without an ice class and because the hull shape may be designed for improved ice-going capability; therefore, the block coefficient (C_b) of a ship may be smaller than in ships designed for sailing only in open water.

5.2.2 DEVELOPMENT OF THE NEW ICE CLASS CORRECTION FACTORS FOR CAPACITY

There has been discussion on the need to extend the ice class correction factors to other ship types. It would also be useful to develop a methodology that makes it possible to determine the ice class correction factors for capacity for ice classes other than the Finnish–Swedish ice classes. The industry has also expressed some concerns about the applicability of the current ice class correction factors in practical design work (see the comments made by BIMCO in MEPC 70/INF.29).

However, due to the small number of ships having an ice class in other ship categories, it is quite difficult to develop correction factors for other ship types using the statistical method. Therefore, a new methodology was applied to develop the new ice class correction factors for capacity.

The ice class correction factors should take into account two issues that will decrease the capacity, i.e. the DWT of an ice-strengthened ship compared to a ship of similar size designed to sail only in open water: The increase in steel weight due to ice strengthening and a smaller block coefficient if the hull form is specially designed for ice-going purpose.

5.2.3 DECREASE OF DWT DUE TO ICE STRENGTHENING

To determine the new ice class correction factors for capacity resulting from a decrease in DWT due to hull ice strengthening, the procedure given in section 2.11.2 of the 2014 Guidelines, i.e. the use of a ship-specific voluntary structural enhancement correction factor, f_{iVSE} (see section 2.11.2 of the 2014 Guidelines), was applied:

$$f_{iVSE} = \frac{DWT_{reference\ design}}{DWT_{enhanced\ design}},$$

where $DWT_{reference\ design}$ is the deadweight of a ship designed for sailing in open water and $DWT_{enhanced\ design}$ is the deadweight of a ship having an ice class. Both ships were assumed to have the same displacement and the same steel grade as required in the 2014 Guidelines.

In addition of the five ship types for which the ice class correction factors for capacity have been given in the 2014 Guidelines, the additional steel weight as a result of ice strengthening was also calculated for ro-ro cargo ships. The calculations were done for four ship sizes, i.e. all ship types having the ice class IC, IB, IA and IA Super. Other aspects of ice strengthening, like ice strengthening of the propulsion machinery, may also decrease the DWT, but in order to simplify the analysis only additional steel weight in the hull as a result of ice strengthening was calculated. More details of the calculations can be found in the document MEPC 71/INF.16.

The results of the calculations are presented in the appendix of the document MEPC 71/INF.16. Interestingly, the increase in hull weight for all ship types and sizes appears to follow the same, almost linear, relationship between the weight increase and the actual DWT for a specific ice class (see Figures 26 to 29 in the appendix to MEPC 71/INF.16). For this reason, it was decided to propose the ice class correction factors for capacity given in Table 34 for all ship types covered by the EEDI regulations and for which DWT is defined as a measure of capacity.

Table 34: Proposal for new ice class correction factors for capacity due to hull ice strengthening.

Ice class	Ice class correction factor for capacity due to hull ice strengthening
Ice class IC	$f_{i(IC)} = 1.0041 + 58.5/DWT$
Ice class IB	$f_{i(IB)} = 1.0067 + 62.7/DWT$
Ice class IA	$f_{i(IA)} = 1.0099 + 95.1/DWT$
Ice class IAS	$f_{i(IAS)} = 1.0151 + 228.7/DWT$

Although the calculations presented in MEPC 71/INF.16 were not done for all ship types covered by the current EEDI regulations, the submitters of this document believe that the formula given above could be applied to all ship types covered by the current EEDI regulations having DWT as a measure of capacity.

5.2.4 DECREASE OF DWT DUE TO IMPROVED ICE-GOING CAPABILITY

The ice-going capability of an ice-going ship can be improved by making the bow form slenderer compared to a ship designed for sailing in open water. This will result in a smaller C_b and, consequently, a smaller DWT compared to an open water ship with the same main dimensions.

The following method should be used to determine the effect of the decrease in the block coefficient on the ice class correction factor for capacity:

$$f_{iC_b} = \frac{C_{b\,reference\ design}}{C_{b\,enhanced\ design}},$$

where $C_{b\text{ reference design}}$ is the average block coefficient for a given ship type and $C_{b\text{ enhanced design}}$ is the actual C_b of a ship with an ice class.

In order to determine the average block coefficient for different ship types, the Maritime IHS database was used to search for information on the main dimensions and displacement of ships. Based on our experience with applying the minimum power requirements given in the FSICR, improving the bow form would be necessary only for so-called “slow ships”, i.e. tankers, bulk carriers and general cargo ships, which usually have a maximum speed of about 15 knots or lower. For the “fast ship types”, the open water design speed results in sufficiently high engine power, which usually exceeds by a good margin the minimum engine power requirements stipulated by the FSICR. Therefore, it would be sufficient to determine the reference values for the block coefficient only for tankers, bulk carriers and general cargo ships. It should also be noted that the ice class correction factors for power (f_j) have been determined for such ship types in the 2014 Guidelines. Information on the average block coefficients of these ship types is presented in MEPC 71/INF.16.

5.2.5 PROPOSAL

Our proposal is to replace the existing ice class correction factors for capacity in section 2.11.1 of the 2014 Guidelines with the following:

The capacity correction factor, f_i, for ice-classed ships having DWT as the measure of capacity should be calculated as follows:

$$f_i = f_{i(ice\ class)} \cdot f_{iC_b},$$

where $f_{i(ice\ class)}$ is the capacity correction factor for ice strengthening of the ship, which can be obtained from Table 35, and f_{iC_b} is the capacity correction factor for improved ice-going capability, which should not be less than 1.0 and which should be calculated as follows:

$$f_{iC_b} = \frac{C_{b\,reference\,design}}{C_b},$$

where $C_{b\,reference\,design}$ is the average block coefficient for the ship type, which can be obtained from Table 36 for tankers and bulk carriers, and C_b is the block coefficient of the ship. For general cargo ships, $C_{b\,reference\,design}$ = 0.80. For ship types other than tankers, bulk carriers and general cargo ships, $f_{iC_b} = 1.0$.

Table 35: Capacity correction factor for ice strengthening of the hull.

Ice class	$f_{i(ice\ class)}$
IC	$f_{i(IC)} = 1.0041 + 58.5/DWT$
IB	$f_{i(IB)} = 1.0067 + 62.7/DWT$
IA	$f_{i(IA)} = 1.0099 + 95.1/DWT$
IAS	$f_{i(IAS)} = 1.0151 + 228.7/DWT$

Table 36: Average block coefficients for bulk carriers and tankers for five size categories.

	$C_{b\,reference\,design}$				
Ship type	Small (< 10 000 DWT)	Handysize (10 000 DWT – 25 000 DWT)	Handymax (25 000 DWT – 55 000 DWT)	Panamax (55 000 DWT – 75 000 DWT)	Aframax (75 000 DWT – 120 000 DWT)
Bulk carrier	0.78	0.80	0.82	0.86	0.86
Tanker	0.78	0.78	0.80	0.83	0.83

Alternatively, the capacity correction factor for ice strengthening of the ship ($f_{i(ice\ class)}$) can be calculated by using the formula given for the ship-specific voluntary enhancement correction factor ($f_{i\,VSE}$) in section 2.11.2. This formula can also be used for other ice classes than those given in Table 36.

5.2.6 DISCUSSION

The new method is based on the same principles as the existing method. It takes into account the increase in steel weight due to ice strengthening and the smaller block coefficient if the hull form is specially designed for ice-going purposes. The new method takes these two issues into account separately by using two coefficients, which can considered a more transparent way to calculate the ice class correction factor for capacity for an individual ship based on its actual design parameters. The new methodology can be applied to all ship types, ice strengthened in accordance with the FSICR or other ice class rules equivalent to the FSICR and having DWT as a measure of capacity. The methodology presented in this document can also be applied to determine the ice class correction factors for ice strengthening for ice classes other than the FSICR, including, but not limited to, the PC ice classes of IACS and the ice classes of the Russian Maritime Register of Shipping, if required.

5.3 CORRECTION FACTORS FOR POWER FOR ICE-CLASSED SHIPS

In this section, a proposal for new ice class correction factors for power is presented.

5.3.1 PROPOSAL FOR NEW CORRECTION FACTORS FOR POWER

The new ice class correction factors for power, f_j, for ice-classed ships are determined in the same way as the existing factors in the 2014 Guidelines (Resolution MEPC.245(66)).

The coefficients f_{j0} and $f_{j,min}$ in the present study are defined in a different way than in the 2014 Guidelines. The essential difference is that the average engine powers in the present study are defined as a function of DWT, whereas they were defined as a function of ship length in the 2014 Guidelines. Otherwise, the principles for defining f_{j0} and $f_{j,min}$ in the present study are similar to those in 2014 Guidelines (see EE-WG 2/2/9 for details).

The basic form of the present correction factor for power f_j is as follows:

$$f_{j0} = \frac{P_{OW,ave}(dwt)}{actual\ power\ MCR\ 100\ \%}.$$

The minimum value of the ice class correction factor for power, f_j, is limited by the fact that the correction should not result in an engine power greater than the minimum power required by the ice class. This is expressed by the lower limit of $f_{j,min}$, which can be defined as follows:

$$f_{j,min} = \frac{P_{OW,ave}(dwt)}{P_{ice\ class}(dwt)}.$$

The purposed ice class correction factors for power for each ship type and ice class are presented in the table below and in more detail in section 4 of this document. It should be noted that in the formula for f_{j0}, *MCR* is used as engine power, whereas in the existing 2014 Guidelines P_{ME} (=0.75 *MCR*) was used.

Table 37: The purposed new power correction factors for each ice class and ship type.

Ship type	f_{j0}	$f_{j,min}$ depending on the ice class			
		IA Super	IA	IB	IC
Tanker	$\frac{17.444 \cdot dwt^{0.5766}}{\sum_{i=1}^{nME} MCR_{ME(i)}}$	$0.2488 \cdot dwt^{0.0903}$	$0.4541 \cdot dwt^{0.0524}$	$0.7783 \cdot dwt^{0.0145}$	$0.8741 \cdot dwt^{0.0079}$
Bulk carrier	$\frac{17.207 \cdot dwt^{0.5705}}{\sum_{i=1}^{nME} MCR_{ME(i)}}$	$0.2515 \cdot dwt^{0.0851}$	$0.3918 \cdot dwt^{0.0556}$	$0.8075 \cdot dwt^{0.0071}$	$0.8573 \cdot dwt^{0.0087}$
General cargo ship	$\frac{1.974 \cdot dwt^{0.7987}}{\sum_{i=1}^{nME} MCR_{ME(i)}}$	$0.1381 \cdot dwt^{0.1435}$	$0.1574 \cdot dwt^{0.144}$	$0.3256 \cdot dwt^{0.0922}$	$0.4966 \cdot dwt^{0.0583}$

5.4 CALCULATING EEDI FOR SELECTED SHIP TYPES

In this section, the attained EEDI is calculated for the selected ships types using the same simplified form as in EE-WG 2/2/9:

$$EEDI = \frac{C_{F,ME} \cdot SFC_{ME} \cdot f_j \cdot P_{ME} + C_{F,AE} \cdot SFC_{AE} \cdot P_{AE}}{f_i \cdot capacity \cdot v} = \frac{C_F \cdot \left(SFC_{ME} \cdot f_j \cdot P_{ME} + SFC_{AE} \cdot P_{AE}\right)}{f_i \cdot capacity \cdot v}.$$

This simplified EEDI formula is also similar to the formula in the *2013 Guidelines for calculation of reference lines* (Resolution MEPC.231(65)), except that the present form includes the ice class correction factors f_j and f_i.

Table 38 gives the values applied in the formula given above. All of the values except the ice class correction factors f_j and f_i are defined according to similar principles as in EE-WG 2/2/9 and the 2013 Guidelines. However, as shown in Table 38, a value of 170 g/kWh was used for the parameter-specific fuel oil consumption, *SFC*. This parameter depends on the type of engine: for 2-stroke engines, the *SFC* typically ranges from 160 to 170 g/kWh and for 4-stroke engines it ranges from 180 to 190 g/kWh. The purpose of these calculations is to show the effect of the new ice class correction factors on the attained EEDI for ships having an ice class and to compare the results with the attained EEDI of ships designed for sailing in open water only. It is not possible to calculate the exact attained EEDI values for the selected ships because each engine has its own *SFC* and the speed used in the EEDI formula corresponds to the speed at 75% MCR. Neither of these values can be obtained from the IHS database. However, the IMO database already contains a great deal of information on the actual attained EEDI values for ships (see MEPC 72/INF.8). After comparing the attained EEDI values for ships sailing in open water given in this section with the actual attained EEDI values given in MEPC 72/INF.8, it was concluded that the calculated attained EEDI values given in this section were closer to the actual attained EEDI values given in MEPC 72/INF.8 if a value of 170 g/kWh was used for the SFC, especially for large ships, which quite often have 2-stroke engines. For small ships, which in most cases have 4-stroke engines, the calculated EEDI values are probably too optimistic. However, as mentioned above, the purpose of these calculations is not to try to provide exact values for the attained EEDI, but to show that, by using the new ice class correction factors, the attained EEDI values for ships with an ice class are roughly on the same level as the attained EEDI values for ships designed to operate in open water only.

Table 38: Parameters and applied values in the simplified EEDI formula.

Parameter	Applied value
Ice class correction factor for power, f_j	According to section 4 of this document
Ice class correction factor for capacity, f_i	According to section 5.2 of this document
Carbon emission factor, C_F	Constant value assumed, $C_F = C_{F,ME} = C_{F,AE}$ = 3.1144 g CO_2 / g fuel
Specific fuel consumption, *SFC*	Constant values assumed Main engine: SFC_{ME} = 170 g /kWh Auxiliary engine: SFC_{AE} = 195 g /kWh
Power of main engines, P_{ME}	75% of the total power of the main engines *MCR* The total power is taken from the Maritime IHS database
Auxiliary engine power, P_{AE}	$P_{AE} = 0.025 \cdot MCR + 250$ when $MCR \geq$ 10000 kW $P_{AE} = 0.05 \cdot MCR$ when $MCR <$ 10000 kW
Capacity, DWT	DWT from Maritime IHS database
Ship speed, *v*	Service speed from Maritime IHS database

The values of the attained EEDI for ships with different Finnish-Swedish ice classes (IC, IB, IA and IAS) have been calculated using the proposed new ice class correction factors for power, f_j, and capacity, f_i. The achieved results are compared to the required EEDI in phases 1, 2 and 3. The required EEDI is calculated according to regulation 21 of MARPOL Annex VI and using the information provided in Resolution MEPC.231(65).

5.4.1 CALCULATED ATTAINED EEDI FOR TANKERS

The attained EEDI values for the open water tankers included in this study were calculated as a reference. Figure 11 presents the EEDI values for the studied open water tankers where $f_i = f_j = 1$.

The attained EEDI values for the ice class tankers were also calculated without the correction factors f_i and f_j ($f_i = f_j = 1$) as reference points for the corrected EEDI values with the proposed new correction factors. The results are shown in Figures 12, 14, 16 and 18.

Figures 13, 15, 17 and 19 give the EEDI value, calculated using the proposed ice class correction factors f_j and f_i for tankers with the Finnish-Swedish ice classes IC, IB, IA and IAS.

The required EEDI for tankers in phases 0, 1, 2 and 3 are also given in each figure.

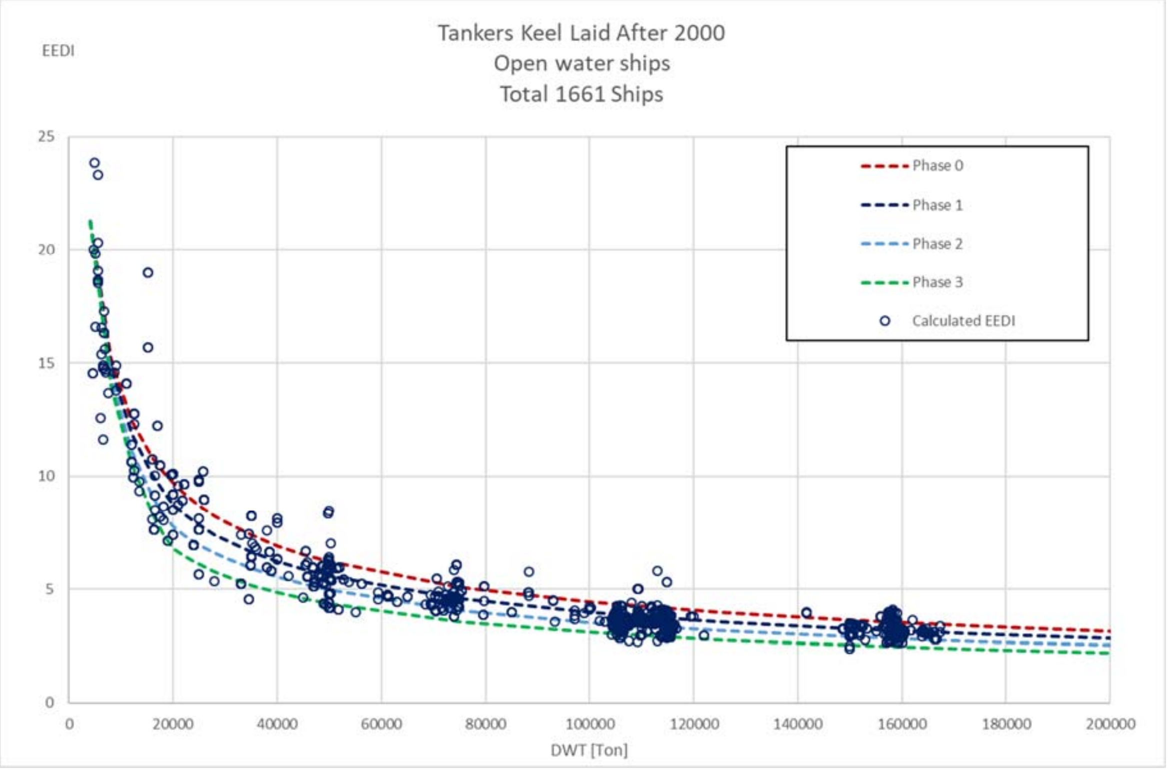


Figure 11: Calculated EEDI values for the studied open water tankers.

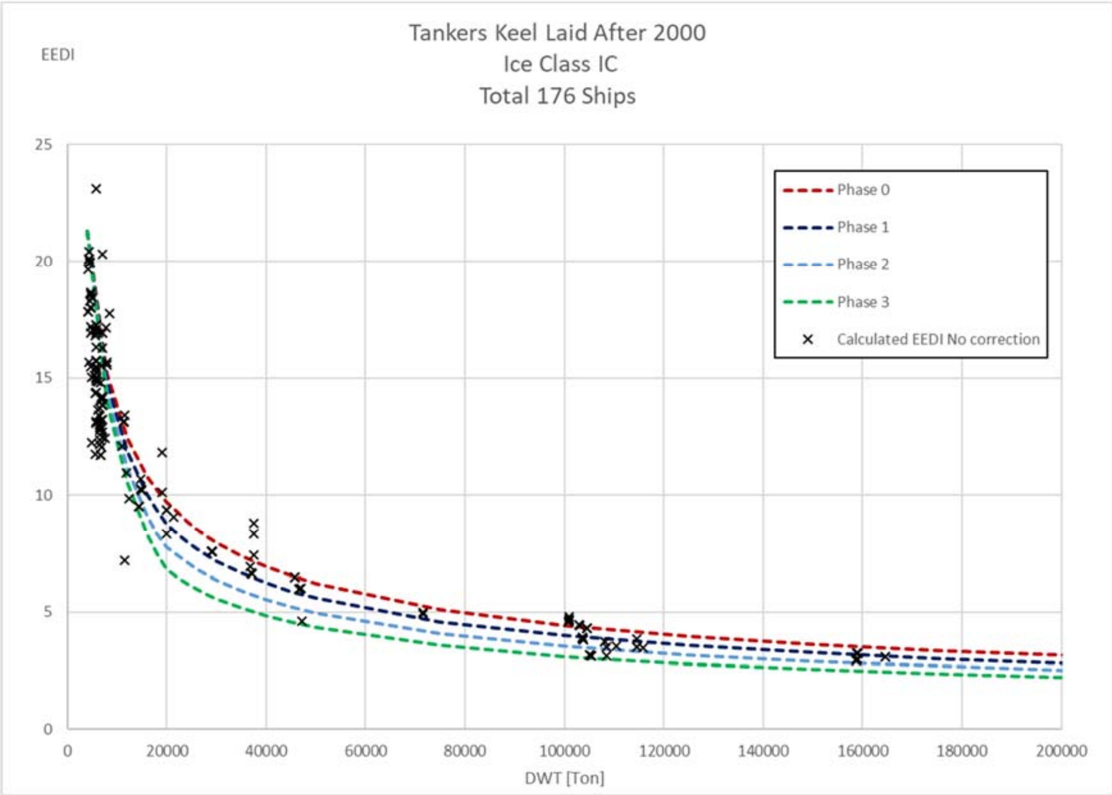


Figure 12: Calculated EEDI for tankers with ice class IC without correction ($f_i = f_j = 1$).

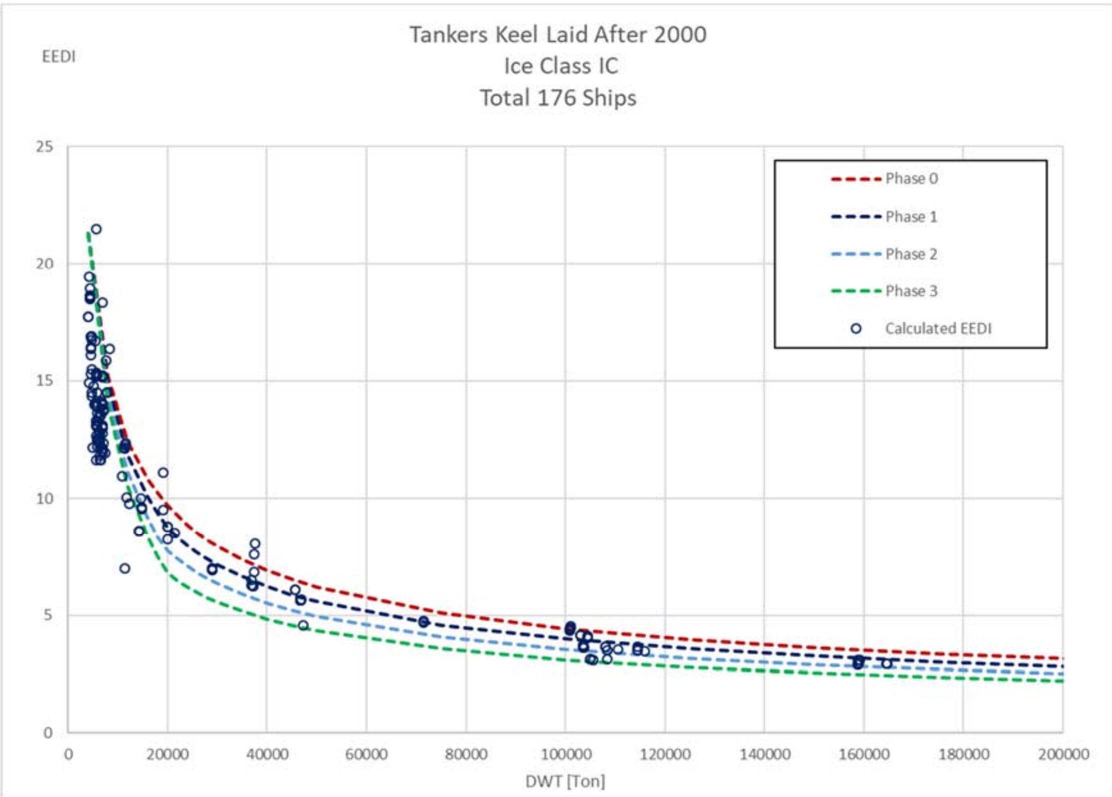


Figure 13: Calculated EEDI for tankers with ice class IC with the proposed new f_j and f_i.

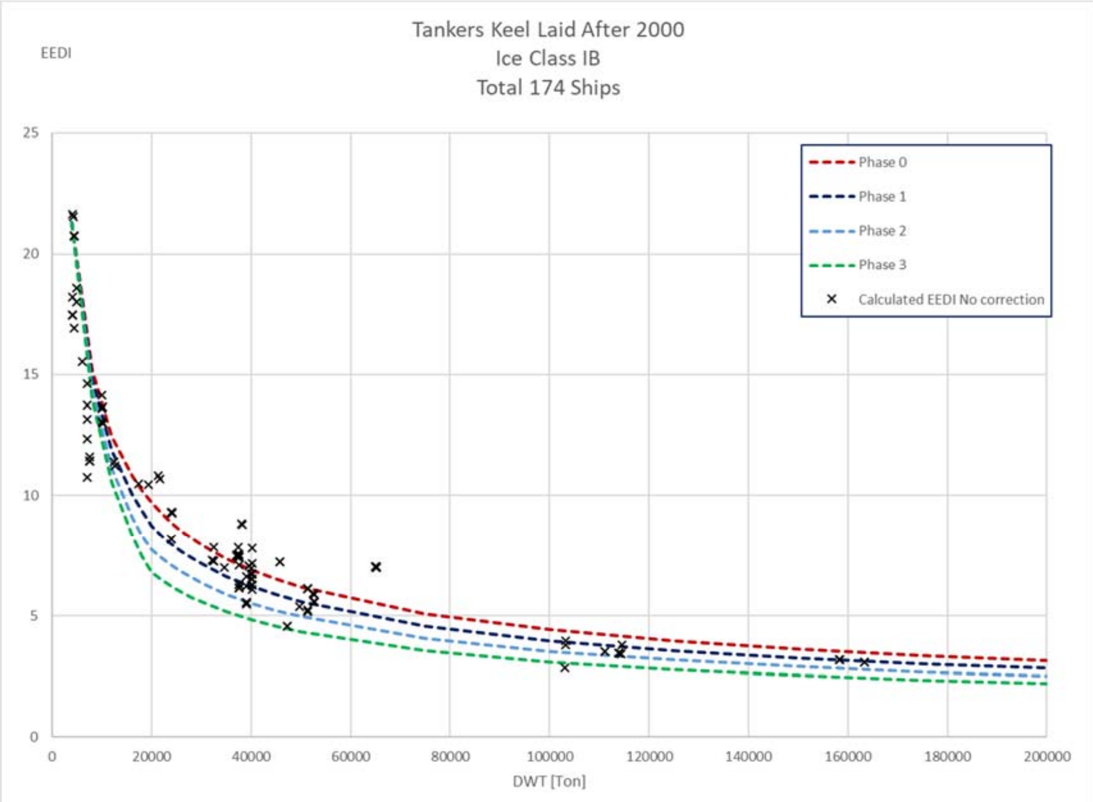


Figure 14: Calculated EEDI for tankers with ice class IB without correction ($f_i = f_j = 1$).

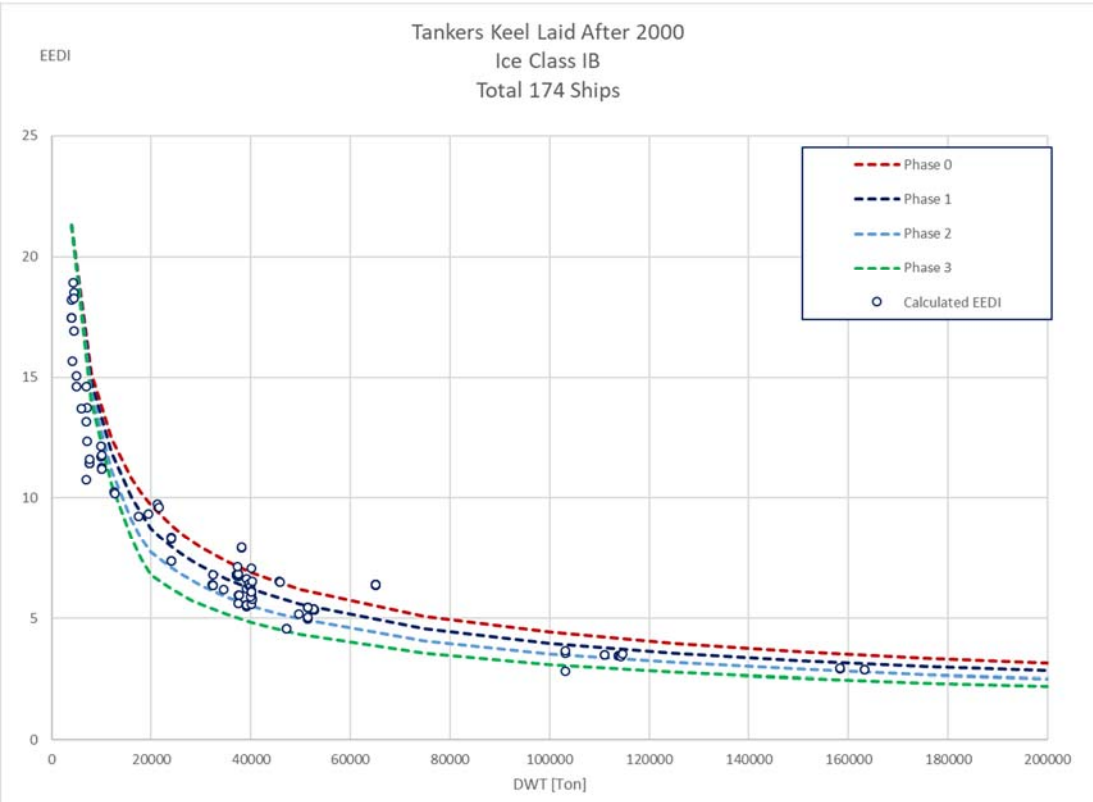


Figure 15: Calculated EEDI for tankers with ice class IB with the proposed new f_i and f_j.

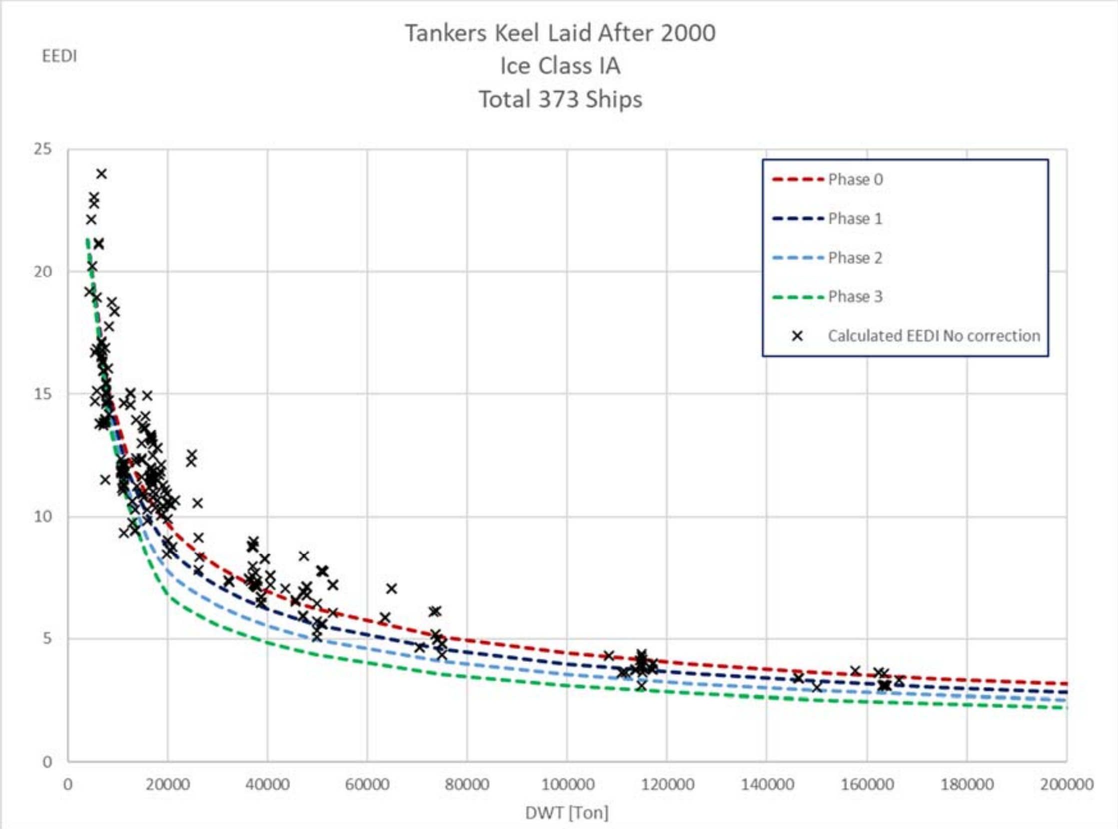


Figure 16: Calculated EEDI for tankers with ice class IA without correction ($f_i = f_j = 1$).

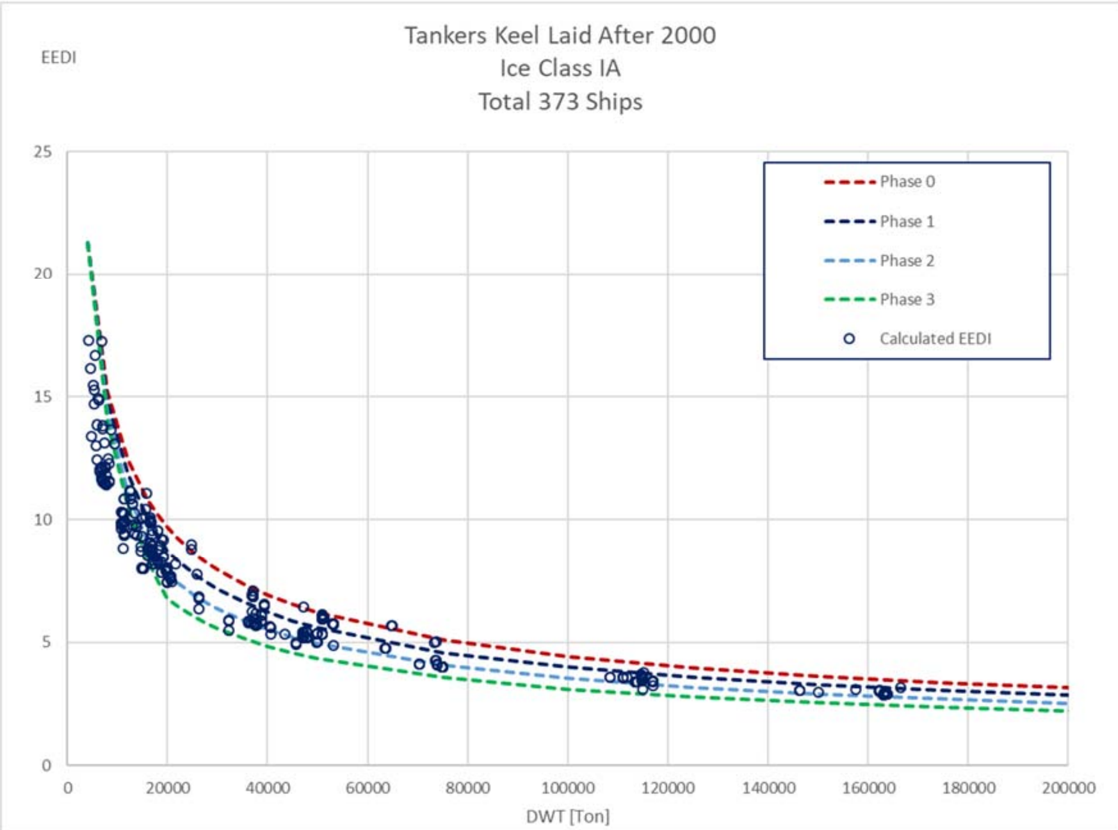


Figure 17: Calculated EEDI for tankers with ice class IA with the proposed new f_j and f_i.

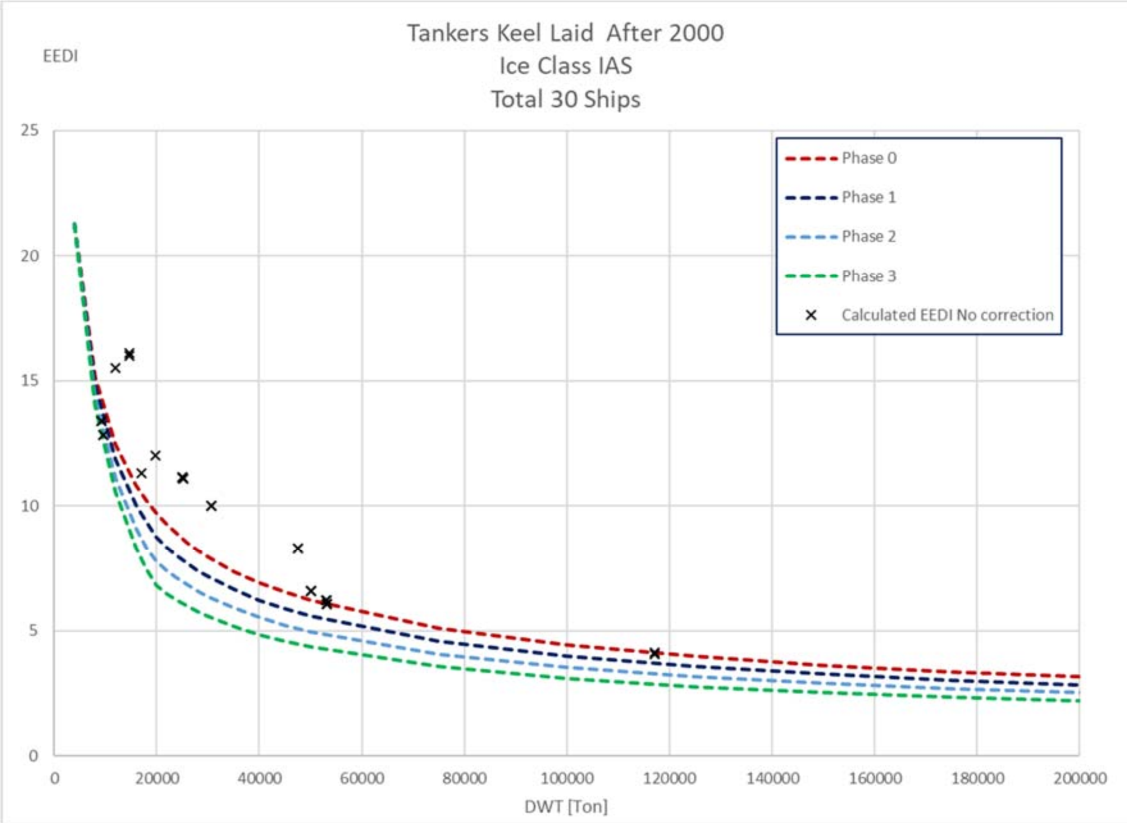


Figure 18: Calculated EEDI for tankers with ice class IAS without correction ($f_i = f_j = 1$).

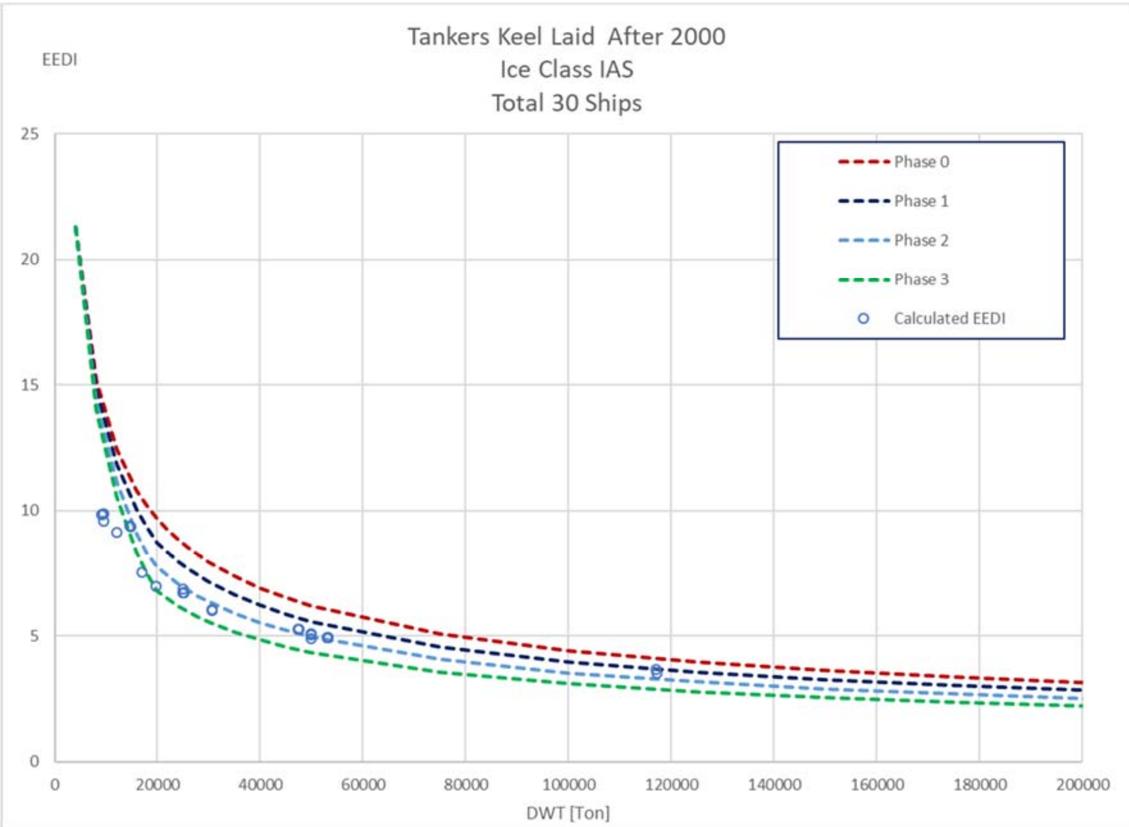


Figure 19: Calculated EEDI for tankers with ice class IAS with the proposed new f_j and f_i.

5.4.2 CALCULATED ATTAINED EEDI FOR BULK CARRIERS

The attained EEDI values for the open water bulk carriers included in this study were calculated as a reference. Figure 20 presents the attained EEDI values for the studied open water bulk carriers where $f_i = f_j = 1$.

The attained EEDI values for the ice class bulk carriers were also calculated without the correction factors f_i and f_j ($f_i = f_j = 1$) as reference points for the corrected EEDI values with the proposed new correction factors. The results are shown in Figures 21, 22, 24 and 26.

Figures 22, 24, 26 and 28 give the EEDI value, calculated using the proposed corrections factors f_j and f_i for bulk carriers with the Finnish-Swedish ice classes IC, IB, IA and IAS.

The required EEDI for tankers in phases 0, 1, 2 and 3 are also given in each figure.

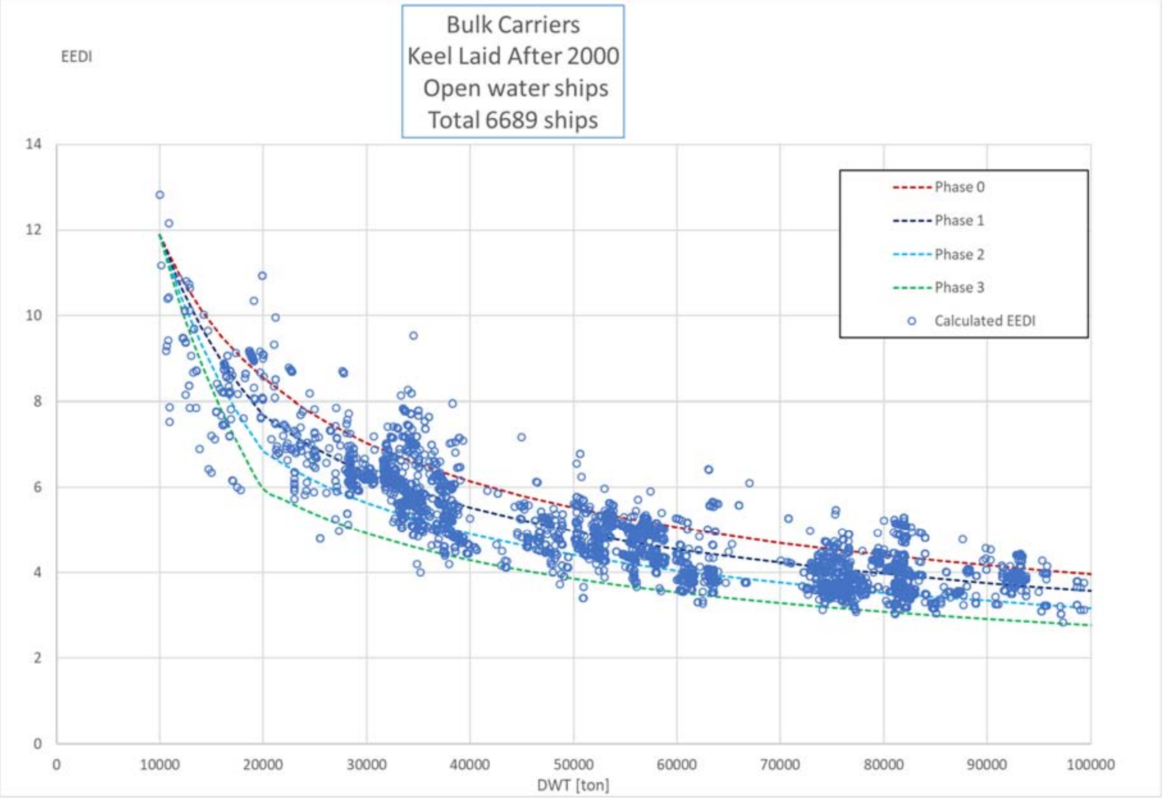


Figure 20: Calculated EEDI values for the studied open water bulk carriers.

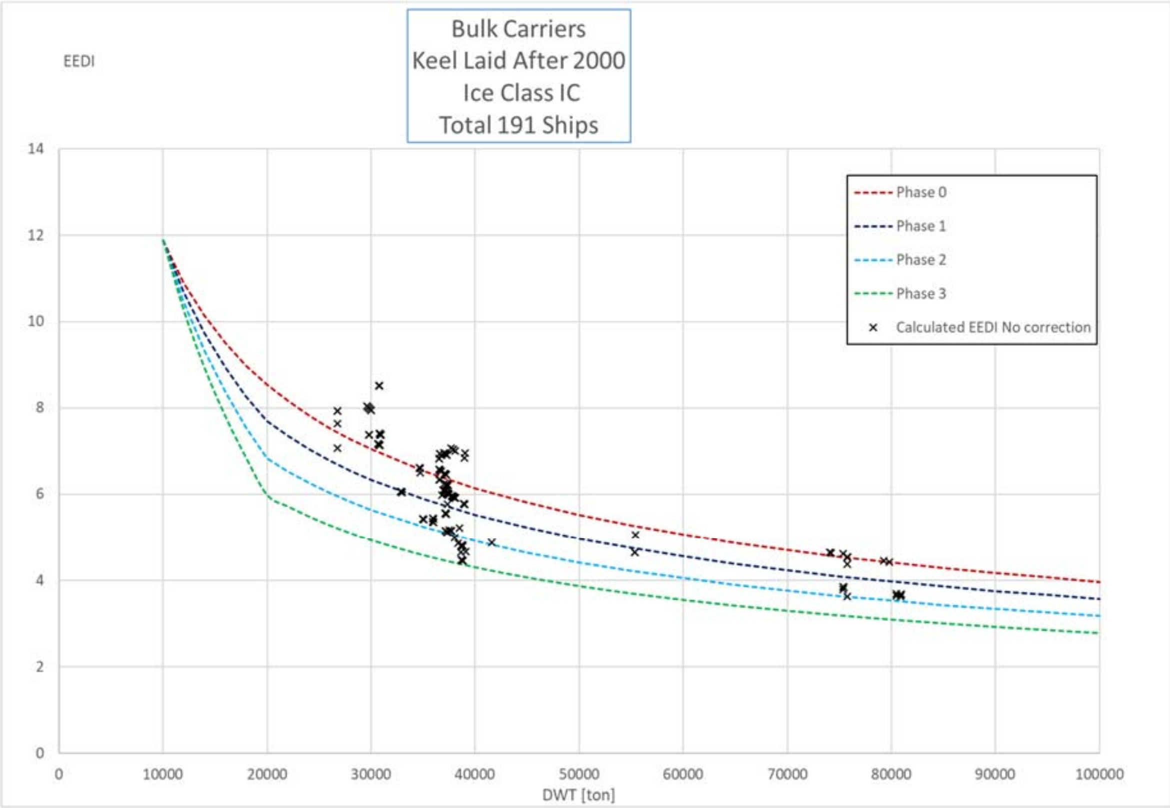


Figure 21: Calculated EEDI for bulk carriers with ice class IC without correction (f_i = f_j = 1).

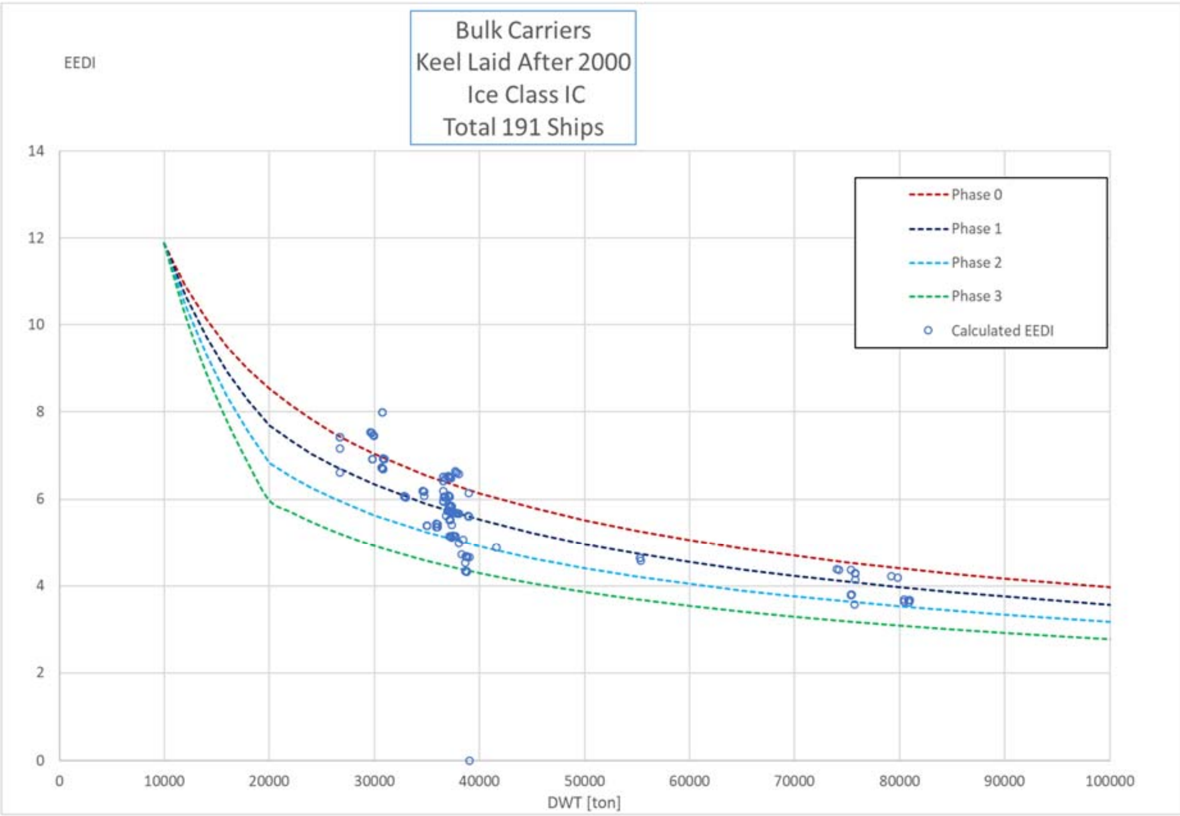


Figure 22: Calculated EEDI for bulk carriers with ice class IC with the proposed new f_j and f_i.

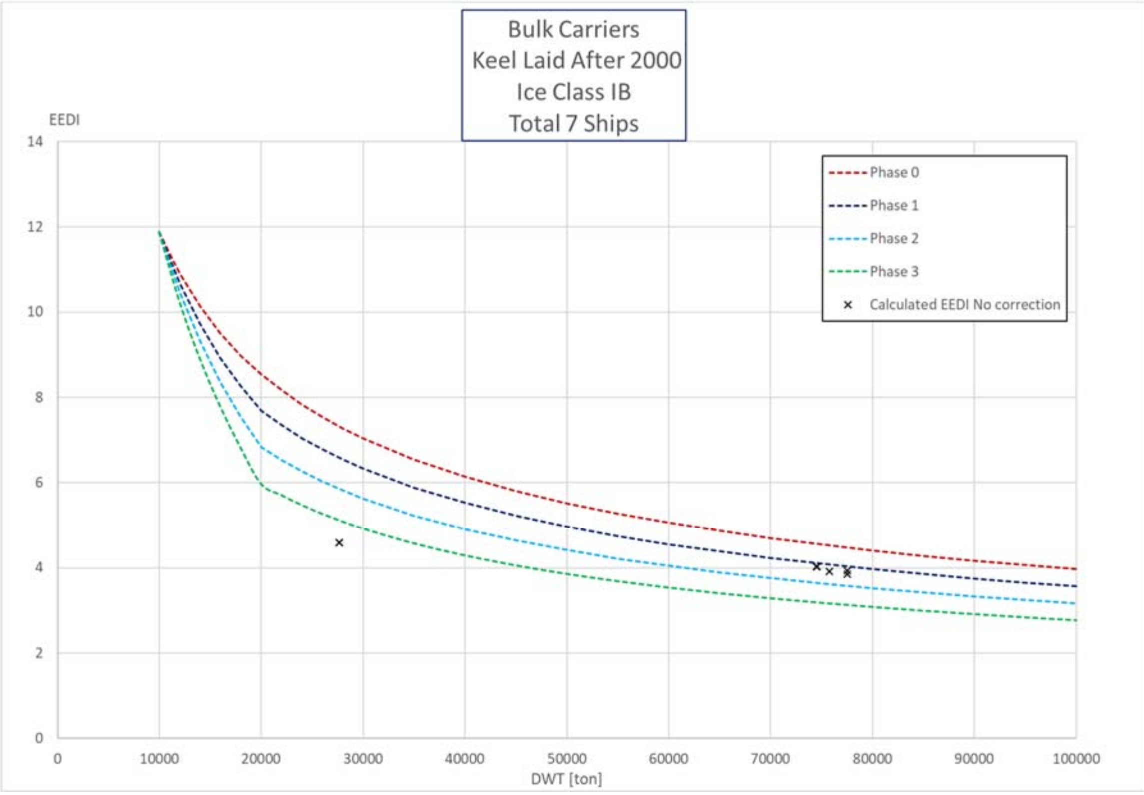


Figure 23: Calculated EEDI for bulk carriers with ice class IB without correction ($f_i = f_j = 1$).

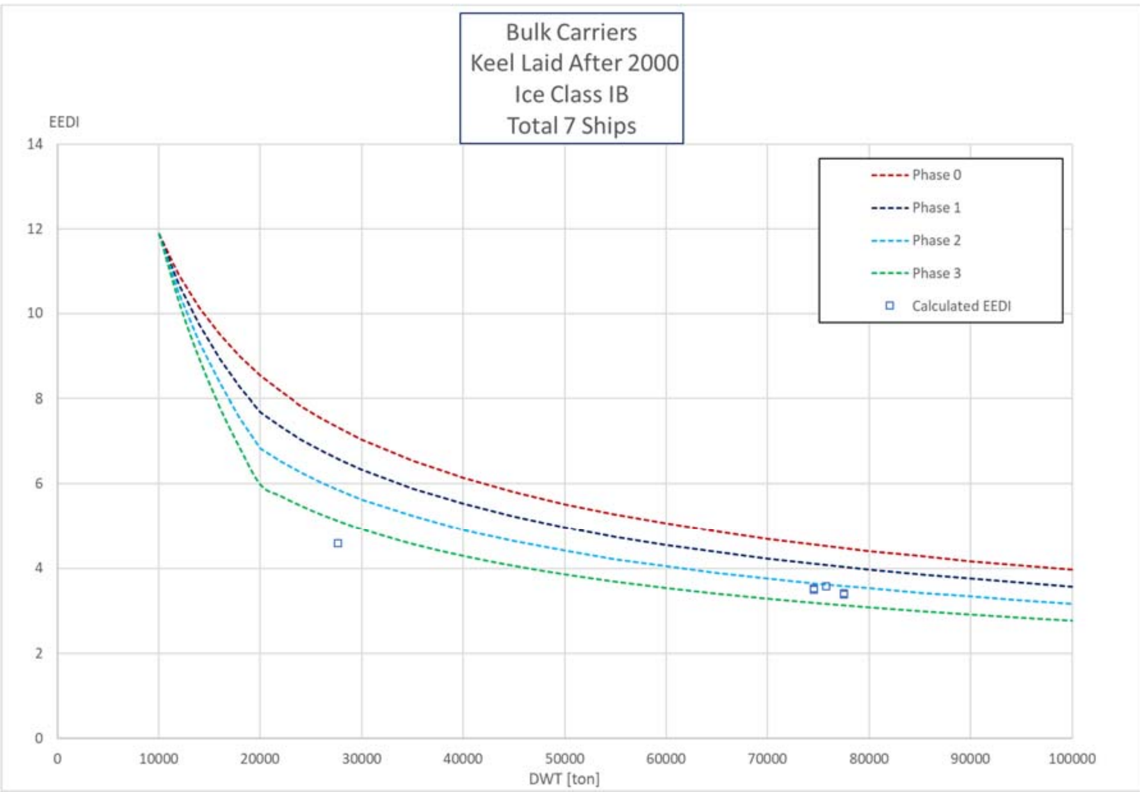


Figure 24: Calculated EEDI for bulk carriers with ice class IB with the proposed new f_i and f_j.

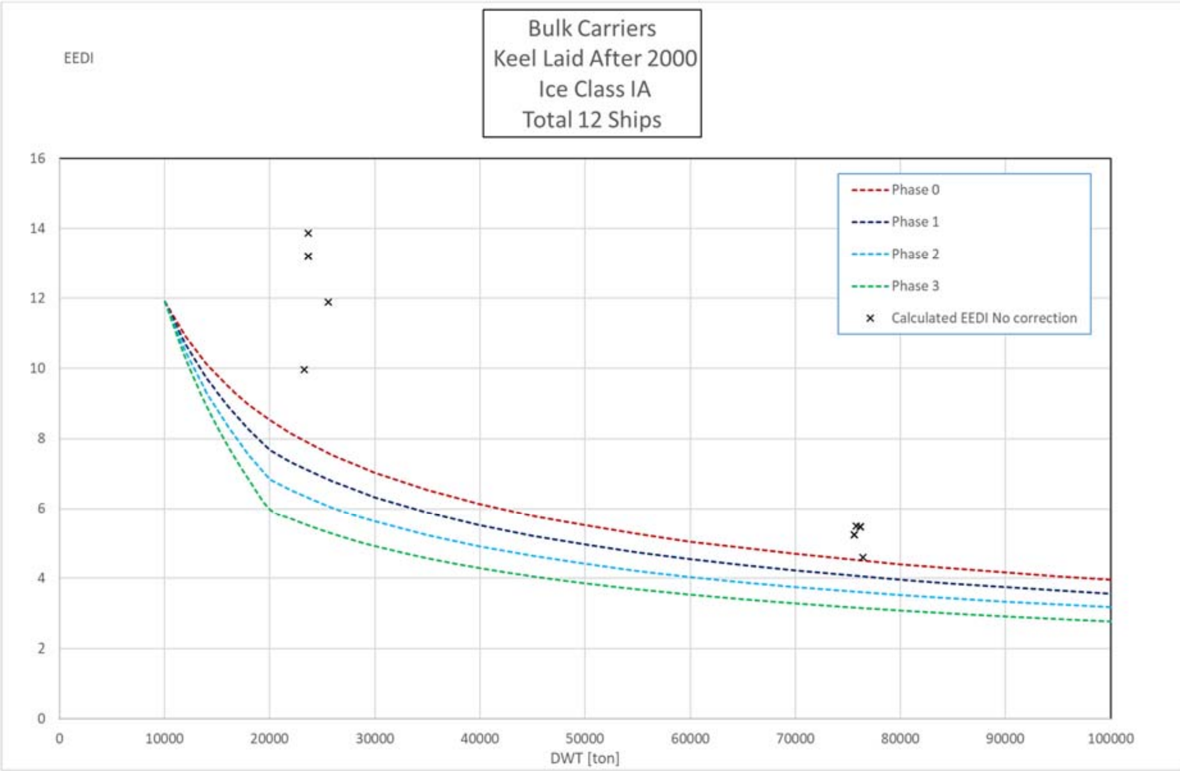


Figure 25: Calculated EEDI for bulk carriers with ice class IA without correction (f_i = f_j = 1).

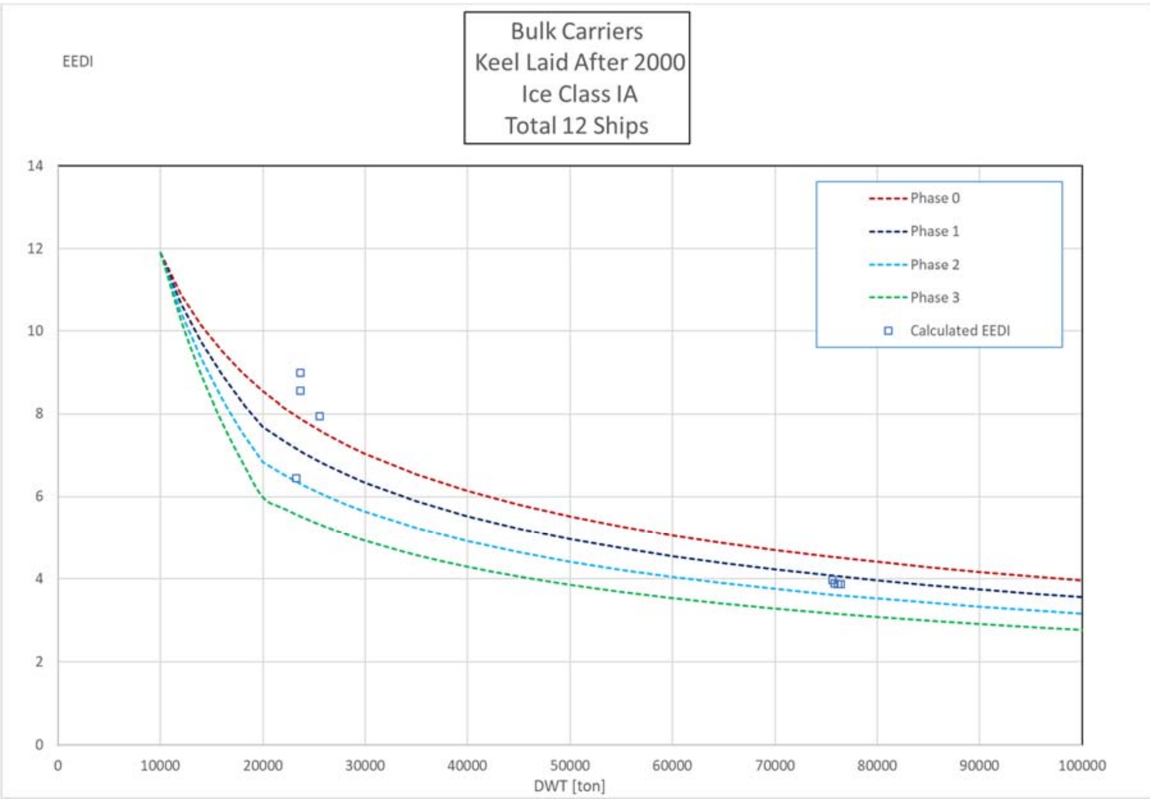


Figure 26: Calculated EEDI for bulk carriers with ice class IA with the proposed new f_j and f_i.

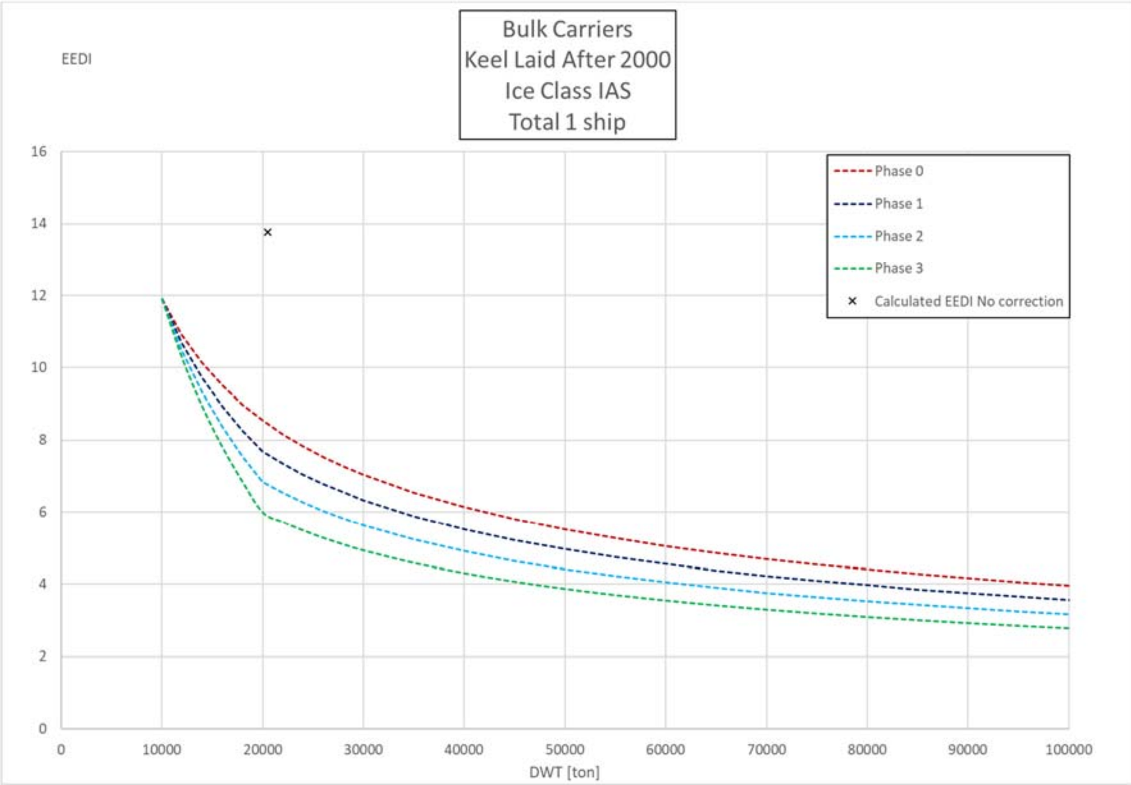


Figure 27: Calculated EEDI for bulk carriers with ice class IAS without correction (f_i = f_j = 1).

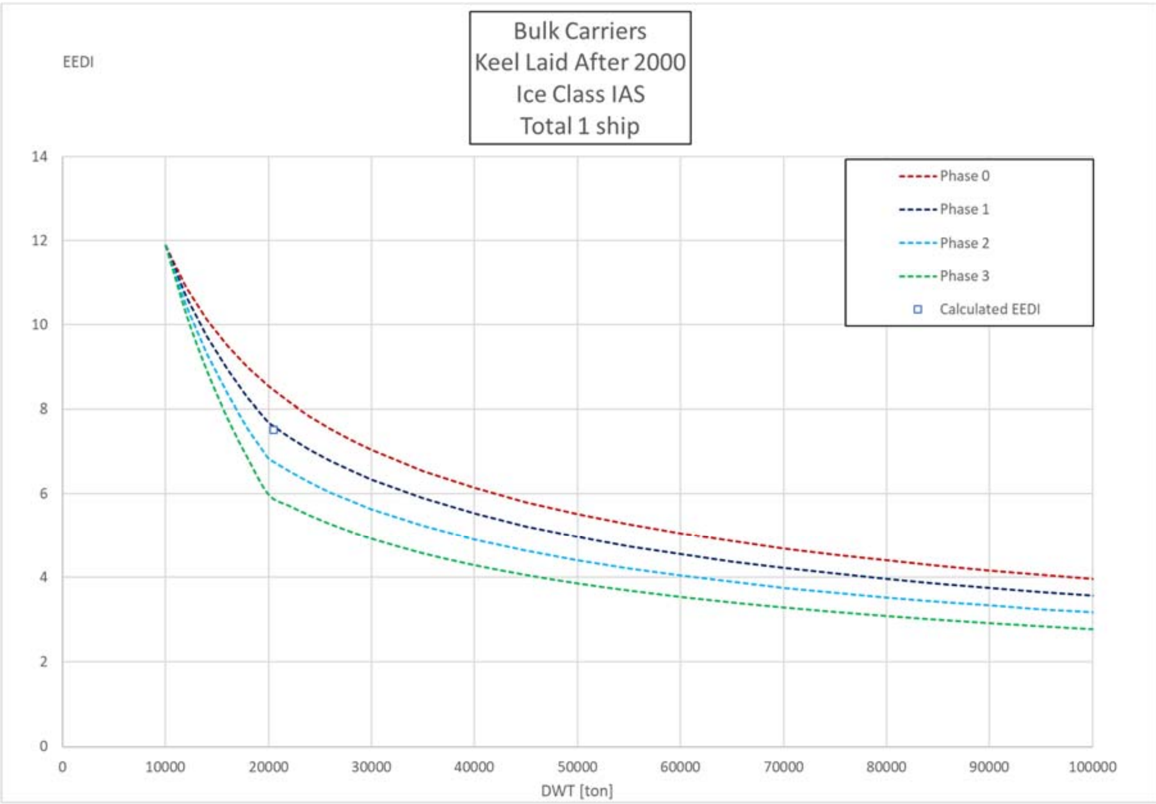


Figure 28: Calculated EEDI for bulk carriers with ice class IAS with the proposed new f_i and f_j.

5.4.3 CALCULATED ATTAINED EEDI FOR GENERAL CARGO SHIPS

The attained EEDI values for the open water general cargo ships included in this study were calculated as a reference. Figure 29 presents the EEDI values for the studied open water general cargo ships where $f_i = f_j = 1$.

The attained EEDI values for the ice class general cargo ships were also calculated without correction factors f_i and f_j ($f_i = f_j = 1$) as reference points for the corrected EEDI values with the proposed new correction factors. The results are shown in Figures 30, 32, 34 and 36.

Figures 31, 33, 35 and 37 give the EEDI value, calculated with the proposed corrections factors f_j and f_i for general cargo ships with the Finnish-Swedish ice classes IC, IB, IA and IAS.

The required EEDI for tankers in phases 0, 1, 2 and 3 are also given in each figure.

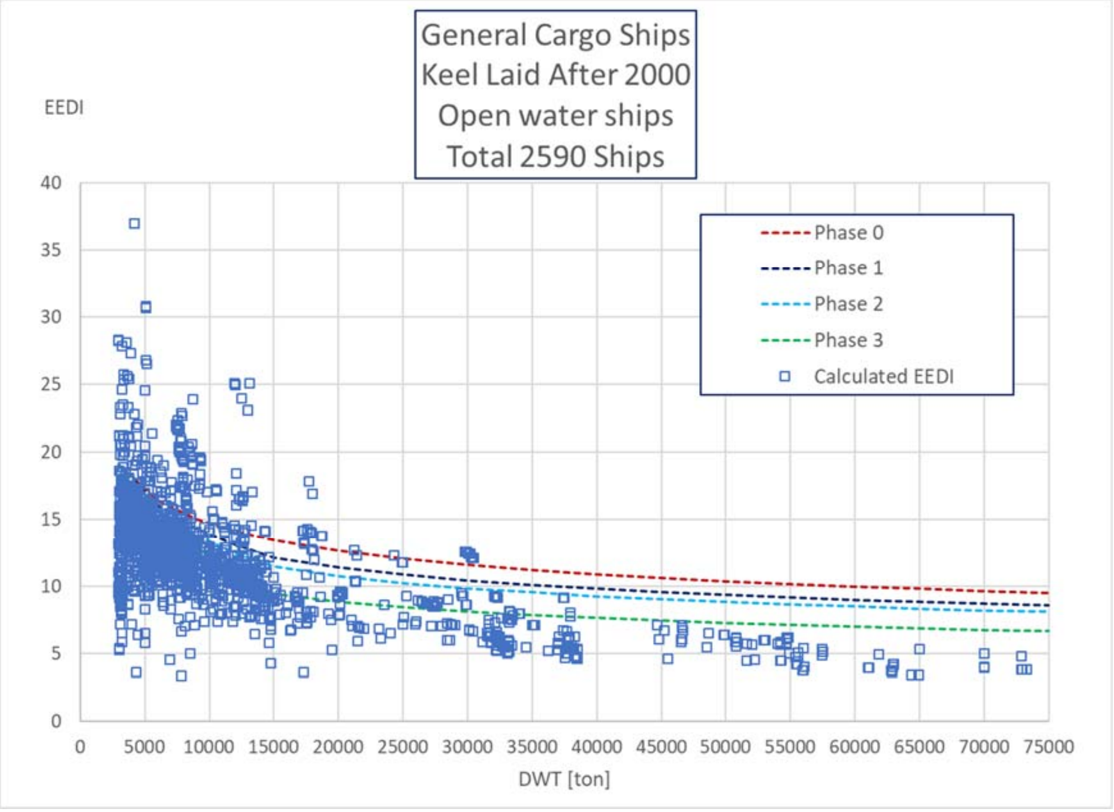


Figure 29: Calculated EEDI values for the studied open water general cargo ships.

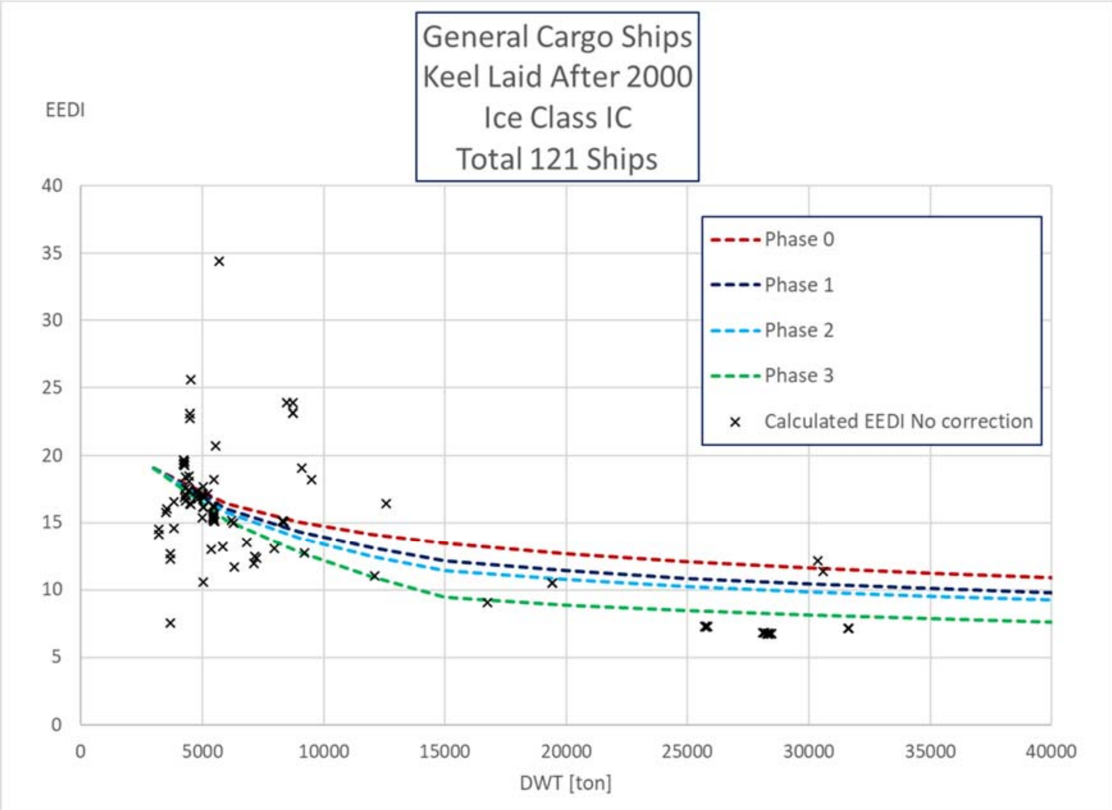


Figure 30: Calculated EEDI for general cargo ships with ice class IC without correction ($f_i = f_j = 1$).

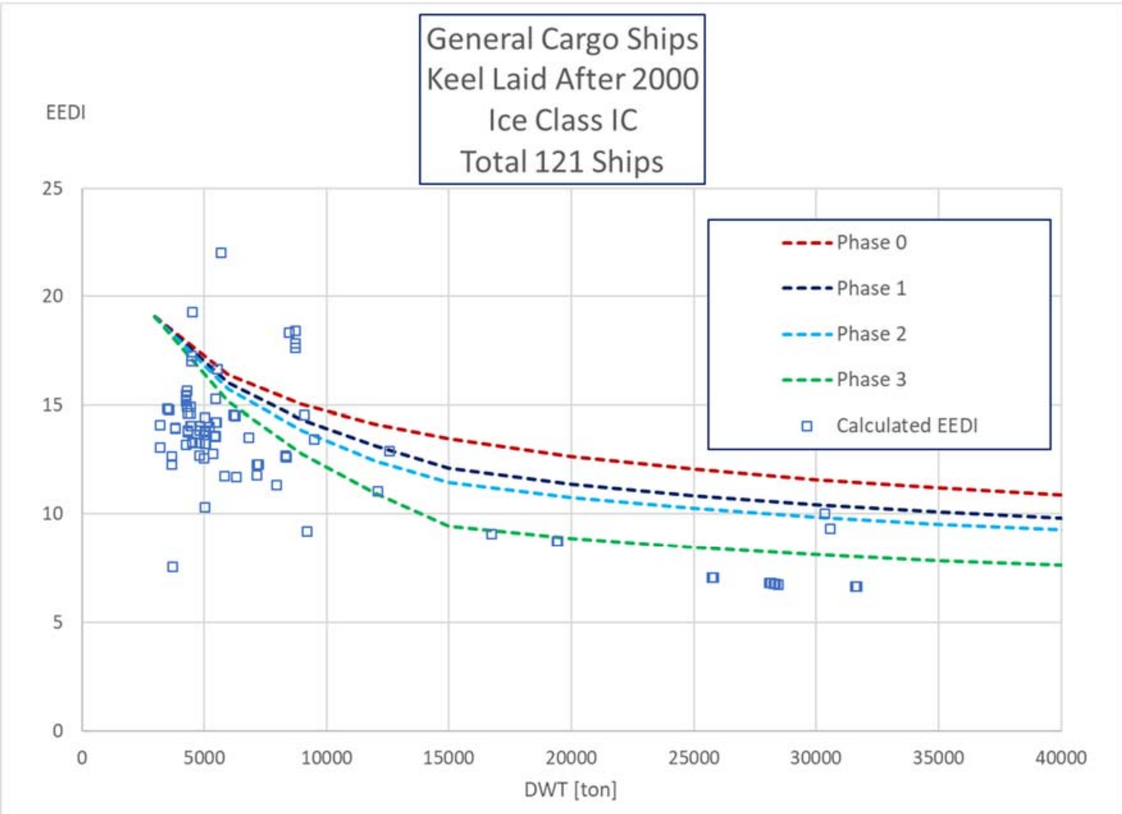


Figure 31: Calculated EEDI for general cargo ships with ice class IC with the proposed new f_j and f_i.

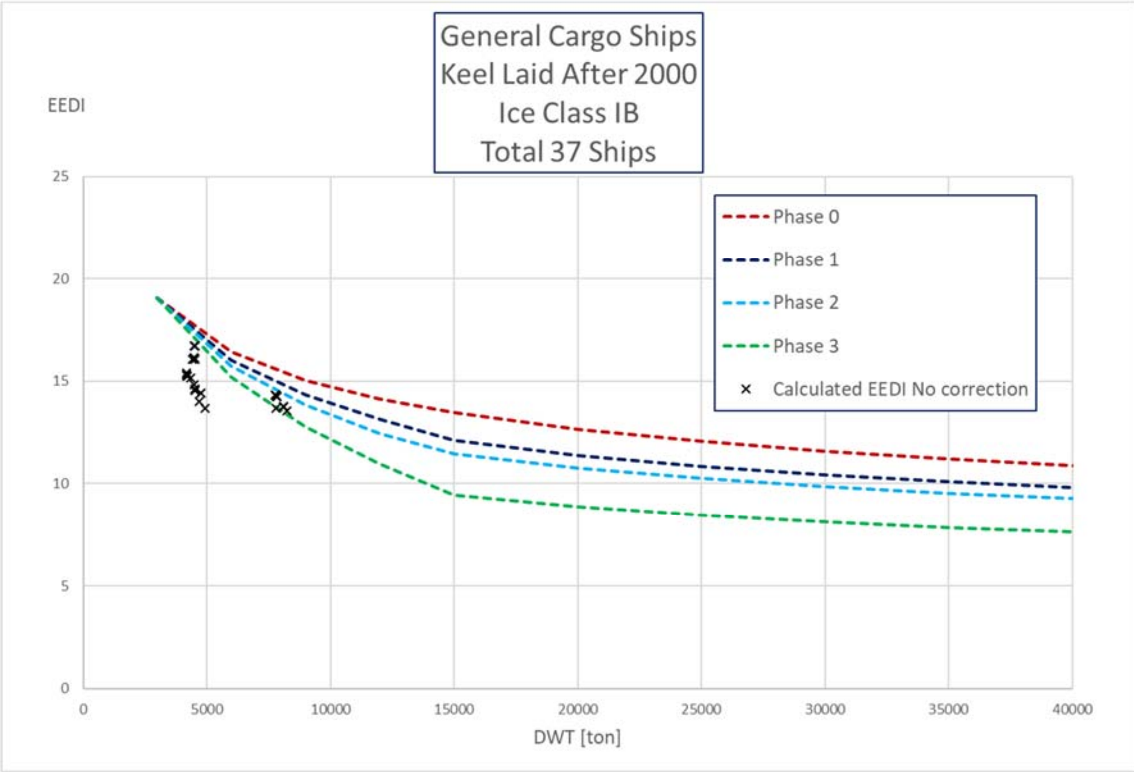


Figure 32: Calculated EEDI for general cargo ships with ice class IB without correction (f_i = f_j = 1).

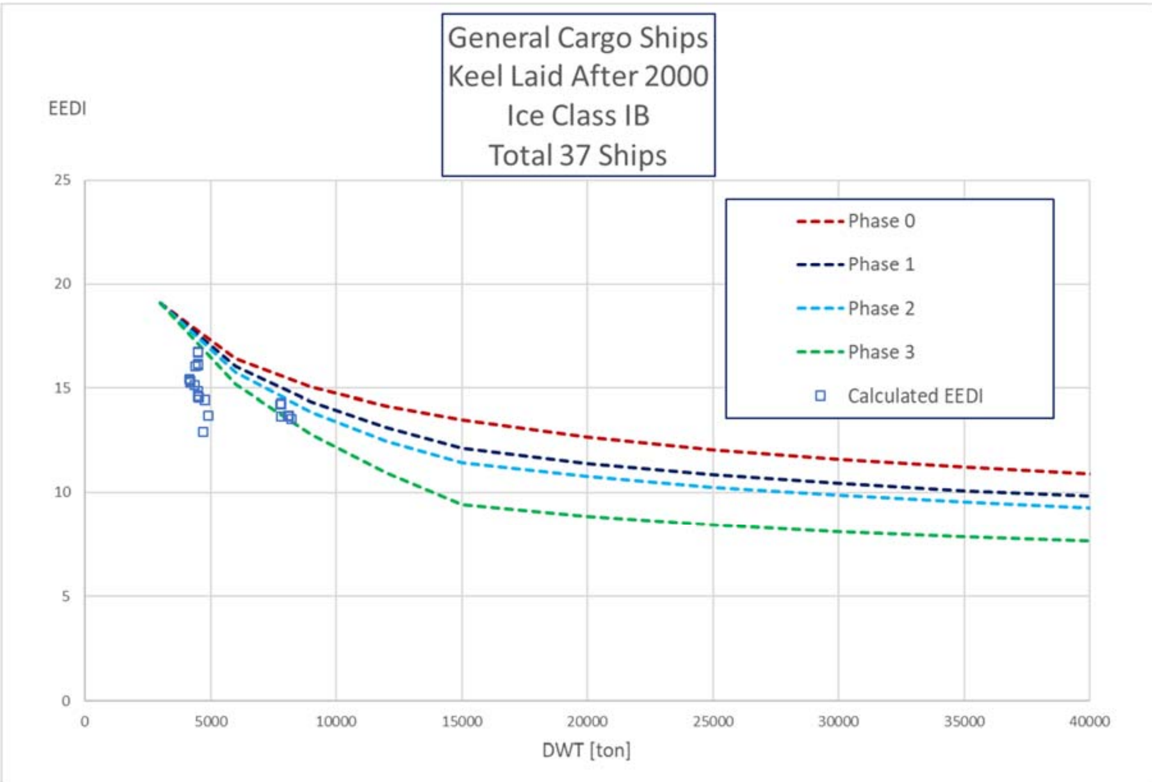


Figure 33: Calculated EEDI for general cargo ships with ice class IB with the proposed new f_j and f_i.

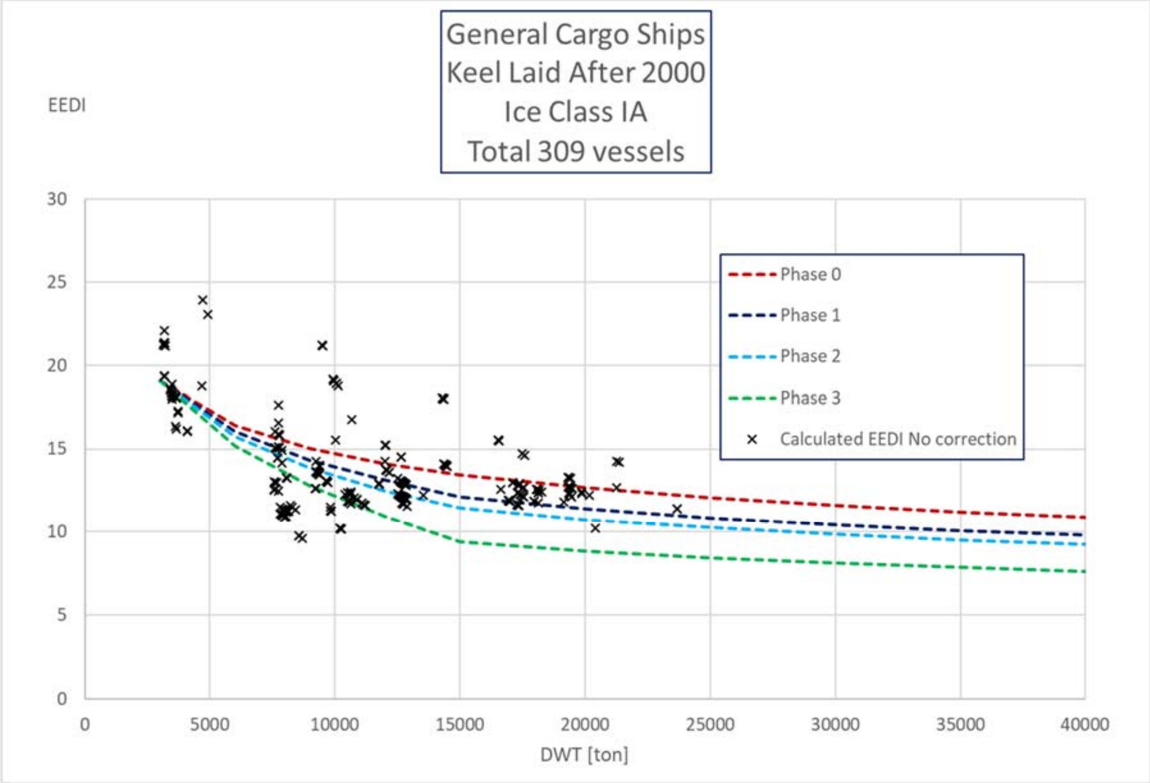


Figure 34: Calculated EEDI for general cargo ships with ice class IA without correction (f_i = f_j = 1).

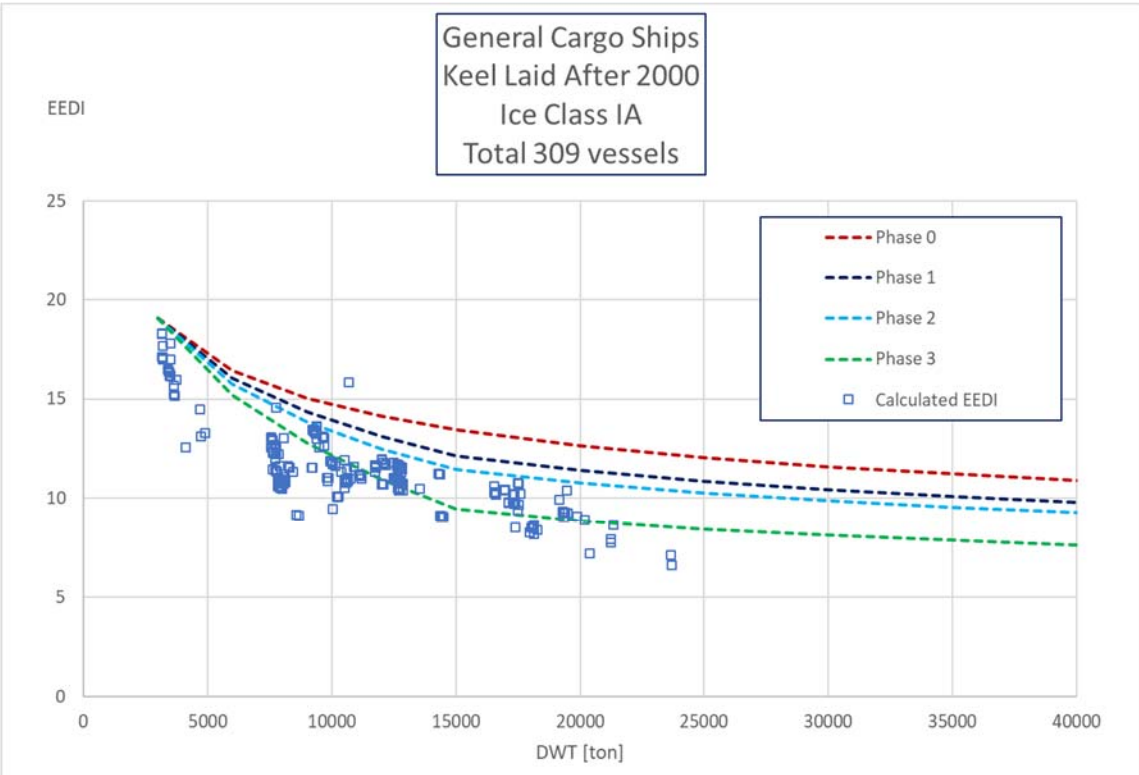


Figure 35: Calculated EEDI for general cargo ships with ice class IA with the proposed new f_j and f_i.

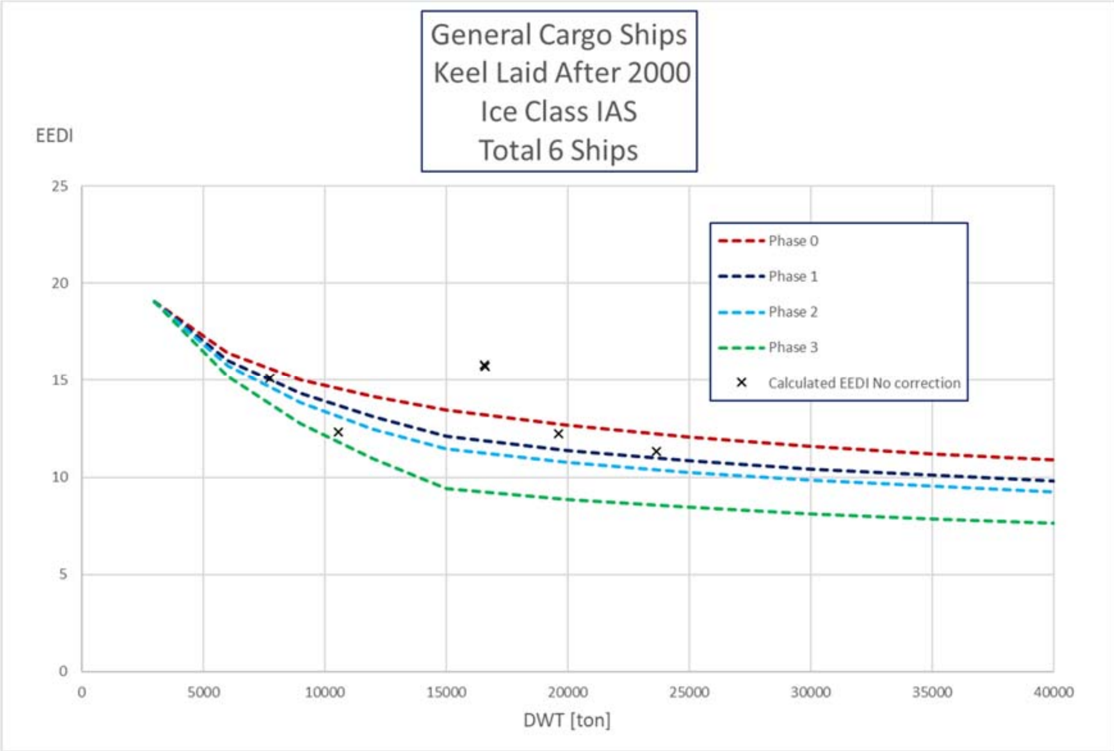


Figure 36: Calculated EEDI for general cargo ships with ice class IAS without correction ($f_i = f_j = 1$).

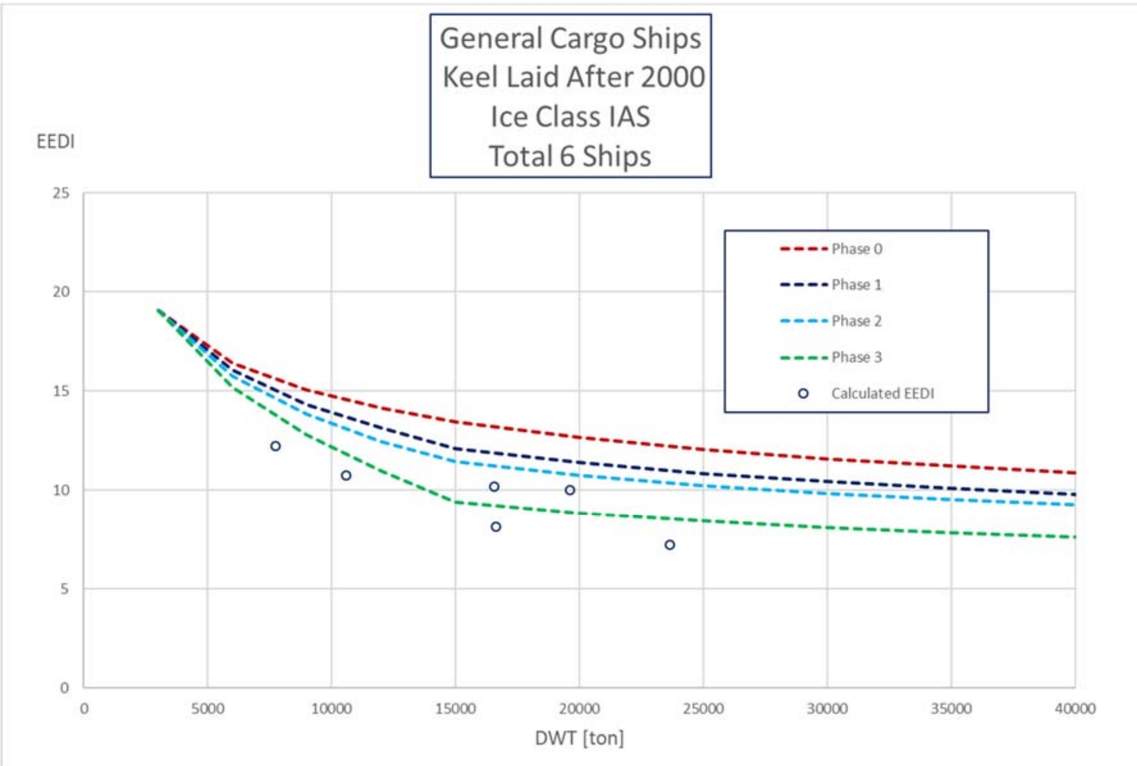


Figure 37: Calculated EEDI for general cargo ships with ice class IAS with the proposed new f_j and f_i.

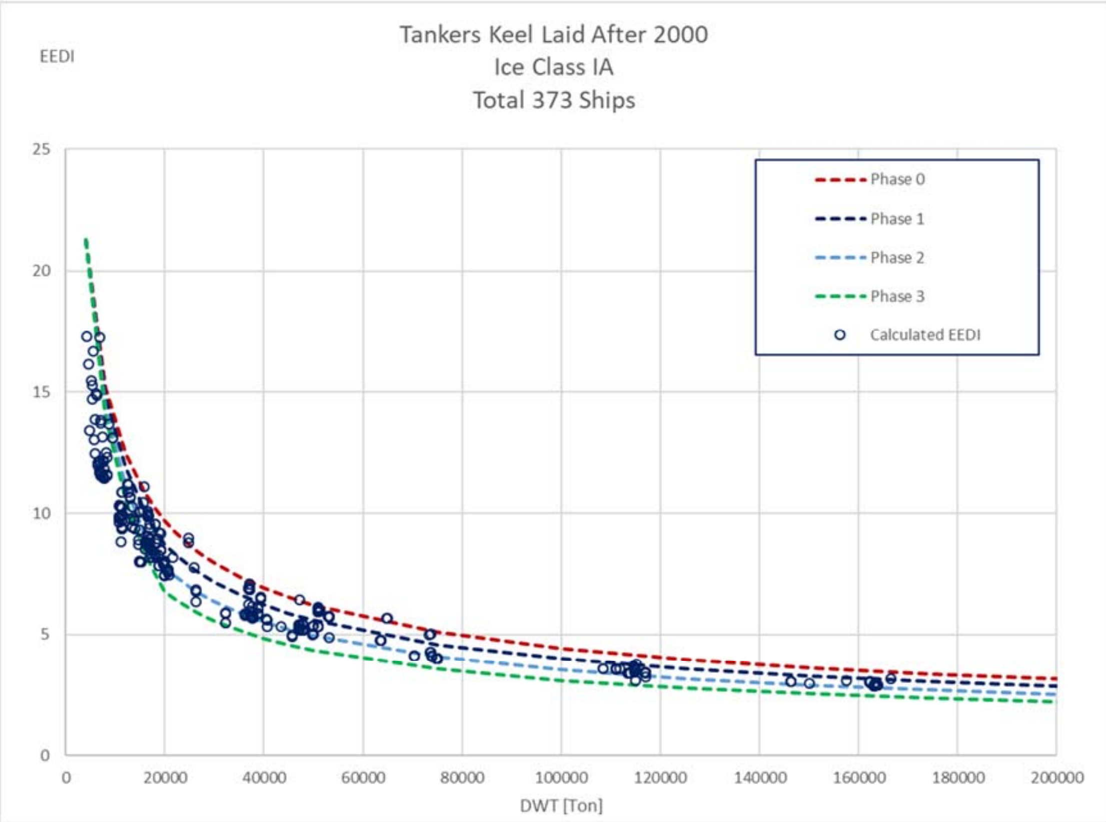
5.4.4 IMPROVING THE ATTAINED EEDI VALUE BY USING LNG AS FUEL

Use of Liquefied Natural Gas (LNG) as fuel can even further reduce the EEDI value due to the better specific energy of LNG. The specific energy of LNG is, on average, 49–50 kJ/g, but it can even be as high as almost 55 kJ/g. The average specific energy of MDO is 42.7 kJ/g. The specific energy of LNG is of importance because the engine manufacturers usually define the specific consumption of LNG as kJ/kWh. This value must be converted into g/kWh as defined in the EEDI formula. The typical specific consumption of LNG reported by some manufacturers is usually below 7500 kJ/kWh, but the best engines have a specific fuel consumption of approximately 7100 kJ/kWh.

By using the average specific energy value for LNG (49 kJ/g), the specific consumption then varies between 145 and 153 g/kWh. The average specific energy value is used to ensure no overestimation of the degrees in the EEDI values.

The EEDI calculation has been made for an average specific consumption of 155 g/kWh of LNG and compared to a consumption of 170 g/kwh MDO.

The comparison has been done for tankers and bulk carries with the ice class IA and IAS.



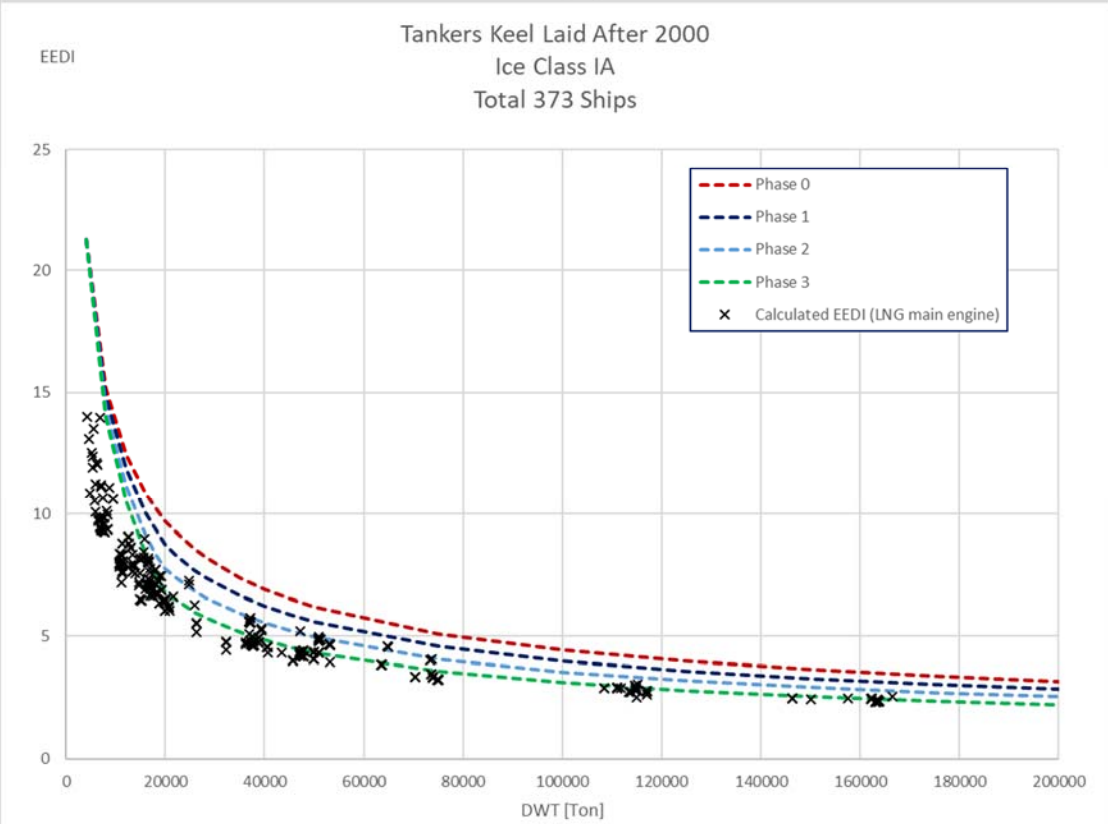


Figure 38: Comparison of calculated EEDI for MDO and LNG as fuel, tankers in ice class IA.

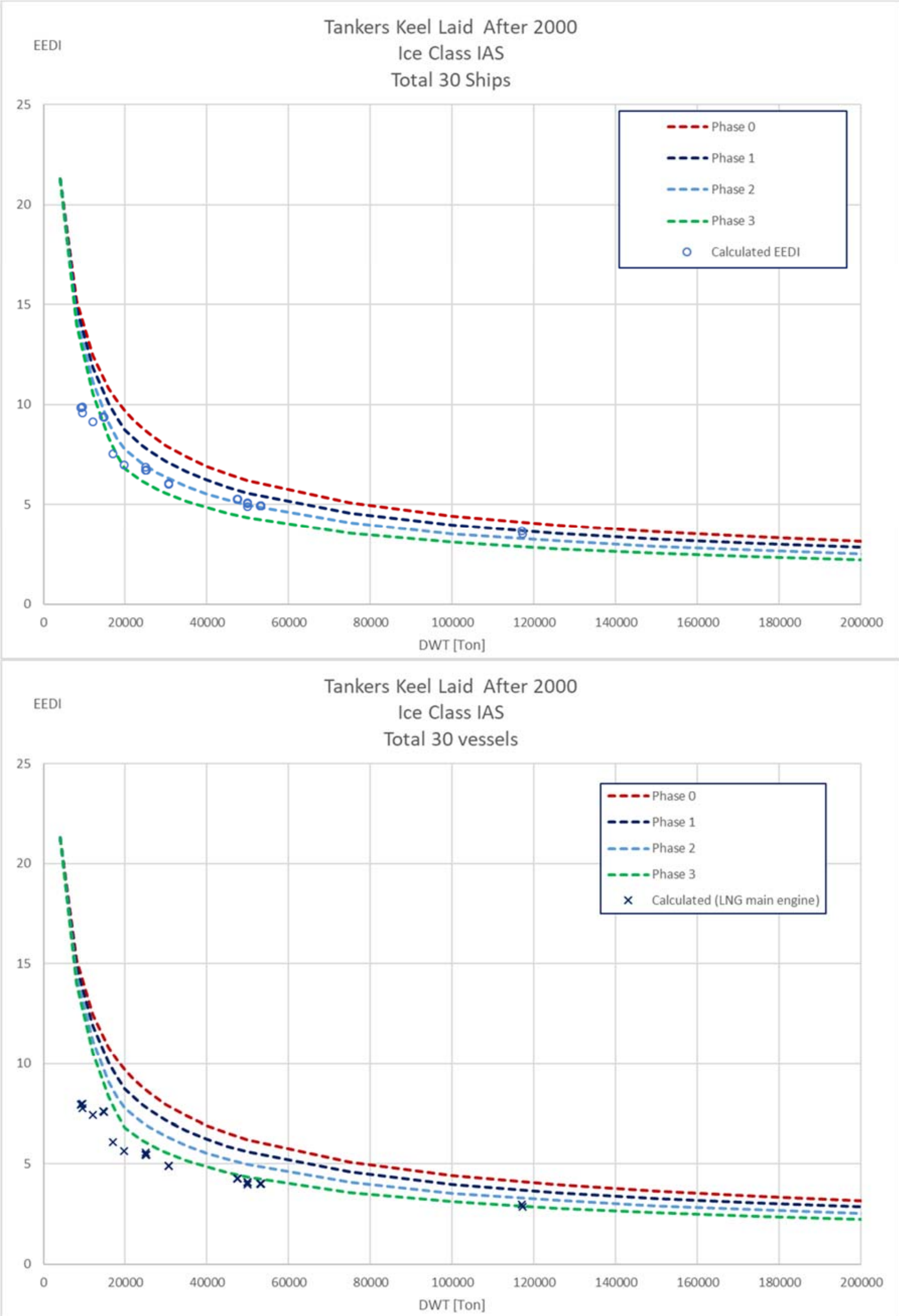


Figure 39: Comparison of calculated EEDI for MDO and LNG as fuel, tankers in ice class IAS.

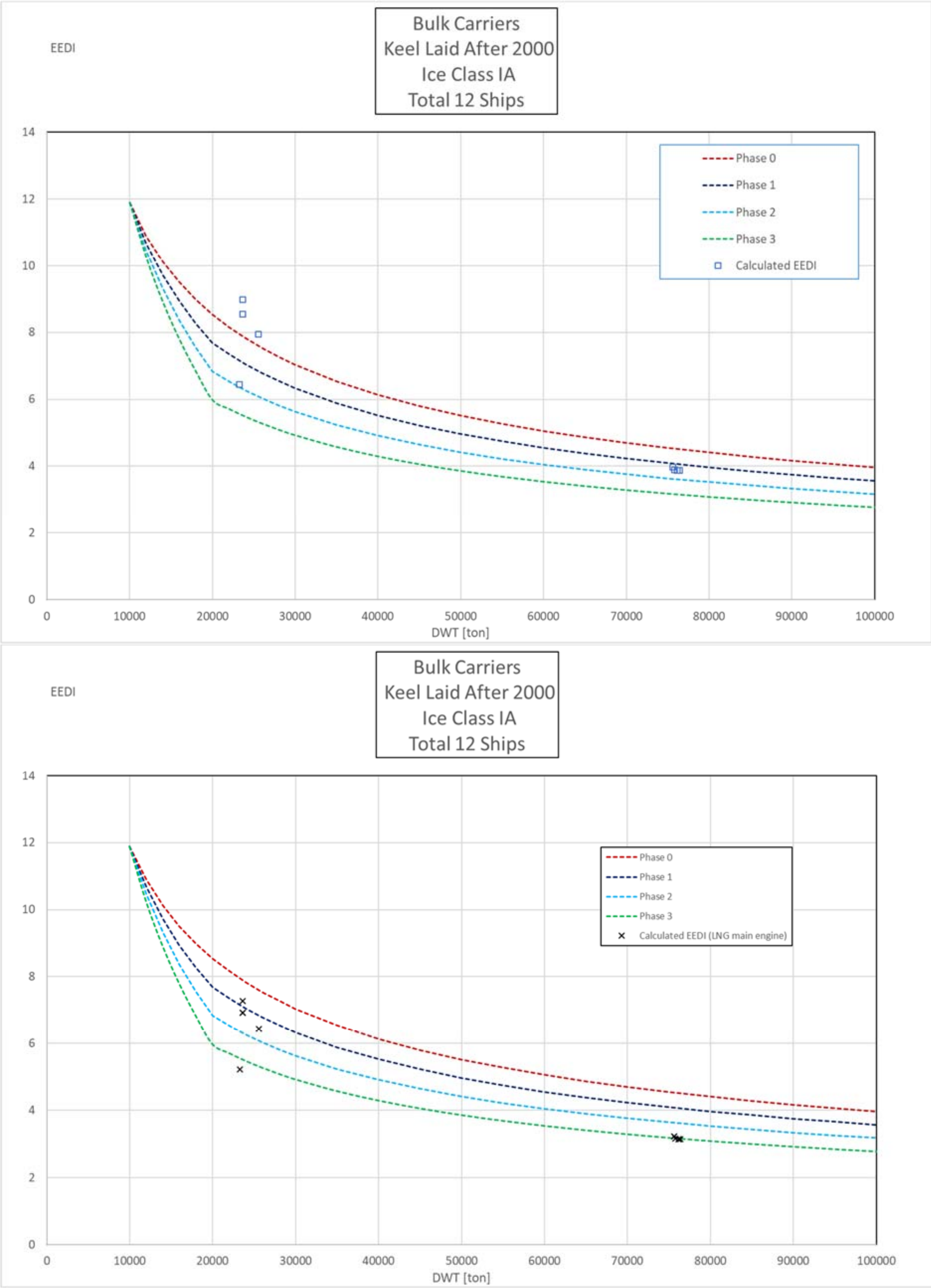
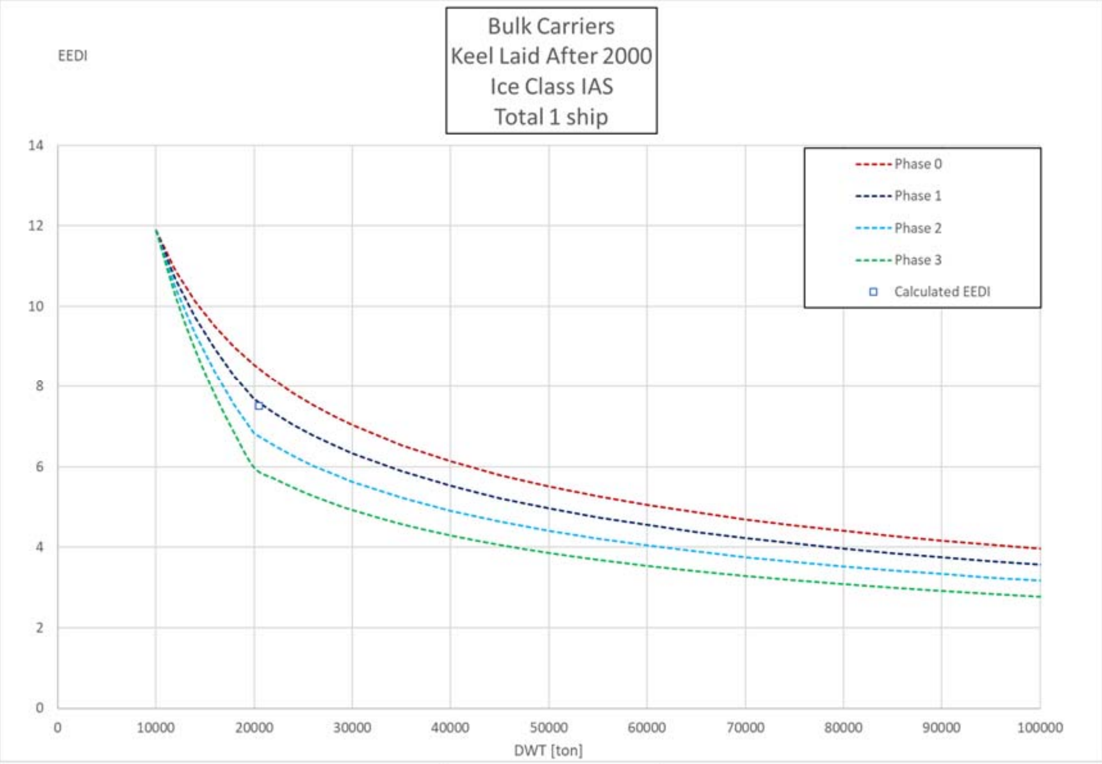


Figure 40: Comparison of calculated EEDI for MDO and LNG as fuel, bulk carriers in ice class IA.



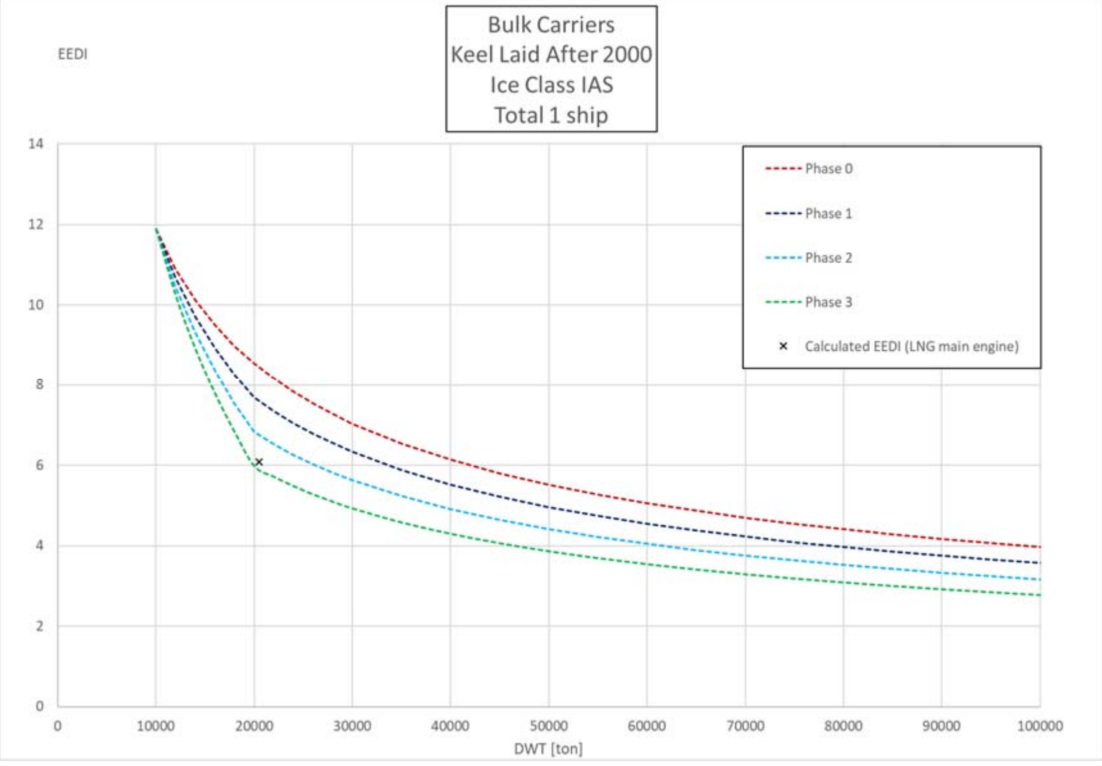


Figure 41: Comparison of calculated EEDI for LNG and MDO as fuel, bulk carriers in ice class IAS.

6 DISCUSSION AND CONCLUSIONS

This study has focused on determining a new way to define ice class correction factors for power, f_j, for ice class ships. The current correction factors are based on the length of the ship, whereas the new proposed correction factors would be based on the deadweight (DWT) of the ship. Using DWT as the parameter for the ship size gives more consistent results, and it is also more convenient because the proposed new correction factors for capacity, f_i, also are developed based on DWT as the parameter for the ship size.

For the three studied ship types, a clear difference in engine power between open water ships and ice class ships was found. The ship types with a clear difference are tankers, bulk carriers and general cargo ships. The new ice class correction factors for power have been developed for these ship types.

The purposed new correction factors f_i and f_j correct the EEDI values to a level similar to open water ships and allow for the required power and hull strengthening for ice without penalising these particular ships due to higher engine power and lower DWT capacity.

<u>Tankers</u>

The new purposed correction factors f_j and f_i seem to be correct for small tankers below 10000 DWT in ice class IA, while ships of such size even fulfil the phase 3 EEDI requirement. For ice class IAS, tankers up to a DWT of 15 000 - 20 000 tonnes come close to fulfilling the phase 2 and 3 EEDI requirements.

Large tankers (>50 000 DWT) in ice classes IA and IAS might have difficulties in fulfilling the EEDI requirements for phases 2 and 3, at least with the present ship designs. The analysis indicates that even large tankers might be able to fulfil phase 3 with the purposed correction factors by using LNG as fuel.

<u>Bulk Carriers</u>

Bulk carriers generally seem to have difficulties in fulfilling the phase 2 and phase 3 EEDI requirements. This results in the fact that even bulk carriers with an ice class have the same difficulty, even if the installed power is corrected to the level of open water ships.

But several newer bulk carriers have been built for ice classes IB and IA according to EEDI phase 0 requirements. These ships almost fulfil phase 1 and even in one case phase 3 of the requirements by applying the proposed new ice class correction factors.

However, the number of ships in the various ice classes is quite limited for this ship type, and this might have influenced the accuracy of the results.

As for tankers, using LNG as fuel could be the solution to fulfilling the EEDI phase 3 requirements for all of the Finnish-Swedish ice classes.

General Cargo Ships

For general cargo ships, it would seemingly be possible to fulfil even the EEDI phase 3 requirements for all of the ice classes of all ship sizes.

Container Ships

The power levels of open water container ships are generally higher than the power required for different ice classes by FSICR. In this respect, it seems that there is no need to introduce power correction factors, f_j, at this moment for container ships.

Ro-Ro Ship

Similar as with container ships, the installed power levels in ro-ro ships are generally higher than required by the FSICR for the various ice classes. As a conclusion, there is no need to introduce ice class correction factors for power, f_j, for ro-ro ships at this time.

LNG Carriers

As for the two previous ship types discussed above, the installed engine power in LNG carriers is usually higher than required by the FSICR. In conclusion then, there is no need to introduce ice class correction factors for power, f_j.

If the power levels for these three ship types are reduced in the future, these conclusions will need to be reconsidered. The correction factors for power, f_j, could then be developed based on regression analysis of the engine power of open water ships and the calculated required minimum engine power for the ice class in question.

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