Further Optimisation of the Enlarged Ship Concept Applied to RORO Cargo/Passenger Vessel

Jakob Pinkster, J.M.J. Journée and S.G. Tan

Report 1182-P **Project Code: 914**

24 - 26th November 1998

Proceedings of the Second International Shipbuilding Conference, St. Petersburg, Russia

TU Delft

Technische Universiteit Delft

Faculteit der Werktuigbouwkunde en Maritieme Techniek
Vakgroep Scheepshydromechanica

Further Optimisation of the Enlarged Ship Concept Applied to RORO Cargo/Passenger Vessel

Jakob Pinkster, J.M.J. Journée and S.G. Tan

Report 1182-P **Project Code: 914**

24 - 26th November 1998

Proceedings of the Second International Shipbuilding Conference, St. Petersburg, Russia

Commissioned by: van der Giessen-de Noord N.V., Schaardijk 23, Krimpen aan den IJssel.

TU Delft

Delft University of Technology

Faculty of Mechanical Engineering and Marine Technology

Ship Hydromechanics Laboratory

Further Optimisation of the Enlarged Ship Concept Applied to RORO Cargo/Passenger Vessel

Jakob Pinkster*, J.M.J. Journée*, and S.G. Tan**

*Department of Marine Technology, Delft University of Technology, Mekelweg 2, 2628 CD Delft, The Netherlands
**Research and Development Department, Marin, P.O. Box 28, 6700 AA Wageningen, The Netherlands

PAPER PRESENTED AT THE SECOND INTERNATIONAL SHIPBUILDING CONFERENCE

(THEME A2 - PROBLEMS OF SHIP DESIGN)

ISC'98

Commissioned by:
van der Giessen-de Noord N.V.
Schaardijk 23
Krimpen aan den IJssel

24th - 26th November 1998
St.Petersburg, Russia

Further Optimisation of the Enlarged Ship Concept Applied to RORO Cargo/Passenger Vessel

Jakob Pinkster*, J.M.J. Journée*, and S.G. Tan**

*Department of Marine Technology, Delft University of Technology, Mekelweg 2, 2628 CD Delft, The Netherlands
**Research and Development Department, Marin, P.O. Box 28, 6700 AA Wageningen, The Netherlands

The "Enlarged Ship Concept" (ESC) was successfully applied to a freighter in the form of a RORO Cargo/Passenger Vessel, see Journée, Pinkster and Tan. [3]. Their results showed a performance improvement both in a technical and economical sense, however recommendations were made for further improvement of the enlarged ship designs in order to produce even better results. These recommendations include the following design work: optimisation of the vertical position of the upper deck of the enlarged vessels in order to reduce the vessel mass, while, at the same time, satisfying the requirements regarding allowable stress values due to longitudinal bending moments; optimise the mass of the enlarged vessels by the utilisation of high tensile steel; optimise the vessel form with regard to vessel resistance and propulsion; optimise the vessels turn around time by not utilising the lower deck for the carriage of trailers. In this paper these recommendations are carried out which lead to an even more promising performance improvement both in a technical and economical sense. It is shown that the ESC certainly has a good viability for these types of vessels creating even more income possibilities for the shipowners and a much safer vessel, eventhough it produces a more expensive ship to buy and exploit.

1. INTRODUCTION

In 1995 Keuning and Pinkster [1] explored the so-called "Enlarged Ship Concept" (ESC) by applying this to a fast 25 knot, semi-planing, 26 m. patrol boat. The Froude number was, based on vessel length, equal to 0.81. The main driver behind this application was the fact that a monohull sailing at high forward speed in head waves may incur unacceptably high vertical accelerations which may hamper the safe operability of the craft. Their work carried concerned three design concepts, namely a base boat with two enlarged ship configurations. The key to the ESC is that deadweight, i.e. payload, fuel and stores as well as vessel speed remain constant and equal to that of the base boat. In essence, they improved the seakeeping behaviour and decreased the resistance of the fast patrol vessel by increasing the length in steps of 25% and 50% and so increased also the length to beam ratio, reduced the running trim under speed and improved the general layout of the ship. The most important results from this study showed that the best design alternative was that with a 50% increase in length. On the one hand, a 68% marked improvement regarding a decrease in vertical acceleration in the wheelhouse in head seas and a 40 % decrease in required propulsion power in calm water at a speed of 25 knots were obtained; on the other hand the maximum purchasing price of the largest design alternative was estimated to be only 6% higher than that of the basic 26 m. patrol boat and the exploitation costs for a given mission profile were relatively reduced by 7%.

In 1997 Keuning and Pinkster [2] presented further research on the ESC topic; extensive model testing related to vessel resistance and motions were carried out and subsequent results were described in detail. This second study confirmed the results of the first study and favoured, once again, the Enlarged Ship Concept. In the meantime, the results from these studies have been applied to a number of new buildings of fast patrol boats in The Netherlands.

A logical question at this stage was then as follows, " Can the ESC also be successfully applied to the common work horse of the seas, the ordinary marine freighter?". In 1998 Journée, Pinkster and Tan [3], answered this question by applying the same ESC to a full time "freight carrying" vessel being a RORO/Passenger Vessel representative for present services in the UK-West Europe route.

2. THE BASE SHIP AND THE ENLARGED DESIGNS

The base vessel of 157 m. length [4] was lengthened by respectively 25 and 50 per cent, while deadweight and speed remained constant, see Figure 1 and Table 1.

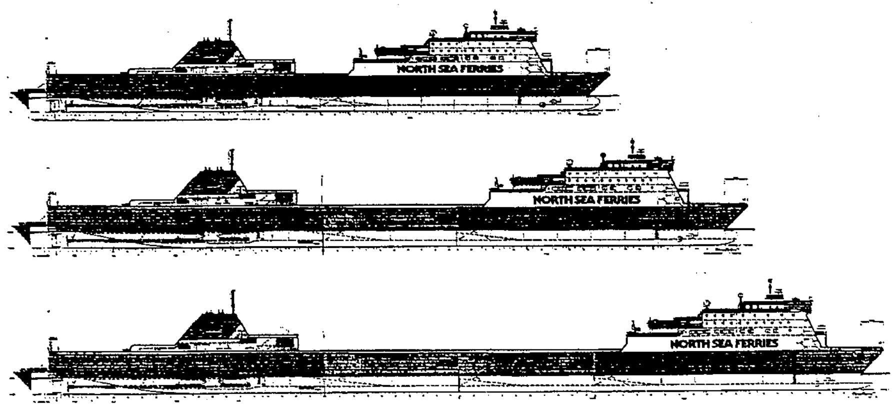

Figure 1

Table 1 Main particulars of the base ship and alternative ESC designs

Parameter	Dim.	ESC-0	ESC-1	ESC-2
Increase in Length	%L	0	25	50
Loa	m	166.77	206.18	244.97
Lpp	m	157.65	197.06	235.85
Bmld	m	23.40	23.40	23.40
T	m	5.80	4.97	4.50
KB	m	3.26	2.69	2.36
BM	m	9.01	10.25	11.35
KG	m	10.42	10.83	10.87
MG	m	1.85	2.11	2.84
Cb	[-]	0.61	0.64	0.66
Depth to main deck	m	8.60	8.60	8.60
Depth to upperdeck	m	14.40	14.40	14.40
Lightshipweight	t	7417	9126	11176
Deadweight	t	6020	6020	6020
Displacement	t	13437	15146	17196
Speed	kn	22	22	22
Propulsion power	kW	24480	25700	33500
Passengers	no	120	120	120
Lane length upperdeck	m	930	1190	1450
Lane length maindeck	m	910	1170	1430
Lane length hold	m	200	0	0
Trailer capacity	no	156	165	165
Water ballast	t	234	0	0
Gross tonnage	GT	17464	21452	25396
Net tonnage	NT	5239	6436	7619
k_{xx}/B	[-]	0.43	0.43	0.43
k_{yy}/Lpp	[-]	0.29	0.29	0.29
k_{zz}/Lpp	[-]	0.29	0.29	0.29

The consequences with regard to vessel mass, stability and trim, cargo hold configuration, propulsion power, freeboard, net tonnage and building costs were evaluated. On the operability side, seakeeping performance as well as operability were also assessed. Finally costs were determined for the base ship as well as for the two ESC alternatives. The most important results shown in Table 1 from this recent study for the best design alternative with a 25% increase in length showed on the one hand, a small and unsignificant improvement regarding a decrease in vertical acceleration in the wheelhouse in head seas and a 5% increase in required propulsion power in calm water at a speed of 22 knots; on the other hand the maximum purchasing price of the largest design alternative was estimated to be 10 higher than that of the basic 157 m. RORO/Passenger Vessel and the exploitation costs for a given mission profile were relatively increased by 8%. All in all, when comparing these results to those related to the 26 m. patrol boat, the RORO/Passenger Vessel RORO/Passenger Vessel at a first glance appears to give a less satisfactory result when enlarged; however, a definitive advantage of the ESC is the provision of space for the accommodation of lighter cargoes if available which consequently significantly increase the earning capacity pro rata and transport efficiency as may be seen from Table 2.

Table 2 Results of economical calculations for the RORO/Passenger Vessel

Index	ESC-0	ESC-1	ESC-2
Increase in length [%L]	0	25	50
Building costs	1.00	1.10	1.28
Power at 22 knots	1.00	1.05	1.32
Operational costs	1.00	1.08	1.18
Transport efficiency[1]	1.00	1.01	0.80
Transport efficiency[2]	1.00	1.17	1.13
Trailer capacity[1]	1.00	1.06	1.06
Trailer capacity[2]	1.00	1.22	1.49

[1] 12.2 m. trailers total all in load of about 30 tons each (dwt = 6020 tons)
[2] maximum number of 12.2 m units possible (dwt = 6020 tons)

With regard to safety, applying ESC to a RORO vessel also renders an improvement in concept design due to a significant increase in survival capability after having suffered the ingress of water into the hull; the condition that the lowest hold remains empty and optimally subdivided for this purpose must be respected.

Furthermore [3] it was thought that further optimisation of the enlarged designs of the RORO freighter/passenger ferry may well lead to more promising results. It was therefore recommended that the vertical position of the upper deck of the enlarged vessels be optimised to reduce the vessel mass and also that the utilisation of high tensile steel be looked into as this will surely reduce the vessel mass while at the same time being able to withstand the higher longitudinal bending stresses; optimise the vessel form with regard to vessel resistance and propulsion and optimise the vessels turn around time by not utilising the lower F deck for the carriage of trailers. In the present paper a number of these recommendations are investigated with regard to their implications and merits and the subsequent results regarding the final design outcome are discussed.

3. FURTHER OPTIMISATION

Since ESC-1 produced overall the best results from the investigations carried out in [3] and in order to make a quick estimate of what the effect on the design would be by altering of specific design parameters within the given concept, the depth of ESC-2 was altered in steps of 0.6, 1.0 and 1.4 m. repectively. The depth to main deck thereby varied from 8.80, 9.2, 9.6, and 10.0 m. The weatherdeck situated at 14.40 m. above the base line for the base ship was also changed by the same amount. In essence, the effect of these changes will result in a change in, amongst others, the vertical centre of gravity, lightshipweight, vessel draft and initial metacentric height. These changes have been estimated to be within a certain range, for example, due to the changes in vessel depth the vertical centre of gravity of the loaded vessel was varied respectively from 10.83, 11.50, 12.00 and 12.50 m., the draft from 4.00, 4.50, 4.97 and 5.50 m. This is taking into account a possible (later to be determined) decrease in lightshipweight due to the effect that an increase in depth may have on required section modulus from a viewpoint of bending moments and/or torsional moment. The main fixed values for these calculations are given in Table 3. In view of the added freedom of the designer to place the decks and cargo according to his own (best suited) requirements, it was decided to make the subsequent motion calculations etc. therefore also for the same combination of the these three design parameters (depth to main deck, vertical centre of gravity and vessel draft) which each have 4 values. These combinations are also shown together in figure 2.

Table 3 Main particulars of the ESC-1 and alternative designs with increase in depth

Parameter	Dim.	ESC-1	ESC-1/0.6	ESC-1/1.0	ESC-1/1.4
Increase in Length	%L	25	25	25	25
Loa	m	206.18	206.18	206.18	206.18
Lpp	m	197.06	197.06	197.06	197.06
Bmld	m	23.40	23.40	23.40	23.40
Increase in Depth	m	0	0.6	1.0	1.4
Increase in Depth	%D to main deck	0	0.07	0.10	0.16
Depth to main deck	m	8.60	9.20	9.60	10.00
Depth to upperdeck	m	14.40	15	15.40	15.80
Deadweight	t	6020	6020	6020	6020
Speed	kn	22	22	22	22
Propulsion power	kW	25700	25700	25700	25700
Passengers	no	120	120	120	120
Lane length upperdeck	m	1190	1190	1190	1190
Lane length maindeck	m	1170	1170	1170	1170
Lane length hold	m	0	0	0	0
Max trailer capacity heavy	no	165	165	165	165
Max trailer capacity light	no	191	191	191	191

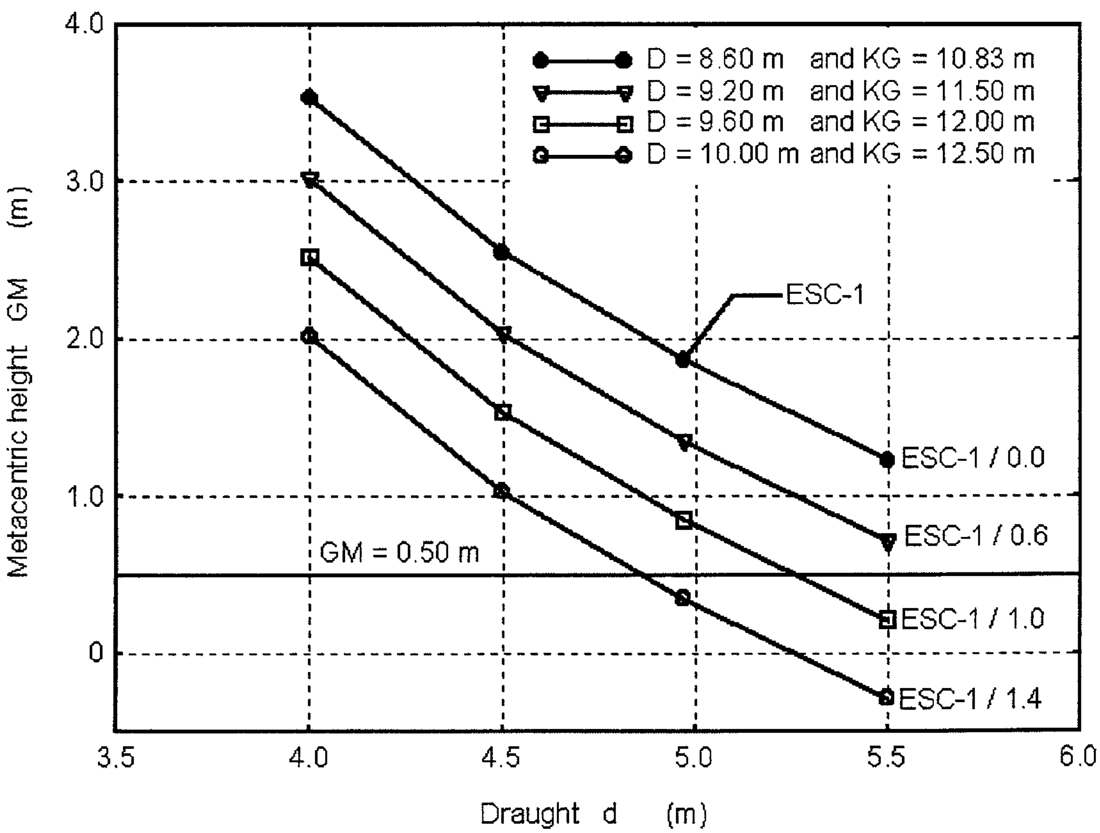

Figure 2: Metacentric Heights of ESC Series (D = depth to main deck)

4. SHIP MOTIONS

The vessel motions were calculated using the linear strip theory program SEAWAY of the Delft Ship Hydromechanics Laboratory [5]. These calculations were carried out in Beaufort 7 to 11, at wave directions ranging from head to following seas. The energy distribution of the irregular waves in the considered coastal areas was described by uni-directional JONSWAP wave spectra. According to Hasselmann [6], this wave energy distribution is a favourable choice for fetch limited seas. Figure 3 shows a commonly used relationship between period, wave height and Beaufort number. The long term probability on exceeding a certain sea state was obtained from Global Wave Statistics whereas the limiting criteria of ship motions were obtained from Karppinen [7]. Since the topic investigated in this paper deals with large seagoing vessels, ship motions are calculated at 20 and 15 knots instead of at a service speed in calm water of 22 knots. When assuming that the still water resistance is proportional to at least the square of the ship speed and using calculated data on added resistance in seaway, a sustained sea speed in rough weather dropped from 22 to 15 knots would expect to be an acceptable average.

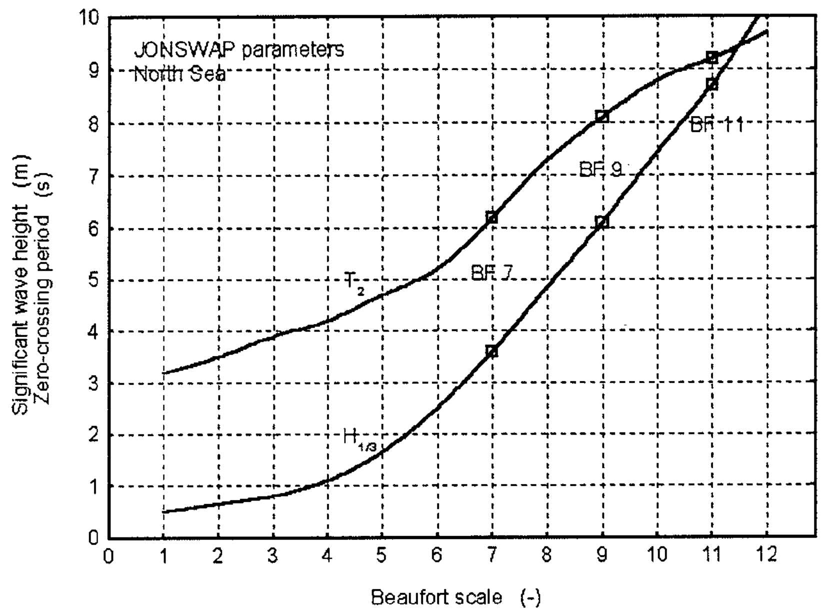

Figure 3. JONSWAP Wave Spectra Parameters.

The vertical significant acceleration amplitude at the bridge in head seas was given as a function of the Beaufort scale with an acceleration criterion of 0.3 g see [3]. At both speeds course can be maintained by ESC-0 in sea states up to Beaufort 8, which will be exceeded during about 2 percent of the year. As expected, the two enlarged ships ESC-1 and ESC-2 can maintain their course up to Beaufort 9 and 10 respectively. Also shown in [3] was the probability on slamming in head waves, defined by a relative vertical velocity criterion at the bow. Using a slamming criterion of 2 per cent, all ESC ships can maintain their course up to Beaufort 8. The effect of ship size and forward speed on slamming appears to be relatively small. In the light of these results no more effort will be put into investigation of these phenomenon for the design alternatives of ESC-1 as presented in the present paper. However, effort will be put into the more critical aspects of these larger vessel which are the strength related phenomenon such as vertical bending moments and tosional moments due to ship motions in a seaway.

5. VERTICAL BENDING MOMENTS

As may be seen from figure 4 the largest significant amplitude of the vertical bending moment is met in head seas (180°) for all Beaufort Numbers. The magnitude of the corresponding vertical bending moments in a BF 11 is in the order of magnitude of the still water bending moment. The difference in vessel speed of 20 or 15 knots in a seaway does not have any meaningful influence on these results. Figure 5 shows that increasing the vessel depth for ESC-1 does not appear to cause any significant changes in the vertical bending moments in a seaway.

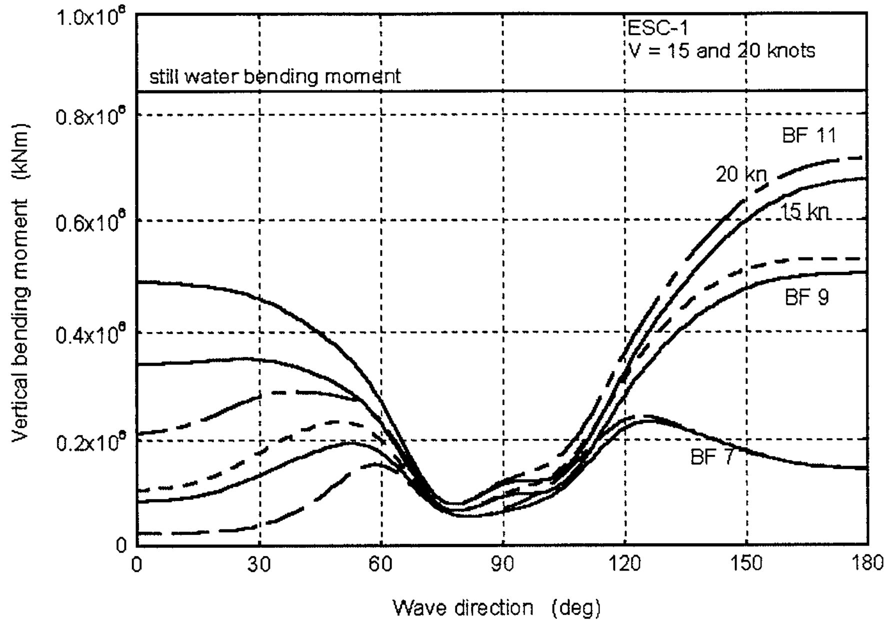

Figure 4. Effect of speed and wave direction on vertical bending moment amidships of ESC-1.

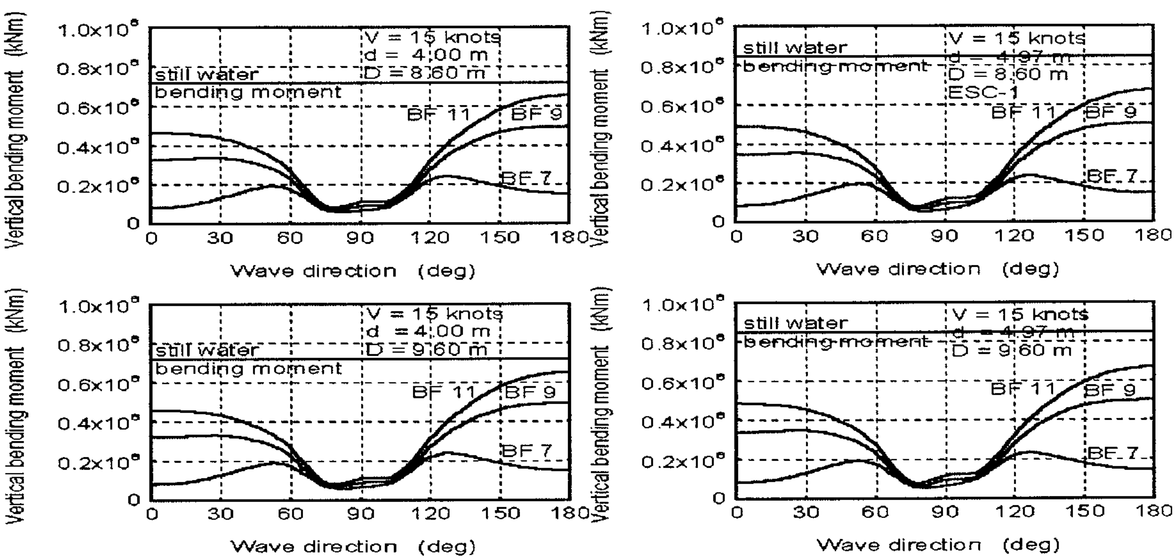

Figure 5. Effect of wave direction on vertical bending moments amidshipsof ESC-1 alternatives at a speed of 15 knots.

Assuming the same level of safety factor for bending moment for all vessel alternatives relative to ESC-1 an the application of the simple elastic beam theory to the sides, bottom and topsides; this means that the scantlings of the vessel for a fixed bending moment value may be estimated using the following relationship between bending moments for the two designs under consideration:

$$\frac{t_{s2}D_2^2 + \left(B/D_2\right)t_{d2}{}^3 + 3B.D_2.t_{d2}}{t_{s1}D_1^2 + \left(B/D_1\right)t_{d1}{}^3 + 3B.D_1.t_{d1}} = \frac{M_{b2}}{M_{b1}} \qquad (1)$$

(hereby the subindex 1 refers to the ESC-1 design and the subindex 2 refers to the alternative with the increased depth value, ts/td refers to the average thickness of the ship's side/deck (including plating and stiffeners etc.), B refers to the ship's breadth and D the Depth).

The basic formula used to derive (1) is that giving the bending stress, σ_b,

$$\left[\frac{M_b}{W_b}\right]_1 = \sigma_b \left[\frac{M_b}{W_b}\right]_2 \qquad (2)$$

(hereby the subindex 1 refers to the ESC-1 design and the subindex 2 refers to the alternative with the increased depth value, M_b refers to bending moment and W_b refers to bending section modulus, using A1 and A2 respectively for the material cross sectional area (including stiffeners), the ratio A2/A1 may be calculated as being a function of Mb_1/Mb_2, see figure 6. From figure 6 the effect on cross sectional area may be estimated for a given vessel depth to weatherdeck and Mb_2/Mb_1 values. In the case under investigation in this paper since $Mb_2/Mb_1 \approx 1$ the reduction in steel weight is approximated as being 0.8%, 1.4% and 1.8% This gives a decrease of respectivily 50 t, 81 t and 110 t for D = 15.00, 15.40 and 15.80 m. This in turn leads to a reduction in building costs of approximately a maximum of 1%.

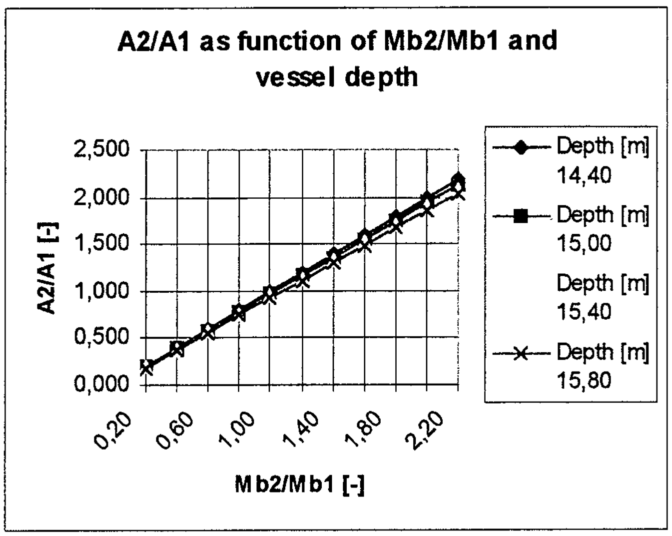

Figure 6 Effect of Mb_2/Mb_1 on ratio cross sectional area of ESC-1 alternatives.

Given A1, t_{s1}, t_{d1} and the ratio Mb_2/Mb_1, the average thickness t_{s2} may be calculated; using the assumtion also that $t_{s1}/t_{d1} = t_{s2}/t_{d2}$. With t_{s2}, t_{d2}, B and D_2 then A_2 is may be determined. The cross sectional areas A_1 and A_2 are defined as follows:

$$A_1 = (t_{s1} * D_1 + t_{d1} * B) * 2 \qquad (3)$$

and

$$A_2 = (t_{s2} * D_2 + t_{d2} * B) * 2 \qquad (4)$$

6. TORSIONAL MOMENTS

As may be seen from figure 7 the largest significant torsional moment amplitude occurs in and around stern quartering waves (70°) for all Beaufort Numbers. The magnitude of the corresponding torsional moments in a BF 11 is in the order of magnitude of twice that found in BF 7 conditions. The difference in vessel speed of 20 or 15 knots in a seaway does not have any meaningful influence on these results. Figure 8 shows that increasing the vessel depth for ESC-1 appear to cause significant changes in the torsional moment in a seaway.

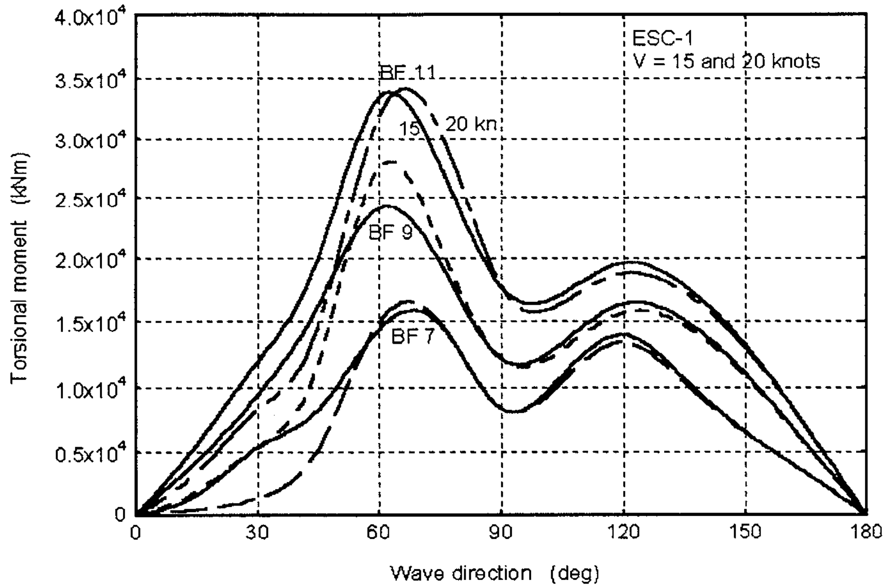

Figure 7. Effect of speed and wave direction on torsional moments amidships of ESC-1.

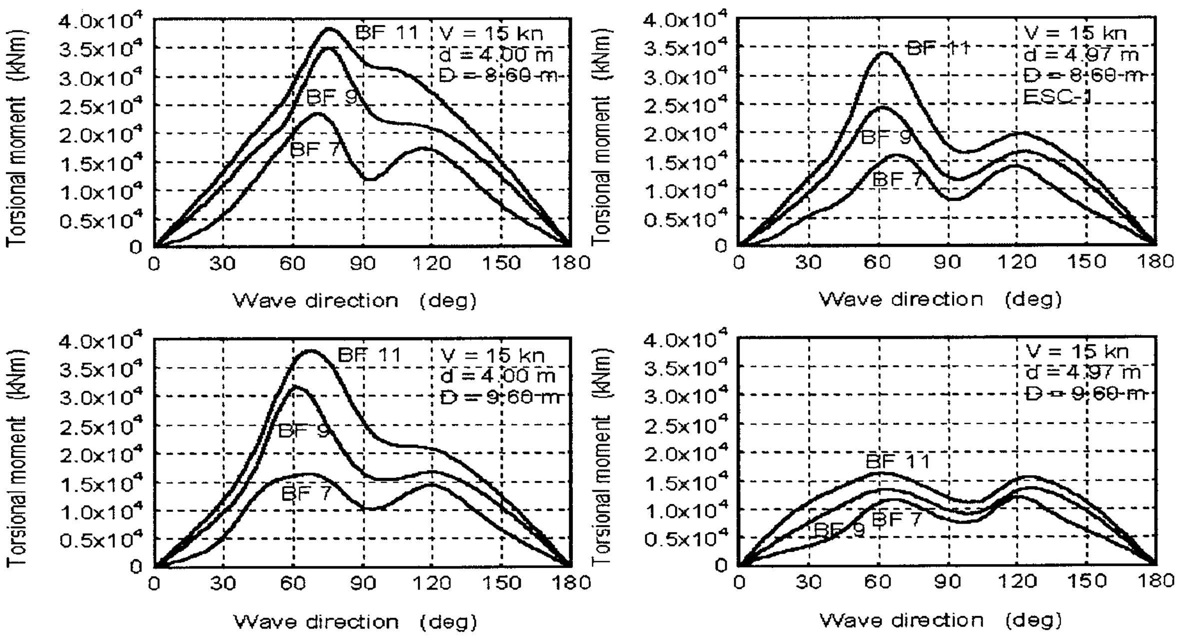

Figure 8. Effect of wave direction on torsional moments amidships of ESC-1 alternatives at a speed of 15 knots.

Assuming the same level of safety factor for torsion for all vessel alternatives relative to ESC-1 and the application of the simple elastic torsion theory for a hollow (singular) rectangular thin walled structure applied to the sides, bottom and topsides; this means that the scantlings of the vessel for a fixed torsional moment value may be estimated using the following relationship between torsional moments for the two designs under consideration [8]:

$$\frac{\dfrac{2t_{s2}.t_{d2}.(B-t_{s2})^2.(D_2-t_{d2})^2}{B.t_{s2}+D_2.t_{d2}-t_{s2}^2-t_{d2}^2}}{\dfrac{2t_{s1}.t_{d1}.(B-t_{s1})^2.(D_1-t_{d1})^2}{B.t_{s1}+D_1.t_{d1}-t_{s1}^2-t_{d1}^2}}=\frac{T_2}{T_1} \tag{5}$$

(hereby the subindex 1 refers to the ESC-1 design and the subindex 2 refers to the alternative with the increased depth value, ts/td refers to the average thickness of the ship's side/deck (including plating and stiffeners etc.), B refers to the ship's breadth and D the Depth).

The basic formula used to derive (5) is that giving the torsion angle, θ,

$$\left[\frac{T.L}{K.G}\right]_1=\theta=\left[\frac{T.L}{K.G}\right]_2 \tag{6}$$

(hereby the subindex 1 refers to the ESC-1 design and the subindex 2 refers to the alternative with the increased depth value, T refers to torsional moment and K is a factor depending on the form and dimensions of the cross section involved, G refers to the modulus of rigidity of the material, L is equal to the length of the member. In a simular fashion as described in paragraph 5 the cross sectional area ratio, A_2/A_1, can again be determined as a function of T2/T1, see figure 9. In the case under investigation in this paper, since T2/T1 = 0.42, as far as torsion is concerned, a reduction in steel weight may be achievable of approximately 16%. This gives a decrease of approximately 1000 tons for D = 15.00, 15.40 and 15.80 m. This could lead to a reduction in building costs of approximately a maximum of 7%.

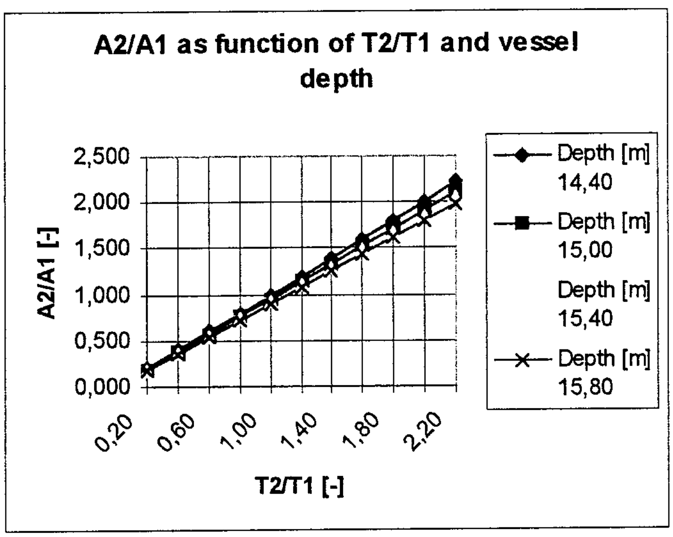

Figure 9: Effect of T2/T1 on ratio cross sectional area of ESC-1 alternatives

7. WAVE PERIODS

A sensitivity analysis has been conducted into the relation between wave period and wave direction on torsional and vertical bending moments at a speed of 15 knots. The results are shown in figure 10.

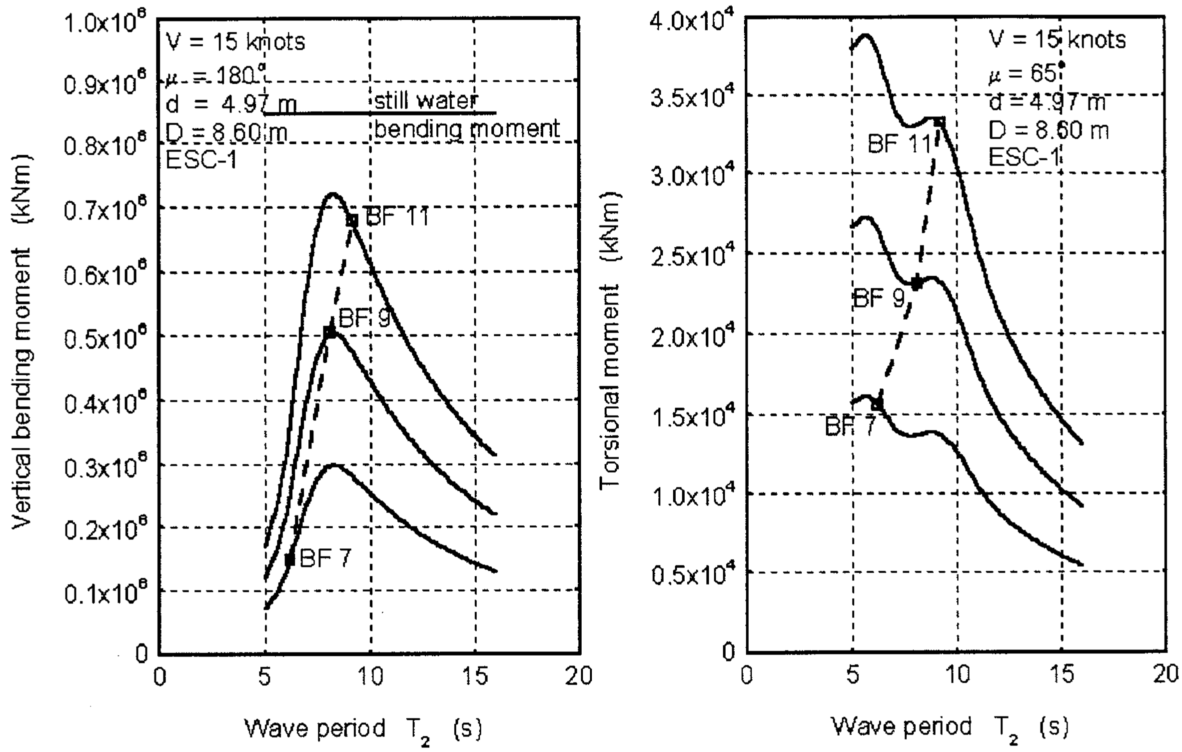

Figure 10. Effect of wave period for a given wave direction on torsional and vertical bending moments amidships at a speed of 15 knots.

Figure 10 shows the effect of a change in wave period (zero upcrossing, T2) on the significant amplitude of the bending and torsional moments for different wave directions and Beaufort Numbers. The broken line in both graphs show the combinations of these parameters utilised in the study presented here. Clearly the chosen wave period has a large influence on the above mentioned moments.

8. ECONOMIC EVALUATION

In order to make an economical evaluation the building costs of the different design alternatives were estimated using the original building costs of the base ship (of which all costs components were known) and correcting this for changes in steel mass of the hull and extra painting costs (i.e. cleaning, preparation and painting) and also for extra machinery costs. Due to the fact that it was not clear at this stage whether the main scantlings were determined by vertical bending moments or torsional moments, the change in steel mass was taken as being the average of the sum of both possible reductions as estimated under sections 5 and 6 respectively. The actual differences in building costs are indexed with regard to the ESC-1 in Table 4.

It is considered that in the light of such small differences as shown in table 4, further optimisation in the form of the application of high tensile steel (above that which is already found in such a vessel) will not cause any significant changes since this is more expensive materiaal and the weight savings to be gained probably do not compensate this.

An attempt has been made to take into account the effect of a displacement reduction on the installed propulsion power of the new designs. This has been estimated using the admirality coefficient method and results in a very slight reduction in power requirements as shown in table 4.

Table 4 Results of economical calculations

Index	ESC-1	ESC-1/0.6	ESC-1/1.0	ESC-1/1.4
Building costs	1.00	0.97	0.96	0.96
Power at 22 knots	1.00	0.998	0.997	0.995
Operational costs	1.00	0.98	0.98	0.98

9. CONCLUSIONS

The following conclusions are drawn with regard to further optimisation of the Enlarged Ship Concept applied to a freight carrying vessel by increasing the depth of the ESC-1 design alternative (see also table 2):

- The vertical midship bending moment in rough weather does not significantly change as the vessel depth increases. In Beaufort 11 the increase is still of the same order as the expected increase of the calm water bending moment which is proportional to the square of the ratio between vesssel length and base ship length.
- The torsional bending moment in rough weather does significantly change as the vessel depth increases. In Beaufort 11 the increase is approximately 40%
- Increasing the depth of ESC-1 may be able to cause an average maximum reduction in steel weight of approximately 8%. This is, more or less, constant for all investigated depth increases.
- Consequently the building costs of the vessel may be reduced by about 4%.
- The operational costs of the vessel may be reduced by approximately 2% by increasing the depth.
- Due to the fact that the vessel steel weight is reduced due to the increased depth, the vessel draft may be somewhat reduced. This yields a further improvement in concept design with regard to a significant improvement in survival capability after having suffered the ingress of water into the hull; the condition that the lowest hold remains empty and optimally subdivided for this purpose must be respected.

10. ACKNOWLEDGEMENT

Although the results and views expressed in this paper are those entirely of the authors, special thanks are due to Shipyard Van der Giessen-de Noord and North Sea Ferries for allowing the authors again to use m.v. NORBANK data as was the case in [3].

11. REFERENCES

1. Keuning, J.A. and Pinkster, Jakob, "Optimisation of the seakeeping behaviour of a fast monohull", Fast'95 conference, October 1995.

7. Keuning, J.A. and Pinkster, Jakob, "Further design and seakeeping investigations into the "Enlarged Ship Concept". Fast'97 conference, July 1997.

8. Journée, J.M.J., Pinkster, Jakob and Tan, S.G., "Enlarged Ship Concept Applied to RORO Cargo/Passenger Vessel", Prads'98 conference, September 1998.

4. "NORBANK", "A new super freighter for North Sea Ferries, Schip en Werf de Zee, November 1993.

9. Journée, J.M.J., "SEAWAY-Delft, User Manual and Technical Background of Release 4.00", Delft University of Technology, Ship Hydromechanics Laboratory, Report no. 910, 1992.

10. Hasselmann, K., et al.. "Measurements of wind-wave growth and swell decay during the Joint North Sea Wave Project (JONSWAP)", Deutches Hydrographisches Institut, Hamburg, 1973.

11. Karppinen, T., "Criteria for seakeeping performance predictions", Technical Research Centre of Finland, Ship Laboratory, Espoo, 1987.

12. Warren C. Young, "Roark's Formulas for Stress & Strain", 6 th Edition, McGraw-Hill Book Company, New York, USA. International Edition 1989. ISBN 0-07-100373-8.