Structural modifications for the longitudinal strength of lengthened ships

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One of the known types of ship conversion is the lengthening of an existing vessel. This may be done in a simple way by inserting a new block amidships. This paper deals with some strength requirements that are to be considered before making the final decision of lengthening. The first step is the estimation of the change in the longitudinal strength requirements; this is related to the form of the ship. The increase in these requirements determines the necessary modifications in the structural design amidships. In order to minimize panels' replacement in the original hull, and if the side and bottom panels are of adequate strength, the additional longitudinal sectional area would be better confined to the main deck. A hull section index defining the characteristics of the longitudinal material amidships is introduced to relate the added deck area to the required section modulus. It is found that for ships with small hull section index, this addition is relatively large, giving rise to some building complexities. This addition may be realized by panel replacement or by using doubler plates. In the former case, the use of high tensile steel may have good advantages.

تُعد الإطالة أحد أنواع تحويل السفن المعروفة، ويمكن إتمامها ببساطة بإدخال جزء مجمع جديد بمنطقة وسط السفينة. تناقش هذه الورقة متطلبات المتانة الابتدائية التي يجب مراعاتها عند تصميم عملية الإطالة ، الخطوة الأولى هي حساب مبدئي للتغير في متطلبات المتانة الطولية و ربط هذا التغير بشكل السفينة. تحدد الزيادة في هذه المتطلبات التعديلات الإنشائية اللازمة لمنطقة وسط السفينة، التي تُترجم في الغالب إلى زيادة مساحة المقطع الطولي. تقترح الورقة حصر الزيادة المطلوبة على السطح الرئيسي للسفينة، و ذلك للحد من عمليات إحلال الألواح للبدن الأصلي. ولكن يُشترط لذلك أن تكون متانة الجانب والقاع مناسبة للسفينة بعد إطالتها.يقدم هذا البحث مؤشراً يعرف الخصائص الإنشائية للمقطع يفيد في ربط زيادة المساحة المطلوبة للسطح بمعامل المقطع المراد تحقيقه. وقد وُجد أنه عندما يكون هذا المؤشر صغيراً فإن الزيادة المطلوبة في المساحة تكون كبيرة نوعاً ،مما يُعقد التعديلات الإنشائية اللازمة. هذه الزيادة يمكن تحقيقها إما بتغيير الألواح تماماً أو باستخدام ألواح بطانة. فى الحالة الأولى، يمكن لإدخال الصلب عالي المتانة في الألواح الجديدة أن يقدم عدة مزايا.

Keywords: Conversion, Ship lengthening, Longitudinal strength requirements, Structural modifications

1. Introduction

Increases in capacity for passengers or cargo may be achieved by lengthening the ship (jumboisation) or occasionally by widening, by heightening between-deck space, by adding accommodation blocks or by re-arranging existing layout. Most jumboisations involve adding a length of parallel middle body by splitting the ship in two in dry dock as seen in fig. 1. By inserting a new 44m-long section into the 220m-long Costa Classica cruise ship, berth capacity increased to 1,020 cabins compared to 654 [1]. The new section can be prefabricated in advance of the actual lengthening operation and then fitted using flotation and mechanical methods.

Fig. 1. Inserting a new section.

Lengthening demands particular skills and facilities and tends to be a specialization of a limited number of shipyards. It has been reported that the time taken for lengthening ranged from less than a month up to four months. There have been 28 cases of ships being lengthened for the period 1994-1996 [2]. Lengthening work has concentrated upon ferries, cruise ships and general cargo ships (often in preparation for another role), chemical tankers and offshore vessels. The possibility of lengthening is sometimes taken into account when a given existing ship has a practically high investment value. This calls for consideration of the ship's strength and the ease with which an additional midbody section may be inserted together with the link-up of onboard services to the new section.

A conversion based on changing any of the principal dimensions may require some structural modifications for the satisfaction of the longitudinal strength standards. Due to the increased beam in a described conversion [3], the allowable bending moment increased proportionately, and a doubler plate had to be fitted to the upper hull girder; to keep the spar deck clear, the doubler plates were fitted on the sheerstrake port and starboard.

Even the change in service may affect the global longitudinal strength characteristics as reported about the conversion of a containership to a sealift Ro/Ro, Lo/Lo ship [4]. In this case the converted ship featured long superstructures forward and aft of the existing house so that their efficiency had to be taken into account for the purpose of assessing longitudinal strength. An interesting case, which changed significantly the longitudinal strength characteristics of the vessel due to the conversion of the operational requirements, was the conversion of some passenger ships into Troop Ships during Falklands Campaign in 1982 [4]. The weight distribution of the converted vessels with the added flight decks, was certainly a highlighted feature of the project.

This paper aims to contribute to the basic design process for a proposed lengthening. During this stage, specifications that address the technical and performance requirements of the conversion are developed and then considered in the decision making.

2. Change in longitudinal strength requirements

Any modification in the ship principal dimensions will affect the longitudinal strength requirements as given by the Rules. These requirements involve mainly the minimum modulus of section amidships. A standard given by the International Association of Classification Societies (IACS) [6] is:

$$W_{min} = cL^2 B(C_B + 0.7)k \quad (cm^3)\,, \tag{1}$$

where:

$c = c_n$ for new ships,

$c = c_s$ for ships in service $= 0.9\, c_n$

$$c_n = 10.75 - \left(\frac{300 - L}{100}\right)^{3/2},$$

k = 1.0 for ordinary hull structural steel, and

for higher tensile steels,

k = 0.78 for σ_y = 315 MPa, and

k = 0.72 for σ_y = 355 MPa.

Another evaluation of the required section modulus is given based on the estimation of the maximum total bending moment. The greater value is that to be taken into account. For purpose of comparison of the required modulus before and after lengthening, eq. (1) will be used here.

If the length is to be increased, the resulting block coefficient and hence the new longitudinal strength requirements cannot be exactly evaluated unless the steps shown in fig. 2 are carried out.

However, the change in W_{min} may be predicted for the preliminary design stage of the conversion as follows:

$$\frac{dW_{min}}{dL} = \frac{\partial W_{min}}{\partial L} + \frac{\partial W_{min}}{\partial C_B} \cdot \frac{dC_B}{dL}\,.$$

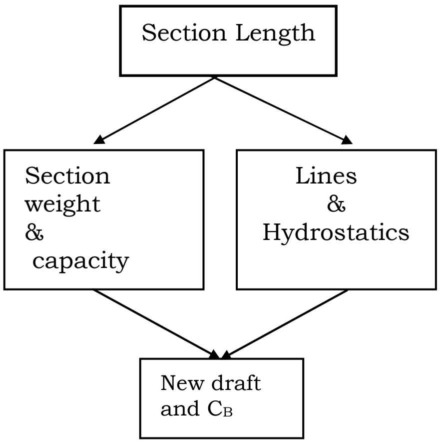

Fig. 2. First design steps of the conversion.

For the interval from L_o to L_n,

$$\delta W_{min} = \int_{L_o}^{L_n} \frac{\partial W_{min}}{\partial L} \cdot dL + \int_{L_o}^{L_n} \frac{\partial W_{min}}{\partial C_B} \cdot \frac{dC_B}{dL} \cdot dL \, . \quad (2)$$

The value of dC_B/dL is a function of the vessel type as well as its form factors; the designer may estimate it roughly upon knowledge of the vessel under consideration. Assuming that it is constant for the considered interval, eq. (1) will give:

$$\delta W_{min} = \left[W_{min} + \frac{dC_B}{dL} \times \frac{B}{100} \times (322.5L^3 + 0.02\lambda^{9/2} - 15.42\lambda^{7/2} + 3240\lambda^{5/2}) \right]_{L_o}^{L_n} , \quad (3)$$

where, λ = 300-L, and C_B used for all the terms is the original block coefficient. The representation of eq. (3) for the forthcoming case study is shown in fig. 3.

For all ships the trend and the significant effect of dC_B/dL is expected to be the same; the greater is the block coefficient gradient, the greater will be the change in the required section modulus. The value of dC_B/dL is larger for ships showing considerable increase in displacement for the required increase in length, i.e. for ships carrying heavy cargo and/or cargo with a high stowage factor (weight critical design) [7]. In

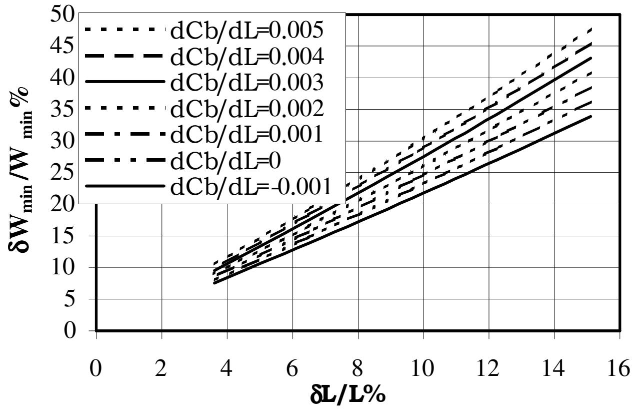

Fig. 3. Increase in section modulus (case study).

such cases, the lengthening process would therefore ask for extensive changes in the strength requirements. Fortunately, lengthening is particularly popular with volume critical ships, such as passenger/vehicle ferries and container ships; these are ships showing small dC_B/dL and hence inquiring small change in longitudinal strength standard according to eq. (3).

The actual section modulus W_o is usually greater than W_{min}. The designer may then have the possibility to lengthen the ship keeping the same structural design of the midship section. This would obviously reduce, or even cancel the appropriate safety margin incorporated in the design represented by,

$$W_{margin} = W_o - W_{min}.$$

If the same safety margin is to be kept for the lengthened ship, then:

$$\frac{\delta W}{W_o} = \frac{\delta W_{min}}{W_{min}} ,$$

$$W_n = W_o \left(1 + \frac{\delta W}{W_o} \right) . \quad (4)$$

This is the first standard to start within the structural design of the converted ship. The new built block may easily fill the increased requirements without greatly affecting the structural continuity of the hull. But if the block length is less than $0.4L_n$ (as mostly expected), some parts of the old hull would require a modification in their sectional characteristics in order to attain the increased section modulus W_n. The area of the longitudinal material is then to be carefully increased.

3. Additional longitudinal material

It is certainly desirable to satisfy the new requirements with the minimum amount of steel replacement within the original hull. Fortunately, many structural members may remain satisfactory after lengthening. Nevertheless, the designer should then admit a reduction in the incorporated factors of safety. If the side and bottom panels are still acceptable, the required sectional area would be better added to the parts of the section which are the most remote of the neutral axis, which is mostly the main deck. This may be a frequent case since for volume critical ships, lengthening would result in a small increase in draft and hence a small increase in the design loads involved in the transverse and local strength of the side and bottom panels. Other design parameters such as the frame spacing and the unsupported span of the various structural components will remain unchanged. The thickness of side shell would be carefully checked for the shearing strength of the lengthened ship and, for the bottom and deck panels (other than the main deck) to be kept, the buckling strength is to be reassessed.

Having decided to limit the structural modifications required within 0.4 L_n to the main deck panel, the relation between the required added area and section modulus may be derived as follows.

For the idealized section given in fig. 4,

the shift in neutral axis $= \dfrac{a * y_o}{A_o + a}$,

$$y_n = y_o\left(1 - \frac{a}{A_o + a}\right),$$

$$y_n = y_o\left(\frac{A_o}{A_o + a}\right).$$

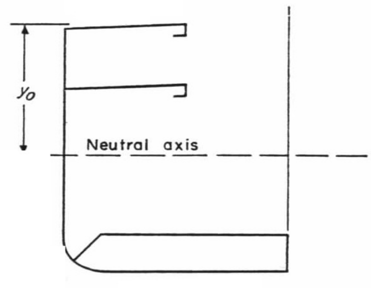

Fig. 4. Idealization of the midship section.

Then,

$$I_n = I_o + a y_o^2 - \frac{(a y_o)^2}{(A_o + a)},$$

$$W_n = \frac{I_n}{y_n} = W_o\left(1 + \frac{a}{A_o}\right) + a y_o,$$

$$\frac{W_n - W_o}{W_o} = \frac{a}{A_o}\left(1 + \frac{A_o y_o}{W_o}\right). \qquad (5)$$

Since,

$$\frac{A_o y_o}{W_o} = \frac{A_o y_o^2}{I_o} = \left(\frac{y_o}{r_o}\right)^2,$$

then, denoting the ratio y_o/r_o by α_o:

$$\frac{a}{A_o} = \frac{\delta W}{W_o(1 + \alpha_o^2)}\ . \qquad (6)$$

The value of α_o gives an indication about the hull sectional properties and the distribution of the longitudinal material. It may be called “the hull section index”. It depends on the midship section configuration, the ship dimensions and framing system. It is mostly affected by the presence of extensive longitudinal material in the bottom. It has been evaluated for a number of ships and is found to have a value in the range 0.8~1.8 for different types of seagoing vessels. The examination of the hull sectional properties of 10 typical merchant ships [8] with longitudinally stiffened double bottom (double-hull tankers, new bulk carriers and container ships) shows that this index is around 1.4

[Appendix 1]. Expression (6) is used to estimate the area to be added to the main deck panel within $0.4L_n$, and is illustrated in fig. 5. A small index will mean a greater additional area and therefore much structural work.

This area may be provided by one of the following options:

- Replacing the actual panel. The added area may be shared between all longitudinal components of the panel, i.e., plating, girders and deck longitudinals (if any). The structural continuity of this new deck panel together with the new section from one side and the old parts from the other side should be respected.

In this case the designer has the opportunity to use high tensile steel for the deck plating in this portion of the old hull. This will reduce the required added area by an amount,

$$a_{rh} = \frac{A_n}{1+\alpha_n^2}\left(1-\frac{\sigma_m}{\sigma_h}\right). \qquad (7)$$

The designer would then check that the deck is of adequate strength against buckling.

- The replacement of some portions of the old deck panel amidships may be difficult or impractical due to the existing arrangement or outfitting. In this case the use of doubler plates will be the simplest option. These may be arranged, wherever possible, not only in the main decks, but also in the sheer strakes and deck girders. The designer may gain benefit of any effective superstructure deck to attain the required section modulus with minimal added sectional area.

The steel weight distribution used to perform the exact longitudinal strength calculation should be carefully regarded. For instance, if the method of producing a "coffin" diagram [6] is adopted, the resulting curve is not expected to be a smooth curve as usual. It would result from the superposition of the steel weight distribution of the old parts and the added material, with another diagram corresponding to the inserted section of heavier construction. The introduction of high tensile steel in the new built block and in the new deck panels within $0.4L_n$ (in case of panel replacement) may give a conventional steel weight distribution. In general, complexity is confronted during all the design processes for the proposed conversion, demanding creative and innovative solutions.

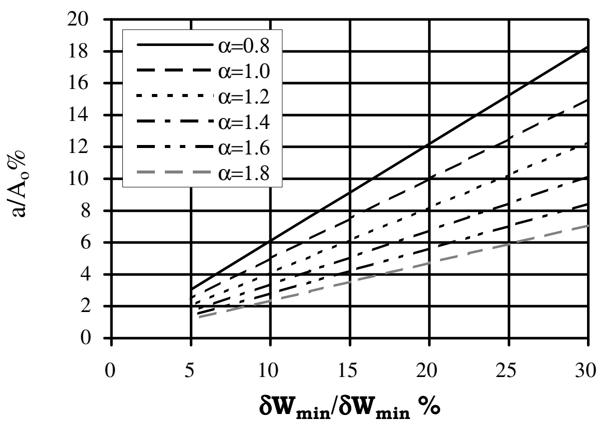

Fig. 5. Addition in deck sectional area.

4. Case study

To illustrate the present study, an existing vessel is selected and a conversion is assumed to be carried out. The vessel under consideration is a refrigerated cargo vessel (built in 1968) having the following characteristics [9]:

LBP = 173.74 m
B_{mld} = 24.69 m
D_{mld} = 14.78m
T_{design} = 10.82m
Δ = 29 890 tons
DWT = 19 732 tons

The age of the vessel is not an important parameter in this hypothetical application, since the global feasibility of the conversion is not discussed here. The availability of the complete data of this vessel was behind this selection in order to study other aspects of the conversion process [10]. Lengthening of this old vessel is not unrealistic since the market has experienced recently the conversion of vessels of the same age [5,11]. On the other hand, the evolution of this ship type was less significant over the last decades than the evolution of other types, e.g. tankers. This vessel has been designed specially for the carriage of unitized and palletized cargo, which with her special

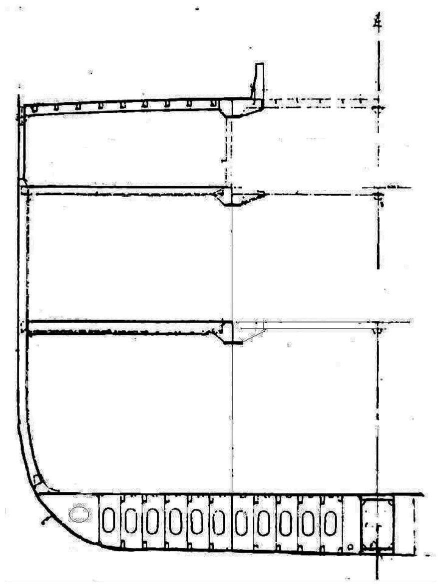

Fig. 6. Midship section of the refrigerated cargo vessel (case study).

Table 1
New & old ships' particulars

Item	Old	New
Length (m)	173.7	191.1
Breadth (m)	24.69	24.69
Draft (m)	10.89	11.3
Vol. of Displacement (m^3)	29161	34014
Block Coefficient	0.628	0.64
$L/\nabla^{1/3}$	5.644	5.879
L/B	7.036	7.705
L/T	16.05	6.858
W_{min} (m^3)	8.45	10.42
Actual W (m^3)	10.2	12.64
I_{min} (m^4)	44.05	59.56
Actual I (m^4)	81.6	90.14
Hull Section Index α	1.435	1.663
Sectional Area A (m^2)	2.63	2.83
y (from deck) (m)	8.	7.418
Thick. of bottom plating [ABS]	15.5	16.7
Actual thick. of bottom plating	16	16
Thick. of side plating [ABS]	14.70	15
Actual side plating thickness	16	16
Min. thick. of plating[ABS]	13.56	13.86

(Note: thickness is in "mm")

cargo-handling equipment will aid rapid loading and unloading. Uniform deck heights throughout the holds and flush decks without sheer or camber permit rapid movement of pallets on forklift trucks operating in the holds. The midship section configuration of the vessel is shown in fig. 6.

The assumed conversion would transform this vessel into a dry cargo ship and increase the length of the parallel middle body, in order to gain an extra compartment of 17.37m length. The assumed lengthening percentage is then 10%.

Following the steps given in fig. 2, it is found that,

$$\frac{dC_B}{dL} = 0.000715 .$$

This small value is quite encouraging as mentioned before. From the calculation of W_{min} for the original and new length, or simply by using fig. 3, it is found that:

$$\frac{\delta W_{min}}{W_{min}} = 24\% .$$

The original margin in section modulus is kept unchanged so that this percentage is used to find W_n as given in table 1, which summarizes most of the particulars involved in this study.

The new section of length 17.3m may easily satisfy the required W_n, as well as the Rules requirements for all its structural components.

The old part remaining within $0.4L_n$ amidships, is a hull portion of length; $0.4L_n$-17.3 = 59 m

At this stage, it is then necessary to check the strength of the existing bottom and side panels within this 59m part. The first look at the thickness values given in table 1, makes the designer optimistic. Only the Rules bottom plating thickness exceeds slightly the actual value. However, this is not a sufficient sign to reject the existing bottom panel; the decision is left to a detailed bottom strength assessment. Assuming that the new reduced safety factors of side and bottom are acceptable, the structural modifications may be limited to the main deck, as proposed here. The value of the hull section index (1.435) is promising; it is not very small, so that the added area will not be very large. Using fig. 4, or eq. (6):

$$\frac{a}{A_o} = 7.8\% ,$$

i.e.

$$a = 0.2063\ m^2.$$

This area may be provided in the form of an extra deck plating thickness of 12.66 mm (in the presence of hatch openings). Extending the area ready for doubling to sheer strakes and hatch girders will certainly reduce this thickness. This addition consists of 92 tonnes of steel resulting in an increase of 1.5t/m in the weight per meter of the old hull portion amidships.

In case of deck panel replacement in this part, the use of high tensile steel of grade AH32 instead of the ordinary mild steel will reduce the deck area by a value of 0.2877 m^2 (a_{rh}), resulting in a thickness similar to the old mild steel panel.

5. Conclusions

• Starting from the increased longitudinal strength requirements, a relation is derived to help in defining the conversion strategy in the preliminary stage.
• The change in the block coefficient due to lengthening is the first sign revealing the increase in the longitudinal strength requirements.
• The extent and simplicity of the structural arrangements required are important factors to be taken into account in the economical evaluation and the production flow of the conversion. Some structural parts, namely side and bottom panels, may fortunately show adequate strength for the lengthened ship, and the required structural modifications may then be limited to the main deck panel.
• A hull section index has been introduced to define the characteristics of the longitudinal material amidships. It has been evaluated for a number of selected vessels to find its range, and it is used to determine the amount of area that would be added to the main deck in order to attain satisfactory longitudinal strength.
• The structural modifications imposed by the increased longitudinal strength standards due to lengthening, will therefore be minimal for smaller block coefficient gradient and higher hull section index. Volume critical ships with longitudinally stiffened double bottom are then the best from this point of view.
• The use of high tensile steel in the new section and/or new built panels may contribute to the avoidance of some building complications; a compromise should then be made since it may also introduce some problems.

Nomenclature

A	required addition in deck area,
a_{rh}	reduction in the area of the high tensile steel deck ,
r	radius of gyration of the sectional area,
y	distance of the neutral axis from the deck,
A	area of the longitudinal material amidships,
I	moment of inertia of the longitudinal material,
M_T	maximum total hull-girder bending moment,
W	hull-girder section modulus,
W_{min}	rules minimum hull girder section Modulus,
α	hull section index,
δL	length of the inserted section,
σ_h	yield stress of the high tensile steel, and
σ_m	yield stress of the mild steel.

Subscripts

"*o*" denotes the section particular of the original ship, and ,
"*n*" denotes the corresponding particular for the new design (after lengthening).

Appendix 1

The introduced index α is given by,

$$\alpha = \frac{y_o}{r_o} = y_o\sqrt{\frac{A}{I}}\ .$$

The hull sectional properties required to calculate α for 10 typical large merchant ships are given in [8]. To evaluate this index for smaller ships (moderate size), a schematic configuration (fig. 7) is assumed to represent the longitudinal material in the section of general cargo ships.

In this idealization, the absence of hatch openings compensates the area of the deck girders. The double bottom height is assumed to be 1.5m, and the tween deck height is one third of the depth. For a pure transverse system of framing a constant thickness is assumed throughout the section. For a combined system of framing, a thickness "*t*" is attributed to the sides and girders, whilst a thickness of "1.2t" is given to all horizontal panels, i.e. decks, inner and outer bottom plating.

This approximate evaluation of the sectional properties is applied to a number of cargo vessels [12]. The results are given in table 2, together with a sample of the former exact calculation of α for vessels with vailable data (denoted with *).

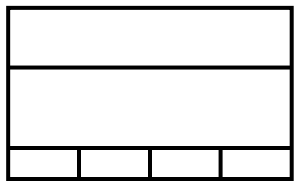

Fig. 7. Midship configuration.

Table 2
Typical values of hull section index

Item	SHT *	DHT *	Bulk *	Cont *	Liner 1	Liner 2	Break B.	Tanker*
LBP(m)	313	233	273	305	171.5	159.1	145.5	306.1
Breadth(m)	48.2	42	44.5	45.3	24.23	21.34	22	48.7
Depth (m)	25.2	21.3	23	27	13.97	13.72	12.4	24.5
A (m^2)	7.858	5.318	5.786	6.19	2.379	1.759	1.888	5.059
I (m^4)	863.69	359.48	508.31	682.75	70.449	48.87	43.57	770.421
y_o (m)	13.02	12.11	12.94	15.38	6.179	6.066	5.502	12.29
α	1.242	1.473	1.38	1.662	1.431	1.452	1.435	0.996

Notes: SHT = single hull tanker[7], DHT = double hull tanker with one center-longitudinal bulkhead[7], Bulk = double sided bulk carrier[7], Cont = 9000 TEU container vessel[7], Liner 1 = *Strat Hardle* (combined sys.)[11], Liner 2 = *Delta Argentina* (transverse sys.) [11], Break B. = break bulk *Golden Chalice* (combined sys.)[11], Tanker = single hull tanker [11]

References

[1] Marinetalk, issue October (2002).

[2] Drewry Shipping Consultants Ltd., Shiprepair and Conversion: The Global Outlook Report (1998).

[3] D. J.Munro, "Widening of the Great Lakes Bulk Carrier MV Algoville", Marine Technology, Vol. 37, pp. 23-29 (2000).

[4] Don Walter, "Conversion of Maersk Lines L Class Containership to Strategic Sealift Ro/Ro, Lo/Lo Ships", Marine Technology, Vol. 33, pp. 14-19 (1996).

[5] J.L. Hannah, "Merchant Vessel Conversions: The Falklands Campaign", The Naval Architect, RINA, pp. 29-47 (1986).

[6] IACS, Requirements concerning Strength of Ships (2002).

[7] David Watson, in: Practical Ship Design, Elsevier Ocean Engineering Book Series (1998).

[8] J. Paik et al., "Ultimate Limit State Design of Ship Hulls", SNAME Annual Meeting (2001).

[9] Shipping World and Shipbuilder, "Port Chalmers: World's Largest refrigerated Cargo Vessel", Vol. 161 (1968).

[10] R. Ramadan, Hydrodynamic and Structural Aspects in Ship Conversion, Ph.D. Thesis, Suez Canal University (2002).

[11] Marcon International Inc., News & Articles (2002).

[12] Ship Design and Construction, ed. R. Taggart, SNAME, p. 54 (1980).

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