Innovative ship design with less ballast water and less GHG

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Abstract

Ballast water management and EEDI/EEOI improvement are of great concern in the maritime industries, because the impact of both transfer of marine species contained in ballast water and GHG emissions should be minimized in order to protect the global environment.
Namura shipbuilding developed the MInimal Ballast water Ship (MIBS) jointly with some other parties in a national project, and designed a VLCC with the concept of MIBS, as an environmentally friendly solution to reduce ballast water loading and GHG emissions, applying pre-CSR rules. After that, research on application of MIBS to various ship types including VLCC, Aframax tanker, VLOC and Capesize bulk carrier has been continued.
In this paper, the MIBS concept is reviewed and some further study on ships' principal dimensions, midship section shape, strength, loading condition, etc., in consideration of applying Harmonized Common Structural Rules (HCSR), is introduced. Typical options to use the philosophy are shown via case study.

1 Background

The demand to reduce the transfer of marine species contained in ballast water and GHG emissions from shipping is increasing, as well known, and the International Maritime Organization (IMO) has strengthened the related regulations as per MARPOL revision on EEDI/EEOI criteria and the ballast water management convention.
In the circumstances described above, the maritime industries are developing various technologies to improve energy efficiency and studying the installation of ballast water treatment systems for new ships and some existing ships as well. It is noted that treatment systems should satisfy the requirements of IMO, and probably some local legislations, and have a great impact on ships' cost, space arrangement, etc.
As an innovative design solution, MIBS can simultaneously cut down GHG emissions and volume of ballast water in a reasonable way.

2 Introduction of MIBS

2.1 Concept of MIBS
MIBS is a design concept proposed by the Shipbuilding Research Centre of Japan based on it's original concept of Non-Ballast water Ship (NOBS), with typical midship section shown in Fig.1. The main features of MIBS are

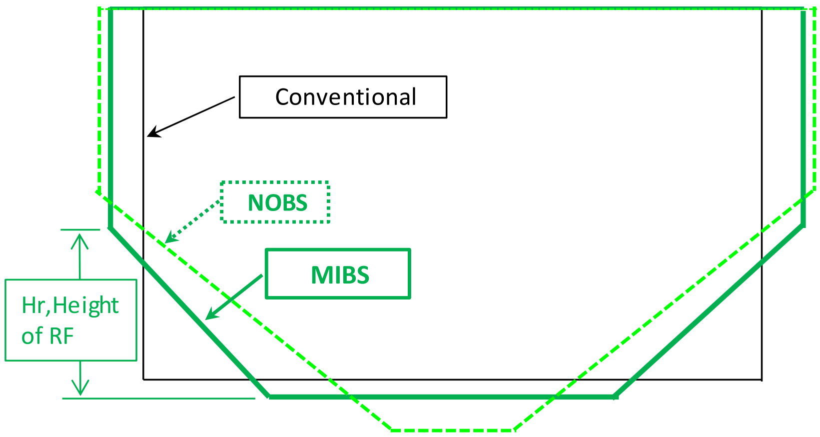
a) a midship section with inclined bottom (rise of floor, RF) and
b) a reduced bow draught (df), (it means greater trim)

in comparison with a conventional cargo ship, while NOBS has an extremely large rise of floor with very narrow flat bottom and a reduced bow draught.

An inclined bottom makes it possible for a ship to maintain the necessary draught to prevent excessive slamming load, propeller racing, instability, etc. with less ballast water (for MIBS) or no ballast water(for NOBS) carriage in ballast (or empty of cargo) condition. The resistance and necessary engine output for the ship to move ahead in water also decline drastically in the ballast condition because displacement and

wetted surface area, that dominate resistance, are much less than a conventional ship.
However, in fully loaded condition, a ship with such midship section without change of principal dimensions of ship length L, beam B, or design draught d, has less displacement and thus less deadweight. If we want to recover the lost deadweight, we need to enlarge some of these principal dimensions.

A reduced bow draught in ballast condition can further reduce displacement and wetted surface area, and thus necessary ballast water and engine output as well. In order to realize a reduced bow draught, some measures are generally considered necessary to improve bridge visibility, bow bottom strength against slamming.
Because fuel consumption and GHG emissions are almost proportional to main engine output, the GHG emission reduction rate is assumed equal to the main engine output reduction rate in this paper.



(Midship Section)

Fig.1 Concept of MIBS/NOBS

2.2 Achievement of trial designs

A joint project to develop MIBS for tankers and bulk carriers was carried out during 2009 to 2012, by Namura Shipbuilding, Oshima Shipbuilding, and the Shipbuilding Research Centre of Japan, subsidized or supported by the Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT), The Nippon Foundation, Nippon Kaiji Kyokai (ClassNK), and Japan Ship Technology Research Association (JSTRA).
For tankers that Namura mainly took charge of, several trial designs for a VLCC applying MIBS concept were conducted, with a rise of floor of about 8 metre height, starting at about 1/4 of beam, and with a reduced bow draught of 3 to 4 metres. The principal particulars are shown in Table 1.

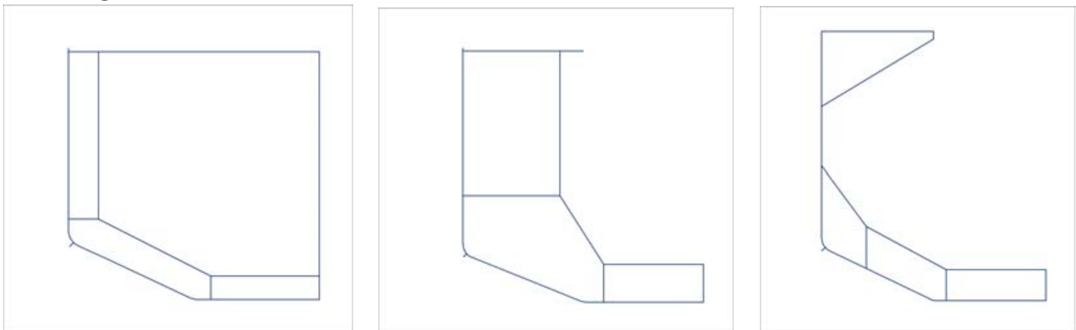
Table 1

	VLCC				
	Conventional Ship	MIBS			
		Case a	Case b	Case c	Case d
Length, bp (Lpp, m)	**324**				
Breadth (B, m)	**60**				
Depth (D, m)	**29**	**30**	**31**	**30**	**30**
Design Draught (d, m)	**20.5**	**21.5**			
Height of Rise of Floor (Hr,m)	**0**	**8.5**			
Bow Draught in Ballast Condition (d, m)	**7**	**4**	**3**	**3**	**3**
Deadweight (DWT, t)	**300 000**				
Ballast Water (BW, t)	**85 000**	**40 000**	**31 000**	**30 000**	**29 000**
BW Reduction	**0%**	**52%**	**64%**	**65%**	**66%**
Fuel&GHG Reduction (Full / Ballast)	**0%**	**-1% / 11%**	**-1% / 16%**	**3% / 17%**	**4% / 20%**
GHG Reduction(Average)	**0%**	**5%**	**8%**	**10%**	**12%**

From the table, it is noted that

・Ballast water (BW) volume can be reduced up to about 66%.
・Fuel consumption, GHG emissions can be reduced up to about 12%.
・Deadweight is the same, and design draught is increased to compensate lost deadweight.

The initial design of the MIBS type VLCC, including stability, loading conditions and key plan structure, has been carried out by Namura, and has attained Approval In Principle (AIP) from Nippon Kaiji Kyokai. The application of the concept to other tankers and bulk carriers, such as Aframax tanker, VLOC, Capesize bulk carrier etc., has also been studied. Here are some examples of midship section with rise of floor in Fig.2.



Aframax tanker VLOC Capesize bulk carrier

Fig.2 Examples of midship section with rise of floor

3 Further study of ship design with less ballast water/GHG applying HCSR

3.1 Determination of principal dimensions L, B, D, d, Cb:
Displacement Δ =1.025 x L x B x d x Cb = 1.025 x L x (B x d x Cm) x Cp
where Cp = Δ / (1.025 x L x Am), Cb=Cm x Cp,
Am=midship sectional area= (B x d x Cm), Cm = Am / (B x d),
A midship section with rise of floor has smaller Cm, Cb and Am than a conventional midship section with same B and d, therefore a ship with this midship section has less displacement.
From the above formulas, extensions of L, B, d, and/or Cp can be adopted to recover lost displacement of inclined midship bottom. Certainly, no dimension extension with less displacement (thus less deadweight) is also an option.
Generally, Cb=Cm x Cp of a MIBS is smaller in practical design even if Cp is slightly increased to compensate reduction of Cm, in full load condition. That is why additional extension of L, B, and/or d is needed to maintain the same deadweight as a conventional design. Cp and hull form should be carefully planned, depending on other dimensions and service speed, in order to minimize increase of wave resistance and pressure resistance. Depth D is raised, if cargo capacity lost due to inclination of the bottom needs to be recovered, or freeboard decreased due to deeper design draught needs to be raised.
Performances including deadweight, speed, engine output are generally dominated by the dimensions.
Some estimation has been done for several cases in section 4, and it is found that increasing draught has the most positive effect on performance.
On occasions when restriction of port/yard facility or canal requirement does not allow extension of L, B or d, less deadweight has to be accepted.
According to HCSR, the following hull form is assumed with respect to environmental loading:

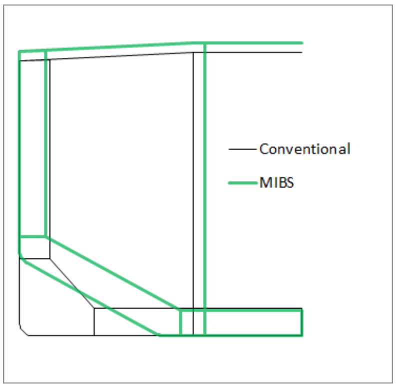
- L_{CSR} < 500 metres
  For ships over 350 m in length, special consideration is to be made for the wave loads by the Class Society.
- Cb > 0.6.
- L_{CSR}/B > 5
- B/D < 2.5

In my study of VLCC, all cases including the base ship are as follows.

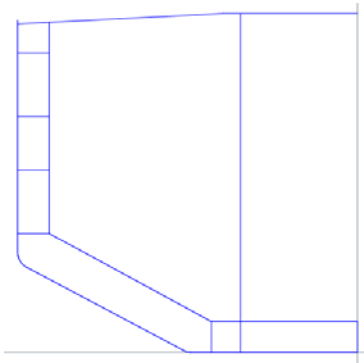
L_{CSR} is abt. 320 or maximum 340 metres, B is 60 or maximum 64 metres, L_{CSR} /B ranges from 5.0 (limit) to 5.7, B/D ranges from 1.9 to 2.3, MIBS has a delicately smaller Cb than a conventional ship, but is still great enough to satisfy the restriction. All Cb values in this study are greater than 0.78.
Consequentially, the variation of dimensions satisfies HCSR scope.

3.2 Midship section shape and geometric property

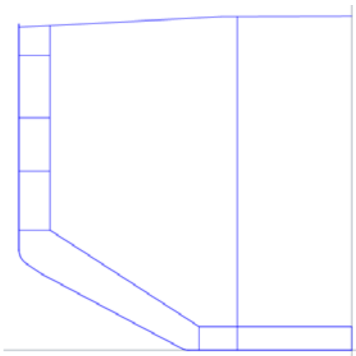
Some ordinary midship sections (Fig.3) and web frames (Fig.4) of a MIBS type VLCC are proposed, being compared with those of a conventional VLCC.



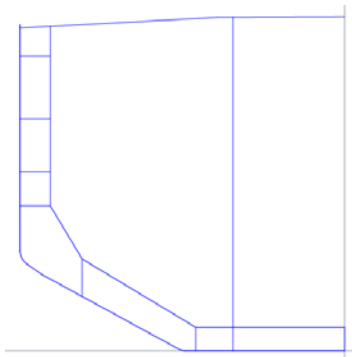
Comparion between MIBS/Conventional shapes



MIBS with parallel bilge structure



MIBS with tapered bilge structure



MIBS with parallel bilge structure with hopper

Fig.3 Comparison of midship sections between conventional and MIBS type VLCCs

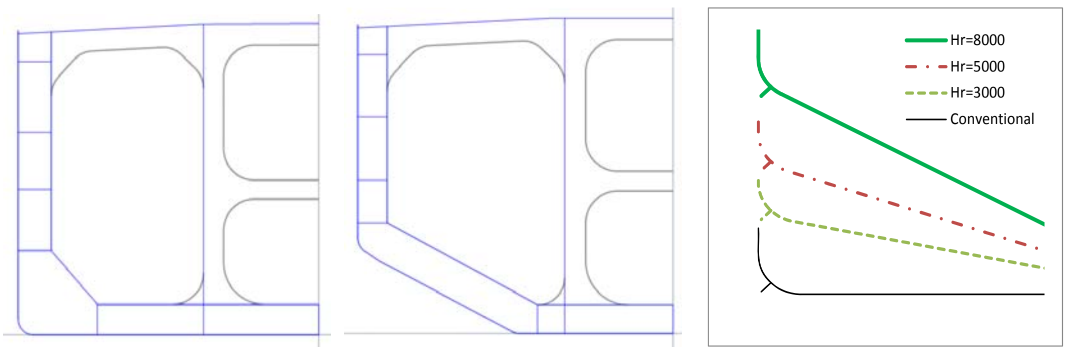


Fig.4 Comparison of web frames & bilge keels between conventional and MIBS type VLCCs

The minimum height of the double bottom (DB) and width of the double side hull (DH) required by HCSR are both 2.0 metres for the VLCC design. In the example of a conventional VLCC, DB height and DH width range from 2.8 to 3.5 metres but they can be slightly reduced in a MIBS in order to assure more cargo oil capacity, because span of DB in central cargo oil tank (CCOT) and span of DH are smaller than those in a conventional design.

As the wing cargo oil tank (WCOT) has a large slope bottom, the inside longitudinal bulkhead can be shifted toward centerline.
A narrow flat bottom remains in the WCOT and the side ballast tank, which is considered useful for survey, and result in faster unloading of cargo oil, and faster deballasting of water.
The DB space beneath CCOT may be used as piping space or void space, instead of ballast water tank. Because required ballast water tank capacity is less than a conventional ship.

While CCOT and double side hull are similar, the bilge shape is very different between MIBS and a conventional ship. The double hull bilge structure is longer and considered weaker than a conventional hopper structure. Therefore, 3 shapes to enhance the strength of bilge structure are proposed here, in Fig.3. The first one is a plain parallel structure, with deeper but uniform height, the second is with tapered height, and the third is a smaller parallel part with a hopper connecting to side hull.
This bilge area should be carefully designed. The depth of this part is increased while those of DB and DH are reduced.
Bilge keels are fitted to dampen rolling motions, which are similar to those for a conventional ship.

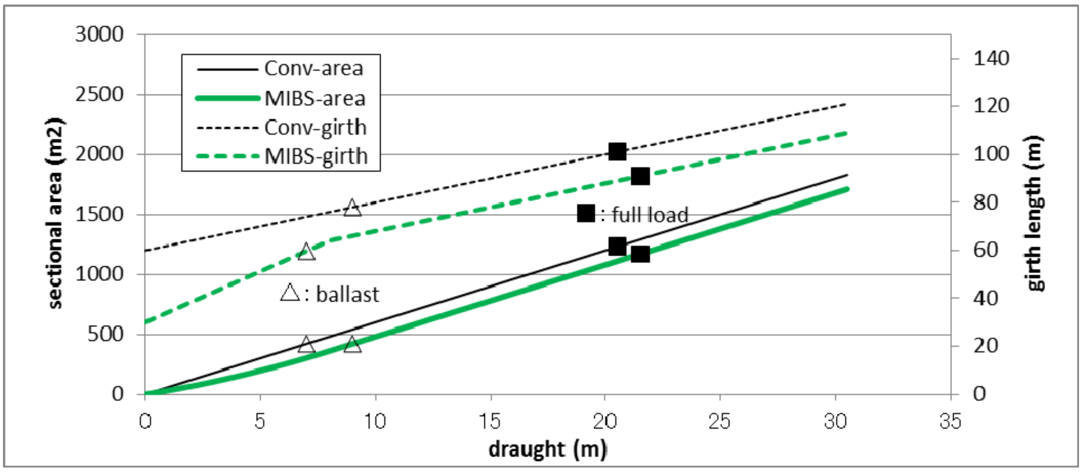


Fig.5 Comparison of geometric property between conventional and MIBS type VLCC sections

Sectional area and girth length are calculated and shown in Fig.5 for the two kinds of sections(MIBS & Conventional) at various draughts. The MIBS section here has an increased draught, while beam and deadweight of full load condition are the same as the conventional base.
The ratios of MIBS type section to conventional section range at about 70%(area) and 80%(girth length) at draughts of 6.5-9 metres around ballast condition. This result indicates great reduction of displacement and wetted surface area in ballast condition.
The ratios are about 90% (both area and girth length) at draughts of 20.5-21.5 metres around full load condition , while less displacement in loaded condition means less deadweight and less fuel consumption as well, but less wetted surface area just implies less fuel consumption. An ideal hull form has less wetted surface area, but more displacement in full load condition; less wetted surface area and less displacement in ballast condition.

If the midship section has a large rise of floor, deadweight may slightly decrease, arrangement of supporting blocks in building or repairing docks may need to be modified, additional measures may be necessary for mooring at ports, tug pushing operation, etc.
On the other side, this midship section can greatly cut down GHG emissions (especially in ballast condition), ballast water volume, ballast water treatment system capacity, unloading /deballasting time, etc.

3.3 Ballast loaded condition and bow draught df

As mentioned in 2.1, a reduced bow draught in ballast condition is also adopted.

For the VLCC example here, the minimum bow draught based on HCSR with respect to slamming seems to be shallower than that based on pre-CSR rules (Fig.6) and thus closer to the reduced bow draught in the MIBS design.

Consequently, a HCSR applied VLCC has already stronger bottom structure and needs less reinforcement for slamming and visibility at a reduced bow draught. That means a HCSR applied VLCC makes it easier to realize a reduced bow draught, compared with a pre-CSR VLCC. This relationship is supposed similar for other tankers and bulk carriers.

In this example, bridge visibility is reduced and it may be required to raise the bridge height or implement other measures to recover bridge visibility, if a reduced bow draught is adopted.

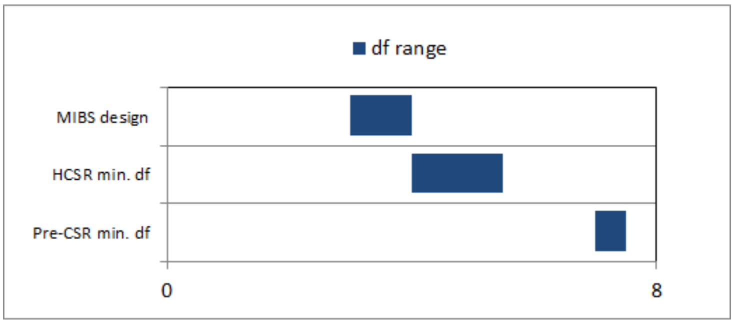


Fig.6 Comparison of bow draught distributions

Though a reduced bow draught may result in reduced bridge visibility and slamming strength, it is easier to reduce bow draught than apply a large rise of floor. Therefore, the author proposes that this method (reduced bow draught) can be applied first to ship designs, and rise of floor can be further challenged in the next step.

3.4 Cost impact

Cost is also an important factor for feasibility study, and it has been roughly estimated by the author for a base ship and some typical MIBS type VLCCs. It is supposed that

for the MIBS type VLCC of of all six cases studied in this paper,

・Ballast water treatment system to be installed can be scaled down by up to about 60%, therefore related initial cost and running cost can also be hugely saved.

・Total operating cost including fuel is definitely lower.

・Total initial cost may probably become lower.

and especially for Cases 1, 2 & 6 in Table 2, in which dimensions are not extended or only draught is enlarged,

・Lightweight and hull structural cost do not rise, they probably tend to fall.

(but rise for Cases 3 & 4, in which ship length or breadth is expanded.)

Therefore I have given priority to Cases 1, 2, and 6 when considering applying the MIBS concept.

Significant factors to diminish cost include

- fuel consumption,
- BWTS, relevant pumps, piping, and electricity etc. corresponding to reduced ballast water capacity to be used in ballast condition.

The most significant factor to push up building cost in a shipyard is considered to be additional labour cost due to being unfamiliar with the new structural shape, and it will become less and less as their experience to build such ships enlarges. Other dominant factors are measures of slamming and bridge visibility.

4 Case Study

Some typical cases with various combinations of design variables are studied to show a wide range of choices, and reduction rate sensitivities to some design variables.

4.1 Typical cases

The reduction rates of BW and GHG have been estimated and summarized in Table 2 and Fig.7 for typical cases.

Height of rise of floor (Hr) of 8 metres, reduced bow draught of 3 metres for relevant cases are used in the calculation.

Base case for comparison is a conventional design (Conventional midship section and normal bow draught of 7 metres) of VLCC shown in Table 1.

Necessary engine output, ballast water volume, and other key performances are estimated roughly using empirical method based on the author's experience and analysis, taking into account of principal dimensions, midship section geometric properties, displacement, wetted surface area, etc.

Table 2 List of cases

Cases	Bow draught df- or Conventional	Midship RF or Conventional	Extension of Dimensions			Redection Rate				Ini. Cost
			d	B	L	DWT	Fuel or GHG	Fuel or GHG*	BW	
Base	Conv.(df=7)	Conv.(Hr=0)	20.5	60	324					
C1 /RF &df-	df-4=3	Hr=8				6%	**13%**	**7%**	69%	- -
C2 /RF d+&df-	df-4=3	Hr=8	d+1=21.5				12%	12%	71%	-
C3 /RF B+&df-	df-4=3	Hr=8		B+4=64		1%	**9%**	**8%**	69%	+ +
C4 /RF L+&df-	df-4=3	Hr=8			L+16=340		9%	9%	68%	+
C5 / df-	df-4=3	Conv.(Hr=0)					3%	3%	39%	
C6 /RF d+	Conv.(df=7)	Hr=8	d+1=21.5				6%	6%	32%	-

(*: For C1 & C3, "reduction rate of GHG - reduction rate of deadweight" is used instead as "relative" reduction rate. Deadweights in other cases are kept the same as the base case.)

Case1 (C1 /RF&df-)

Midship section with rise of floor / reduced bow draught / no extension of dimensions

There is a great effect to reduce GHG and BW. Deadweight decreases, however the reduction of GHG (about 13%) overstrides the reduction of deadweight (about 6%), therefore there is still approximately 7% positive "relative" reduction rate of GHG against deadweight. Lightweight drops considerably, and hull construction cost is lower.

Case 2 (C2 /RF d+&df-)

Midship section with rise of floor / reduced bow draught / enlarged design draught(d+1=21.5)

There is the greatest net effect among the 6 cases to reduce GHG and BW. Lightweight drops slightly, and hull construction cost is lower, though design draught is raised.

Case 3(C3 /RF B+&df-)

Midship section with rise of floor / reduced bow draught / enlarged beam(B+4=64)

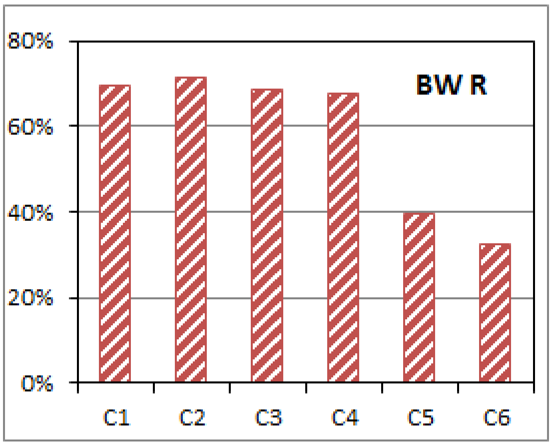
There is a great but less "relative" reduction rate than Case 2. Lightweight rises, and hull construction cost is higher. Beam cannot be extended over 64 metres, due to minimum L_{CSR} /B restriction, though

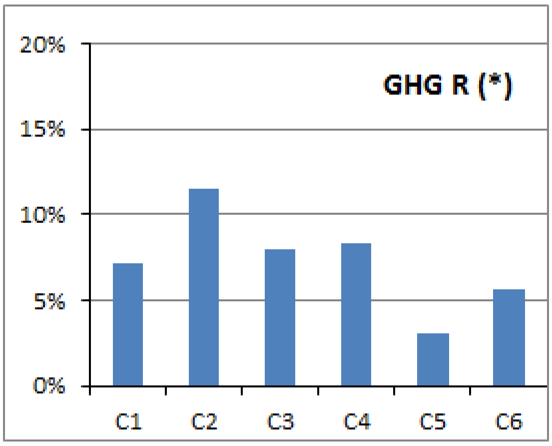
wider beam is needed to assure the same deadweight as base case.
Deadweight drops in this case, however the reduction of GHG (about 9%) overstrides the reduction of deadweight (about 1%), therefore there is still 8% positive "relative" reduction rate of GHG against deadweight.

Case 4(C4 /RF L+&df-)
Midship section with rise of floor / reduced bow draught / enlarged length(L+16=340)
Similar to Case 3, there is a great but less effect than Case 2. Lightweight increases, and hull construction cost is higher.
In the 3 cases of C2, C3, C4, d, B, and L is increased respectively.

Case 5 (C5 /df-) Conventional midship section / reduced bow draught
The effect of reduced bow draught alone is less than cases C1-C4 with rise of floor, but still substantial, and this case seems the easiest to be realized, because there is relatively less difficulty supposedly.

Case 6 (C6 /RF d+) Midship section with rise of floor / normal bow draught / enlarged design draught
The effect of rise of floor alone is less than C1-C4, but still substantial. GHG reduction rate is greater, but BW reduction rate less than C5. Lightweight drops slightly, and hull construction cost is lower, similar to C2.





Case	C1	C2	C3	C4	C5	C6
GHG R*	7%*	12%	8%*	9%	3%	6%
BW R	69%	71%	69%	68%	39%	32%

(*: For C1 & C3, "reduction rate of GHG - reduction rate of deadweight" is used instead as "relative" reduction rate. Deadweights in other cases are kept the same as the base case.)

Fig.7 Reduction rates for typical Cases

Case C2 has the best effect (improvement) of GHG reduction and BW reduction, among the six cases. However, there seem to be higher hurdles to clear for cases with rise of floor.

4.2 Sensitivities of reduction rates to rise of floor, bow draught
In 4.1, typical cases with different combination are estimated and compared. In this section, typical sensitivities are checked by calculation.

a. Sensitivities to Hr, in midship section
Height of rise of floor may vary as shown in Fig.8, and sensitivities of reduction rates to it are shown in Fig.9. It is noted that a larger Hr results in greater reduction rates of GHG and BW, and a smaller Hr still has significant reduction effects. Therefore, the author recommends that smaller Hr be applied first, and

then larger Hr be challenged in the next step.

And calculated reduction rates show good agreement with those of the optimized case based on model tank tests in previous research. It is noted that there are fluctuations of reduction rates for the same dimensions and the same Hr, due to different hull form details. The results additionally marked "(Pre)" in Fig.9 indicate reduction rates based on model tank tests in previous research. Design draught d is adjusted for each case to maintain the same deadweight.

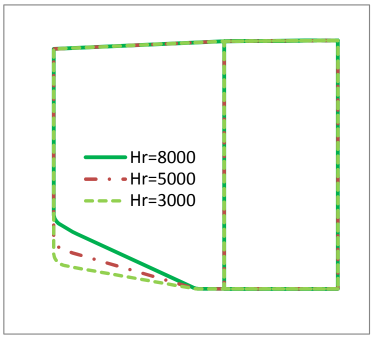
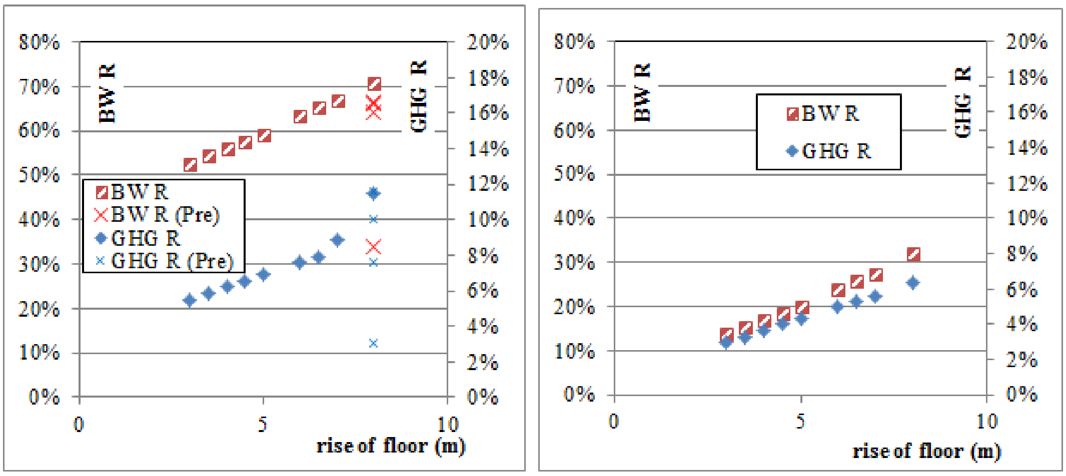


Fig.8 Variation for rise of floor



(at reduced bow draught) (at normal bow draught)

Fig.9 Sensitivities of reduction rates to rise of floor

b. Sensitivities to df, bow draught
As bow draught becomes shallower than base case, reductions increase. In Fig.10, relationships between reduction rates and bow draught are shown for a conventional VLCC (i.e., Hr=0).
Therefore, a reduced draught itself can attain substantial reductions, even without rise of floor.

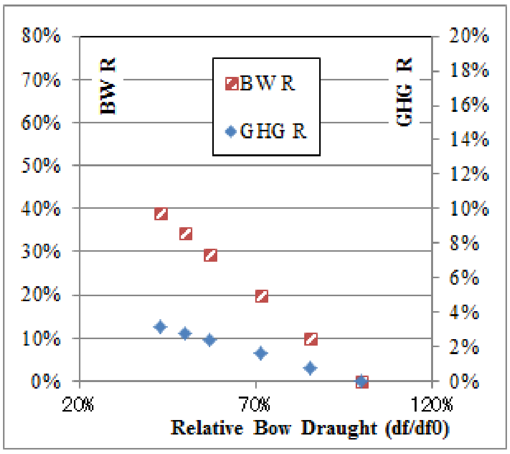


Fig.10 Sensitivities of reduction rates to bow draught (df0: normal df of base case)

5 Conclusions

In this paper, an innovative ship design concept with less ballast water and less GHG emissions has been reviewed in respect of performance, HCSR requirements, midship structure, and optional cases. Maximum reduction rate can exceed 10% for GHG emissions and 70% for BW. The hull form with large rise of floor can be within the HCSR scope, and an HCSR based design has a closer bow draught to the reduced bow draught of a MIBS than a pre-CSR based design.
Various combinations of principal dimensions (L, B, d), rise of floor (Hr) in midship shape and bow draught (df) in ballast loaded condition have been studied, and the reduction effects, their changing trends with Hr & df, difficulties of large RF and reduced df have also been examined, which provides wide range of options for ship owners and shipbuilders to select from.
The author also suggests a realistic step by step application of the innovative design philosophy, i.e., reduced df only at a first stage, additionally smaller RF at the second stage and then large RF at the third stage.

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