HYDRODYNAMIC AND ECONOMICAL ANALYSIS FOR THE PERFORMANCE OF INLAND SHIPS IN BANGLADESH

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ABSTRACT

Shallow water affects the performance of the ship and decrease the efficiency from economic and hydrodynamic point of view. Operations in shallow water is different from open and deep water, sometimes very dangerous if the affects are not understood properly by the Naval Architects at design stage and Mariners during operation. In this paper an effort was made to analyze the effect of shallow water on Bangladeshi inland ship performance in the light of speed loss and increased fuel cost. As this increased fuel cost has the direct impact on the freight rate, effect was also analyzed and measured economically. Some suggestions are also made for the Naval Architects to overcome these losses at the initial design stage.

KEY WORDS: Shallow water, Squat, Depth Froude Number, EEDI, IMO

Nomenclature

EEDI: Energy Efficiency Design Index

H: Depth of the Water in the Channel

F_{NH}: Depth Froude Number

L_{OA}: Overall length of ship

L_{WL}: Waterline length of ship

L_{BP}: Length between perpendiculars of ship

T: Maximum Loaded draft of ship

H/T: (Channel water depth)/ (Maximum Loaded draft of ship)

B: Moulded beam of ship

D: Moulded depth of ship

BHP: Break Horse Power

L/B: Length over Beam ratio of the ship

B/T: Beam over draft ratio of the ship

C_P: Prismatic Coefficient

C_B: Block Coefficient

1.0 INTRODUCTION

According to Bangladesh Inland Water Transport Authority (BIWTA), Bangladesh has about 24,000 kilometers of rivers, streams and canals that together cover about 7% of the country's surface. Most part of the country is linked by a complex network of waterways which reaches its extensive size in the monsoon period. Out of 24,000 kilometers of rivers, streams and canals only about 5,968 kilometers is navigable by mechanized vessels during monsoon period which shrinks to about 3,865 kilometers during dry period.

Bangladesh being riverine country, one of her major transport and communication medium is shipping. The ship owners always want to decrease the fuel consumption to maximize the profit and want to get the best possible output from the installed engine. It is a well known phenomenon that due to the effects of shallow water, a ship faces different type of problems, such as, increased resistance, problem in maneuvering.

These effects have been analyzed by Schlichting (1940) and Barras (2004) and in order to calculate these effects on the Bangladeshi inland vessels, there methods have been followed. The evaluation and presentation of Schlichting's results however did not cover all range of ship parameters. Schlichting (1940) has described the loss in shallow water comparing the speed in deep water, while Barras has considered the ratio of water depth in the river and the vessel draft. Both of the methods are used to analyze the losses due to the shallow water effect for the vessels of Bangladesh.

Energy Efficiency Design Index (EEDI) is a new index adopted by the International Maritime Organization. The EEDI value indicates the performance of a vessel and evaluates the performance by fulfilling the environmental, economical and off course the hydrodynamic aspects. Hasan (2011) has made an extensive analysis for different types of vessels. In this paper, this index was used to show how it can be used to reduce the affects of shallow water on vessel's performance.

2.0 SHALLOW WATER EFFECTS ON SHIP PERFORMANCE AND PHYSICAL SIGNS ON A VESSEL WHEN ENTERS INTO SHALLOW WATER

A vessel when enters into shallow water, there is an appreciable change in potential flow around the ship due to the proximity of the bottom, where the flow passing below the ship will speed up more than in deep water. This consequences lead to a greater reduction in pressure and increased speed and thus increased resistance. This effect is named the back flow effect and is usually assumed to affect both viscous and wave-making resistance. Due to the increase in resistance, there will be a drop in speed at the same engine power. This speed can decrease by about 30%, when H/T is 1.10-1.40.

Due to the same effect of shallow draft on bottom flow characteristic, the vessel will face 'Squat'. Squat increases the sinkage. It causes reduced clearance below the keel. Thus in shallow water, the vessel will have higher draft and less freeboard with the same weight of the ship.

There is a strong possibility that the vessel will become more sluggish to maneuver, that is the vessel will become less steerable. Propulsion efficiency will be decreased and greater tendency towards vibration as a result of propeller induced vibration.

In general, shallow water effects become pronounced when H/T . At higher ratio, the effect is reduced and becomes negligible for H/T . This ratio is the mathematical approximations or criteria for a pronounced shallow water effect on a ship. But, for the mariners, it is very important to know the physical signs when a vessel enters into shallow water. These signs can be summarized as:

a) The vessel will become less steerable.

b) Draught indicators on the bridge or echo sounders will indicate changes in the end draughts.

c) Propeller rpm indicator will show a decrease. If the ship is in 'open water' conditions, i.e. without breadth restrictions, this decrease may be up to 15% of the Service rpm in deep water. If the ship is in a confined channel, this decrease in rpm can be up to 20% of the service rpm.

d) There will be a drop in speed. If the ship is in open water conditions this decrease may be up to 30%. If the ship is in a confined channel such as a river or a canal then this decrease can be up to 60%.

e) The ship may start to vibrate suddenly. This is because of the entrained water effects causing the natural hull frequency to become resonant with another frequency associated with the vessel.

f) Rolling, pitching and heaving motions will be reduced as ship moves from deep water to shallow water conditions. This is because of the cushioning effects produced by the narrow layer of water under the bottom shell of the vessel.

g) The appearance of mud could suddenly show in the water around the ship's hull say in the event of passing over a raised shelf or a submerged wreck.

h) Turning Circle Diameter could increase by 100%.

i) Stopping distance and stopping time increase, compared to when a vessel is in deep water.

j) Rudder is less effective when a ship is in shallow water.

3.0 METHODS USED FOR ANALYZING THE EFFECTS

One widely-used analysis of speed loss in shallow water is the 'Schlichting' method. It can give us a general sense of the potential speed loss. Schlichting (1940) found that there is typically no measurable speed loss as long as the depth Froude number, FNH is less than about 0.4. As F_{NH} increases, however, the speed loss begins to take effect. Table 1 gives the % of speed loss in shallow water according to Schlichting.

Table 1: Loss of Speed (%) at different Depth Froude Number

F_{NH}	0.0-0.4	0.6	0.8	1.0
Speed Loss	No loss	1% loss	4% loss	14% loss

Source: HydroComp, Technical Report (2003), Report no 124.

Barras (2004) has given two simplified equations for loss in speed for two different ranges H/T ratio. He produced two equations as

H/T= 1.1-1.15, % of Loss in speed = 60-(25xH/T)

H/T = 1.5-3.0, % of Loss in speed = 36-(9xH/T)

Based on the above mentioned methods, the effects on the Bangladeshi inland ships are analyzed from hydrodynamic and economic point of view.

4.0 ANALYSIS OF THE PERFORMANCE OF INLAND WATER CRAFTS IN SHALLOW WATER

4.1 Hydrodynamic Analysis

As shown in table 2, 11.39 % of the total rivers have 3.66 meter or more water depth in summer.

By applying Schlichting (1940) method the speed loss in the rivers of Bangladesh is measured. The analysis was made considering the water depth of river of Bangladesh from 1.0 to 4.0 meter which will give an overview of the reduction in speed in shallow waterways of Bangladesh. It should be noted that losses here are calculated only considering for shallow draft. The effect from restricted channel width is not considered. Also, calculation was continued until the speed loss reaches to 14%.

Figure 1 shows speed loss in % at different depth of the river and corresponding speed in deep water. If 4% speed loss in any condition is considered as negligible, it is observed that after 4, 6, 8 and 9 knots speed in 1, 2, 3 and 4 meter water depth accordingly, the speed loss increases very rapidly.

From table 2 shows that 11.39% of the total inland waterways of Bangladesh have a water depth of 3.66 meter or more, it is obvious that almost 100% inland vessels are losing her efficiency more than 10%.

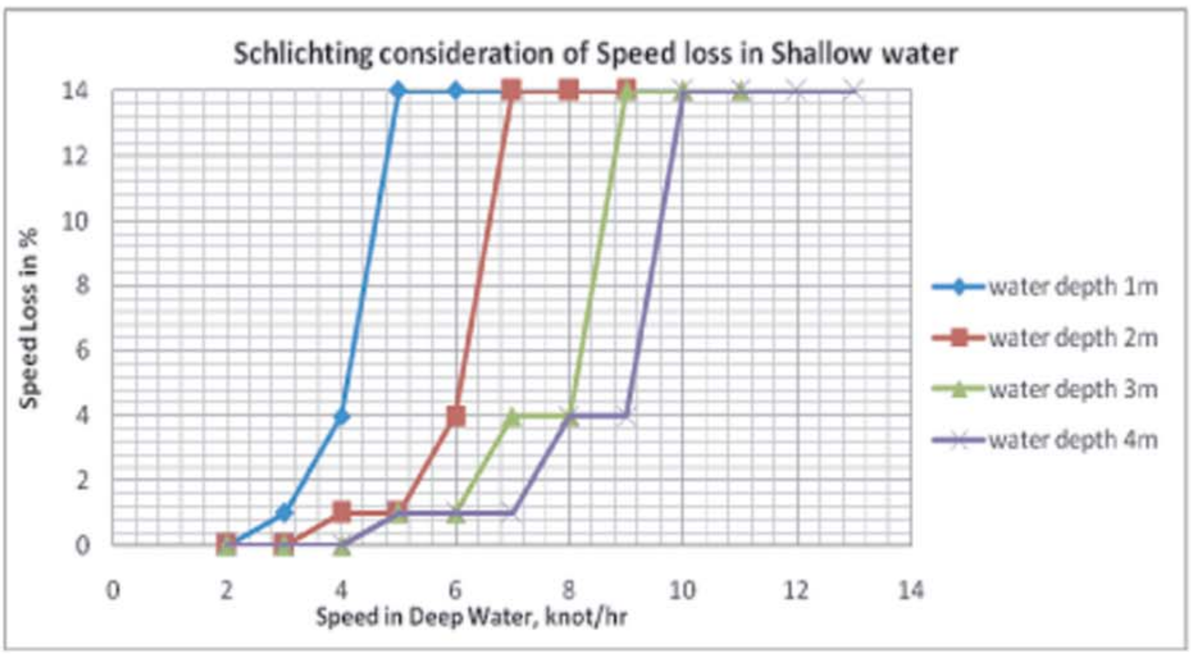

Figure 1: Speed loss in shallow water of Bangladesh according to Schlichting

Table 2: Depth of the water of the rivers of Bangladesh

Name of Route	Minimum Depth	Length of Route and Percentage	Minimum Vertical Clearance	Minimum Horizontal Clearance
Class-I	3.66 m	683 kilometers (11.39%)	18.30 m	76.22 m
Class-II	2.13 m	1027 kilometers (17.13%)	12.20 m	76.22 m
Class-III	1.52 m	1885 kilometers (31.44%)	7.62 m	30.48 m
Class-IV	< 1.52 m	2400 kilometers (40.04%)	5.00 m	20.00 m
Total		5995 kilometers (100%)		

Source: Website information, Bangladesh Inland Water Transport Authority (2011).

Schlichting (1940) has given an approximate speed loss for a certain range depth Froude number. It does not give the speed losses in between the range or when the depth Froude number is greater than 1. Barras (2004) has given another way to calculate the speed loss in shallow water. In his formulation, two equations were developed from the exact speed loss of from different existing vessels to cover the range of H/T from 1.10 to 1.50 and 1.50 to 3.00. The first range was selected by the author because it covered more dangerous situations leading to possible groundings. The second range was one that could lead to groundings at high speed, but the probability was comparatively decreased.

Considering the method as described by Barras (2004) for the waterways of Bangladesh, the speed losses are calculated in % for Different H/T ratio.

Calculated result in figure 2 shows that, in a water depth of 4 meter, a vessel having draft of 3.5 meter will give loss of 31.43 %, almost one third. That means, a vessel having speed of 12 knot/hr in deep water will have around 4 knot/hr speed at the same propulsion power. The losses in other situations are even worse. The other way of looking into fig. 2 is to determine the minimum draft of the ship to have lowest possible loss. For an example, when the water depth is considered as 3.5 meter and 4% loss is allowed, H/T will be 3.2 which mean the allowable draft of the ship is 1.09 meter at 4% loss. With these particulars and for vessel speed 10 knots, the depth Froude number becomes 0.87. According to table 1, the loss is also 4%.

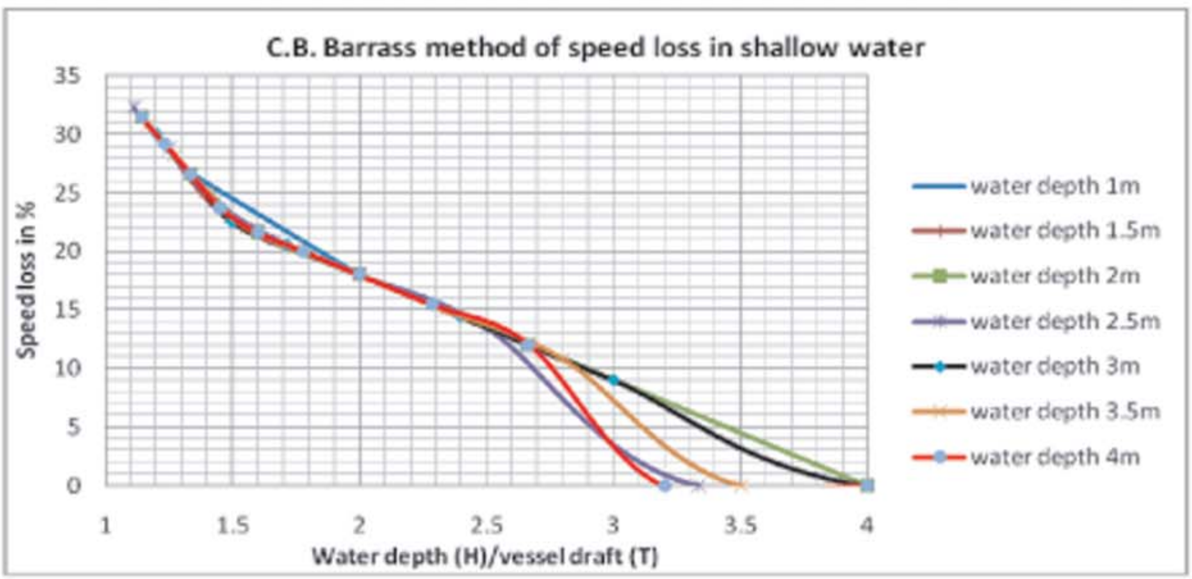

Figure 2: Speed losses in shallow water of Bangladesh according Dr. C.B. Barras

4.2 Economical Analysis

The economical analysis is carried out by comparing the loss for the vessel named M.V. TITU-13, a general cargo vessel, owned by 'Abul Khair Carrier Ltd.' in two different routes, one in deep water and another in shallow. By comparing the highest speed at two different routes, the % of losses would be measured.

The particulars of the vessel are as following:

Length over all, L_{OA} = 60.15 meter

Length waterline, L_{WL} = 58.02 meter (Hydrodynamic length)

Length between perpendicular, L_{BP} = 56.13 meter

Moulded breadth, B= 11.00 meter

Moulded depth, D= 4.15 meter

Maximum loaded draft, T= 3.70 meter

Maximum capacity = 1300 tonne.

Required Speed = 9 knots/hour

Fuel consumption = 205 gm/kW.hr

Required Engine Power in deep water = 300 X 2 BHP

Shallow water depth considered, H = 4.00 m

According to Barras (2004), the loss becomes 33% in shallow water, since H/T becomes 1.08. That means, the speed will fall down to 3 knots/hour. So, the vessel requires three times higher travel period as well as the fuel to cover the same distance in deep water. Thus the carrying cost becomes three times higher at least.

5.0 DESIGN OPTIMIZATION METHODS

Since shallow water gives a rise in resistance to a vessel at the same speed, design optimization is very important to reduce the total resistance of ship. At the initial design stage, designer could think of two different optimization methods, namely the statistical approach and the Computational Fluid Dynamics (CFD) solutions. The following subsection will describe these methods. In this paper, optimization with the statistical approach will be discussed.

5.1 Statistical Method for design optimization

A well known and the most accurate statistical solution for calculating the required break power of an engine for ship is given by Holtrop, J., Mennen, G.G.J., (1982). This is a very well-known approximate resistance and power prediction method for displacement and semi displacement vessels. However, not all types of ships are covered by this method. The approximate formulations are based on hydrodynamic theory with coefficients obtained from the regression analysis of the results of 334 ship model tests. This method works well for tankers, general cargo vessels, bulk carrier, container ship; fishing vessels tug boats and frigates with a certain boundary of prismatic coefficient, L/B and B/T. The limitations are shown in table 3. In order to have the most accurate results for the power prediction by this method; these limitations were maintained in the analysis process.

Table 3: Limitation for Holtrop and Mennen's method.

Ship type	Max Froude no.	Cp		L/B		B/T	
		Min	Max	Min	Max	Min	Max
Tankers, bulk carriers	0.24	0.73	0.85	5.1	7.1	2.4	3.2
Trawlers, tugs	0.38	0.55	0.65	3.9	6.3	2.1	3.0
Container ships, destroyers	0.45	0.55	0.67	6.0	9.5	3.0	4.0
Cargo liners	0.3	0.56	0.75	5.3	8.0	2.4	4.0
RoRo Ships, Car ferries	0.35	0.55	0.67	5.3	8.0	3.2	4.0

Source: Hasan (2011)

5.2 Concept of the Energy Efficiency Design Index (EEDI) for ship design optimization

In order to control this CO2 emission from shipping, International Maritime Organization (IMO), (2012), has developed the first ever global CO2 reduction index in the world, known as 'EEDI'. The basic formulation of EEDI is based on the ratio of total CO2 emission per tonne.mile. Hasan, S.M.R. (2011) has shown how CO2 emission depends upon fuel consumption and fuel consumption depends upon the total power requirements and eventually this EEDI formulation has certain impact on ship design parameters and hydrodynamics.

From EEDI equation it is very easy to understand that, the higher EEDI will indicate a less efficient vessel and vice versa.

In order to make a design parameter optimization in a holistic way, the author has integrated the Holtrop, J., Mennen, G.G.J., (1982) power prediction method and EEDI formulation, since formula requires predicted power for each case. The effort was made to see how each design parameters affects the EEDI.

EEDI can be described in its simplest form as following:

$$\text{EEDI} = \frac{CO_2\ Emission}{Transport\ work}$$

$$= \frac{Power * Specific\ fuel\ consumption * CO_2\ conversion\ factor}{Capacity * Speed}$$

$$= \frac{Emission\ from\ Main\ Engine + Emission\ from\ Auxiliary\ Engine + Emission\ for\ running\ shaft\ motor - Efficient\ Tech.\ Reduction}{Capacity * Reference\ Speed}$$

$$= \frac{\left(\prod_{j=1}^{M} f_j\right) * \left(\sum_{i=1}^{nME} P_{ME(i)} * C_{FME(i)} * SFC_{ME(i)}\right) + \left(P_{AE} * C_{FAE} * SFC_{AE}\right) + \left(\prod_{j=1}^{M} f_j * \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} * P_{AEeff(i)}\right) * C_{FAE} * SFC_{AE} - \left(\sum_{i=1}^{neff} f_{eff(i)} * P_{eff(i)} * C_{FME} * SFC_{ME}\right)}{f_i * Capacity * V_{ref} * f_w}$$

$$= \frac{KW * \frac{g\ fuel}{kwk} * \frac{g\ co_2}{g\ fuel}}{Tonna * knotical\ mile/h}$$

$$= \frac{g\ co_2}{Tonna * knotical\ mile}$$

5.3 Evaluation of Ship Design Parameters with Respect of EEDI

For this analysis, EEDI was calculated for one reference vessel particulars of a general cargo vessel and then the change of EEDI was checked by increasing the length, beam, draft and displacement by 5% individually.

Table 4 and figure 3 gives the parametric change in EEDI with change of 5% increase in length, beam, draft and displacement for constant C_B. According to table 4, a designer should increase the length and decrease beam and draft of a vessel for constant displacement and C_B.

But the parameter a designer should look for is the EEDI, since this is an index of efficiency. Though table 4 shows that 5% increase in the length is the most favorable in terms of resistance (shows in effective or main engine power), increasing the displacement is more efficient from the economic point of view, since it gives the minimum EEDI.

Table 4: Change in EEDI with the change in vessel's particulars for constant block coefficient, C_B

	L_{WL} (m)	B (m)	T (m)	C_B	Displacement (m^3)	Effective Power (kW)	Main Engine Power (kW)	Attained EEDI ($gmCO_2$/tonne*knotical mile)
Reference vessel	70.0	12.5	4.0	0.7	2450	249.81	668.44	14.29014
5% increase in length	73.5	12.198	3.903	0.7	2450	248.4	667.27	14.26519
5% increase in Beam	68.313	13.125	3.903	0.7	2450	253.2	669.44	14.31146
5% increase in draft	68.313	12.198	4.2	0.7	2450	248.3	668.68	14.29525
5% increase in displacement	71.148	12.705	4.065	0.7	2572.5	256.3	669.84	13.63801

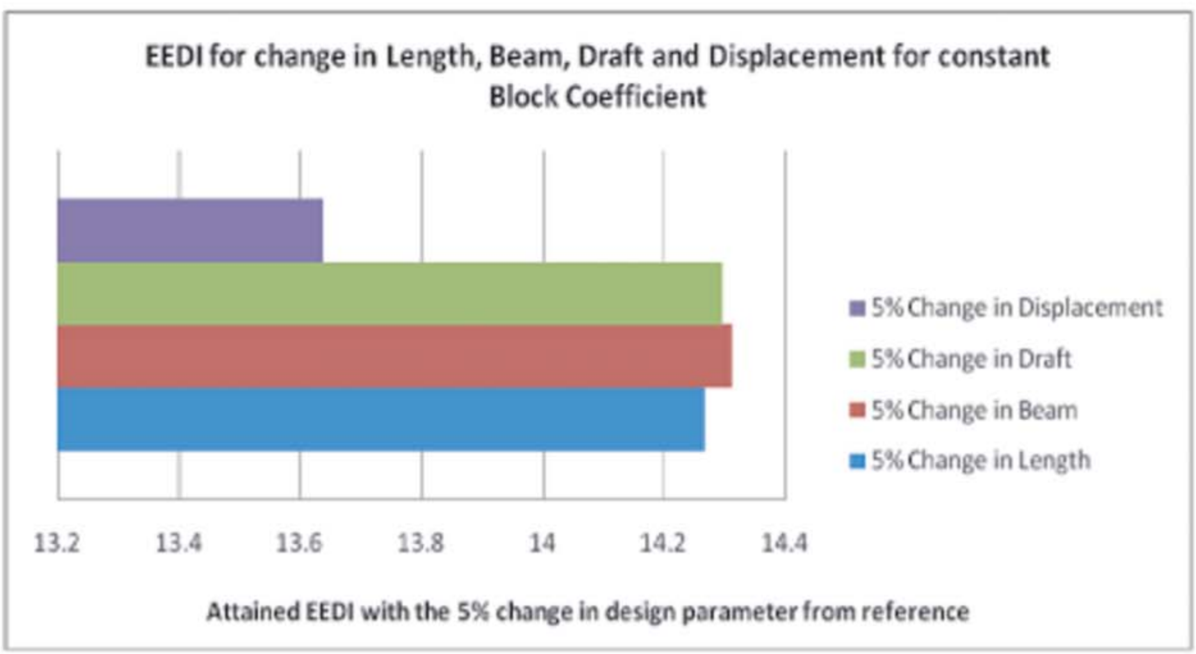

Figure 3: Change in EEDI for the change of vessels particulars for constant block coefficient

Results in table 5 and figure 4 are similar type calculated results as for table 4, but made with variable block coefficient. It is very easy to understand, small range change in block coefficient does not make a large variation in engine power keeping the same displacement.

Table 5: Change in EEDI with the change in vessel's particulars for variable block coefficient, CB

	L_{WL} (m)	B (m)	T (m)	C_B	Displacement (m^3)	Effective Power (kW)	Main Engine Power (kW)	Attained EEDI ($gmCO_2$/tonne *knotical mile)
Reference vessel	70.0	12.5	4.0	0.7	2450	249.81	668.44	14.2901
5% increase in length	73.5	12.50	4.0	0.67	2450	247.2	667.28	14.2653
5% increase in Beam	70.0	13.125	4.0	0.67	2450	249.78	669.45	14.3117
5% increase in draft	70.0	12.5	4.2	0.67	2450	246.73	668.68	14.2954
5% increase in displacement	70.0	12.5	4.0	0.74	2572.5	260.34	669.81	13.6376

Hasan (2011) in his paper has made an extensive analysis for three different types of vessels, namely Bulk carrier, Container vessel and Oil tanker. He made some suggestions based on his analysis in order to improve the EEDI index for those vessels. Table 6 gives the summery, where it could be understood, how the principle design parameters of ships, such as water line length, beam, draft, L/B, B/T ratio and prismatic coefficient should be changed to improve the efficiency.

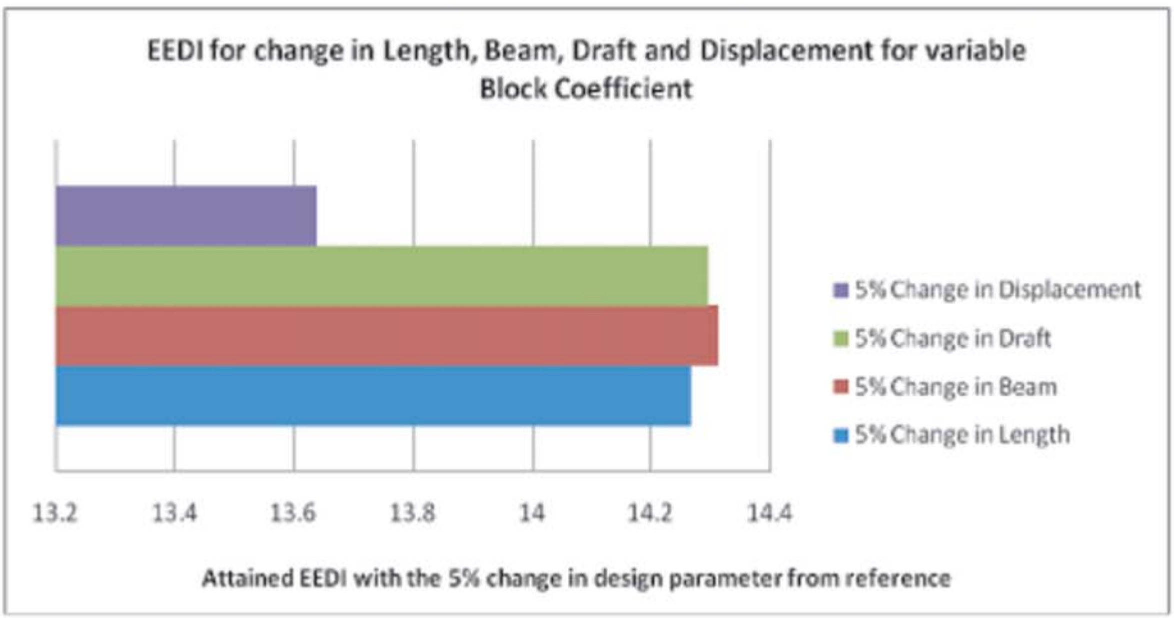

Figure 4: Change in EEDI for the change of vessels particulars for variable block coefficient

Table 6: Suggestion to change the individual ship parameter to improve EEDI.

Vessel type	Speed	Length (waterline)	Beam	Draft	L/B	B/T	Prismatic Coefficient, Cp
Bulk Carrier	Decrease	Decrease	Decrease	Decrease	Increase	Increase	Decrease
Container	Decrease	Decrease for slow speed vessel, Increase for High speed vessel.	Decrease for slow speed vessel, Increase for High speed vessel.	Decrease for slow speed vessel, Increase for High speed vessel.	Increase for slow speed vessel, Increase for High speed vessel	Increase for slow speed vessel, Increase for High speed vessel	Decrease
Tanker	Decrease	Decrease for slow speed vessel, Increase for High speed vessel.	Decrease for slow speed vessel, Increase for High speed vessel.	Decrease for slow speed vessel, Increase for High speed vessel.	Increase for slow speed vessel, Increase for High speed vessel	Increase for slow speed vessel, Increase for High speed vessel	Decrease

6.0 POSSIBLE WAYS AND MEANS TO REDUCE AND CONTROL THE LOSSES IN SHALLOW WATER

a) Avoid permanent ballast. It is been observed in the vessels of Bangladesh that, permanent ballast is mostly used when ballast is needed. When it is possible to control the on board ballast system, it is possible to control the draft and trim of the vessel, thus the effect of shallow water to some extent.

b) Design of low draft vessel with the highest possible L/B is favorable. Fuel consumption will also be low if the vessel has large L/B ratio.

c) Good training of the crew, proper and regular maintenance of the vessel, using up to date charts and competent experienced Captains, coupled with proper navigation aids in the waterways and emergency services on the routes planned, these measures should be taken for a already build ship to reduce the effect.

d) A chart should be provided in every ship containing the ship's speed, water depth and speed loss. As one of the quickest and most effective ways to reduce squat and resistance is lowering the speed, captain of the ship must know the minimum speed needed for safe maneuvering and maximum allowable speed in shallow water without (or allowing a certain percentage) speed loss.

e) The analysis shown in the section 4 is a rough estimation of how the vessels of Bangladesh are making the losses. The designer can either compensate the loss by reducing the draft or increasing the installed power. Which way will be better depends upon exact calculations and the exact calculation depends upon the route, water depth throughout the year, type of cargo, availability of cargo etc.

7.0 CONCLUSION

One of the main objectives of this paper was to show the amount of economical/financial losses that [illegible] to compensate the shallow water affect. In either way, the vessel is losing her economic efficiency, estimated as almost half of the usual efficiency. According Schlichting (1940) method, this loss goes to 14% and Dr. C.B. Barras method shows this loss could go more than 30%, depending upon different ship parameters.

The economical losses are even more significant. Analysis in this paper shows that, power requirement could increase more than twice than the required power in deep water. This means the more than twice fuel costs and for a vessel the annual travel or running cost is governed by the fuel cost, which is actually more than 60% in normal case.

Statistical calculation and parametric evaluation of ships particulars will help to finalize the ship design parameters to achieve the minimum required power and EEDI index will give us the guideline for a economically, environmentally, hydrodynamically efficient ship. Though calculating EEDI is not mandatory right now according to IMO for inland vessels, but it could be a very useful index to compare vessels both economical and hydrodynamic aspects.

It can be said that the losses due to the shallow water cannot be avoided for Bangladeshi ships, since the water depth of the country's rivers is not high. But of course a combined effort by the Naval Architects, ship owners and operators will help to minimize the losses. In many cases the affects or losses due to shallow water have been overlooked which is visible when the ship owners claim that the new built vessel is not able to reach the desired speed.

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