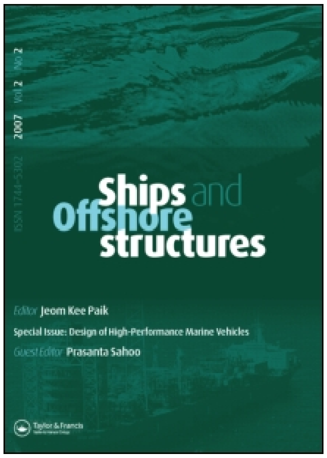

Ships and Offshore Structures

Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t778188387

Least cost optimization of large passenger vessels

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Online Publication Date: 01 December 2007
To cite this Article: Richir, T., Caprace, J. -D., Losseau, N., Pircalabu, E., Toderan, C. and Rigo, P. (2007) 'Least cost optimization of large passenger vessels', Ships and Offshore Structures, 2:4, 339 - 345
To link to this article: DOI: 10.1080/17445300701699507
URL: http://dx.doi.org/10.1080/17445300701699507

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doi:10.1080/17445300701699507

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Abstract: The LBR-5 software allows optimizing ship structures according to objectives of higher inertia, less weight and/or lower cost. This last criterion offers the choice between two approaches of calculation. The first approach is based on a simplified assessment of the cost in which the total cost is described by rather simple analytical functions which bring into play on the one hand the design variables and on the other hand empirical parameters. In the second approach, the calculation of the cost is based on data specific to the shipyard. The material cost is analyzed according to the first approach while the cost of the labor considers each relevant operation of the ship building with respect to the LBR-5 model. A survey of all the tasks was carried out at Aker Yards France, and a thorough study made it possible to develop assessment tools of the labor cost for each operation as functions of the design variables. Plate straightening operations are also considered in this analysis. This paper presents a cost-based optimization study carried out on a large passenger ship structure with more than 600 design variables, by the use of the detailed approach for the cost calculation. The structural model has been formulated on the basis of technical documentation prepared by Aker Yards France. The loads and strength criteria applied on the model are considered according to classification society rules (Bureau Veritas). Results and conclusions of the study are presented.

Key words: LBR-5, cost, optimization, scantling, straightening

INTRODUCTION

LBR5 is a structural optimization tool that, in the preliminary design stage of the project, allows for

- a 3D structural analysis of a portion of the structure (usually located in the mid-ship region);
- a scantling optimization of the structural elements (plate thickness, size and spacing of the longitudinal and transversal members), based on different objective functions as higher inertia, less weight and/or lower cost.

A cost-based optimization can be performed using one of the two available cost modules.

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The basic cost module (BCM) is based on a simplified assessment of labor and material costs. To calibrate the module, the cost of a standard LBR-5 stiffened panel (Figure 1) must be assessed using the unitary production costs of the shipyard. These unitary costs are related to assembling and welding for the plates and the longitudinal and transversal members, transverse member prefabrication, slots, brackets etc.

The advanced cost module (ACM) is a more complex cost assessment tool that takes into account detailed shipyard database. About 60 different fabrication operations are considered, covering the different construction stages, such as girders and web-frames prefabrication, plate panels assembling, blocks pre-assembling and assembling, as well as 30 types of welding and their unitary costs.

BASIC COST MODULE

With the BCM, the objective function is the construction cost that includes the labor costs and the material cost (proportional to the weight). In order to link the objective function to the design variables, the unitary costs of

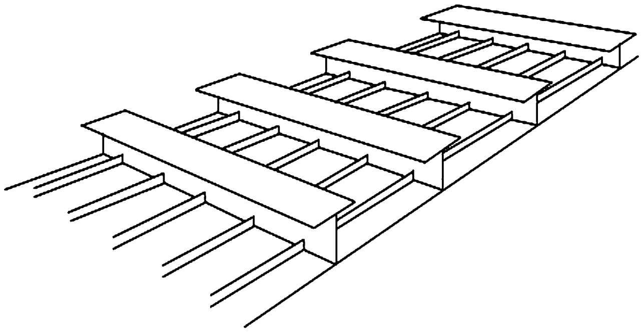

Figure 1 Standard LBR-5 stiffened panel.

raw materials, the productivity rates for welding, cutting, assembling must be specified by the user.

These unitary costs vary according to the type and the size of the structure, the manufacturing technology (manual welding, robots, etc.), the experience and facilities of the construction site, the country, etc. It is therefore obvious that the result of this optimization process (scantling optimization) will be valid only for the specified economic and production data. Sensitivity analyses of the economic data on the optimum scantling can also be performed, thus providing the manager with valuable information for improving the yard.

Global construction costs can be classified into three distinctive categories: cost of raw materials, labor costs and overhead costs (equation (1)).

$$TC = \text{Mat}C + \text{Lab}C + \text{Ov}C. \quad (1)$$

The overhead cost is not a function of the design variables, so it can be ignored by the analytical cost model. Therefore, the considered cost will be:

$$TC = \text{Mat}C + \text{Lab}C. \quad (2)$$

The material cost and the labor cost are expressed in equations (3)–(4):

$$\text{Mat}C = \sum_{j=1}^{k} Q_j \times P_j \quad (3)$$

$$\text{Lab}C = \sum_{i=1}^{\text{NT}} T_i \times M_i \times S_i, \quad (4)$$

where j is the reference number of a given material, k is the number of materials, Q_j is the expected quantity of the j material; P_j is the unit price of the j material (euro/unit); i is the reference number of a given task, NT is the number of tasks; T_i is the required working load for the standard i task (man-hours), M_i is the number of repetitions for the T_i task, S_i is the labor cost (euro/man-hour).

Detailed information about the BCM is given in Rigo (2001).

ADVANCED COST MODULE

Given the generalist nature of the BCM approach, the cost assessment made with this method for large complex ship structures presents rather important differences with respect to the shipyard predictions. A number of sensible parameters related to production costs cannot be taken into consideration. ANAST carried out a study in collaboration with Aker Yards, France for the development of a cost module that will be a better answer to the shipyard's needs.

The new module complies with a number of issues that were incompatible with the BCM:

- the specificity of each LBR-5 panel is considered according to the real structure (horizontal–vertical, straight–formed etc.), for a distinctive employment of the shipyard's unitary costs;
- better implementation of the unitary costs variation with the thickness of the structural members, which is not always linear;
- considering the costs related to the stiffening of important web height members (ex: flat bar stiffening of the webframes);
- considering the plate straightening related costs;
- considering that several workshops are involved in construction, with different production costs;
- introduction of an exhaustive representation of the fabrication operations related to the existing design variables.

The cost for each operation is calculated with a general analytical expression (equation (5)).

$$\text{CO}_{ik} = \text{Q}_{ik} \times \text{CU}_{ik} \times \text{K}_{ik} \times \text{CA}_{ik} \times \text{CAT}_{ik}, \quad (5)$$

where i is the LBR-5 panel index, k is the operation index, CO_{ik} is the cost for operation k on panel i, Q_{ik} is the operation related quantity (welding length, number of brackets etc.), CU_{ik} is the operation related unitary cost, K_{ik} is the corrective coefficient used to calibrate the operation-related quantity with respect to model particularities; CA_{ik} is the accessibility coefficient for the operation k on panel i, CAT_{ik} = workshop coefficient for the operation k on panel i.

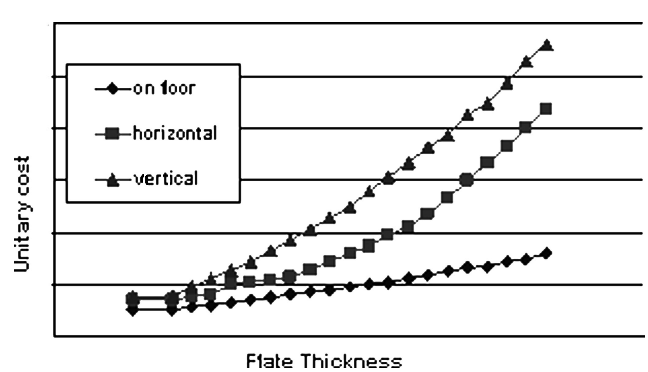

Figure 2 Unitary cost variation for different welding positions.

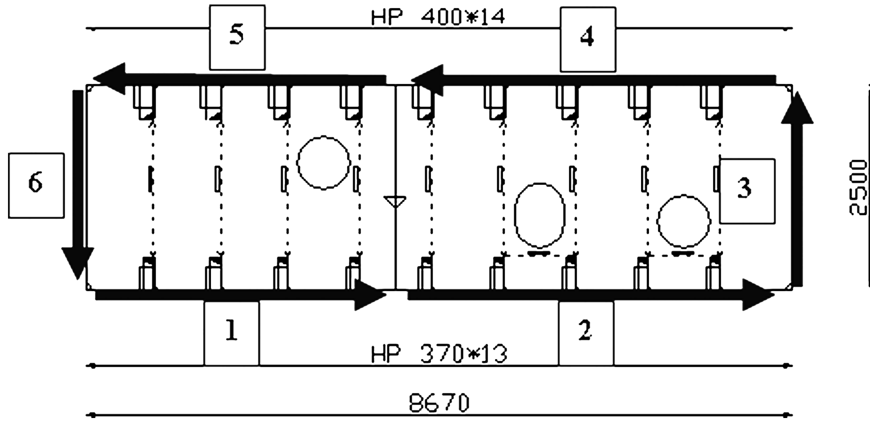

Figure 3 Double hull panel.

The total structure cost will be the sum of all CO_{ik} (equation (6)).

$$CT = \sum_i \sum_k CO_{ik}. \tag{6}$$

The LBR-5 optimization module (Fleury 1989) is a gradient-based method; therefore, the simple cost assessment is not sufficient for the optimization process, an analysis of the objective function sensitivities with respect to each design variable is needed to give the direction of search. When BCM is used, the cost function is continuous and its sensitivities could be calculated analytically. This advantage is lost if the cost function is evaluated by ACM. Basically, the ACM sensitivities can be written with the equation (7) for each LBR5 panel, each design variable and each operation.

$$\delta_{ijk} = (T_1 \times CU_{ik} + T_2 \times Q_{jk}) \times K_{ik} \times CA_{ik} \times CAT_{ik} \tag{7}$$

where T_1 is the sensitivity of the quantity by each design variable X_j (equation (8)), which is calculated analytically, T_2 is the sensitivity of the unitary cost by each design variable X_j (equation (9)), which is usually a discrete function (Figure 2) and its calculation requires a numerical procedure.

$$T_1 = \frac{\partial Q_{ik}}{\partial X_j} \tag{8}$$

$$T_2 = \frac{\partial CU_{ik}}{\partial X_j}. \tag{9}$$

Equation (9) represents the first derivative of the unitary cost (CU) by a design variable (Xj). For instance, it represents the variation of the unitary welding costs when the plate thickness changes.

A number of tests were performed on simplified structures—double hull panel (Figure 3), and on real hull structures in order to validate the ACM in terms of design variables sensitivities and total costs.

The cost variation for some of the design variables on the selected double hull panel was analysed. Figure 4 shows for instance the total cost variation as a function of the strake 1 thickness. As can be noticed, the ACM calculation gives a clearly improved slope with respect to the direct calculated cost, compared to the BCM result. The average uncertainty related to the ACM, taking as reference the direct calculation, is about 4%.

PLATE STRAIGHTENING

Straightening costs are taken into account with both BCM and ACM. The welding of structural elements involves heating within the material; this phenomenon causes deformations which have to be reduced to obtain an acceptable surface flatness.

The straightening is the process that consists in eliminating/reducing these distortions in order to improve the structure flatness for esthetical or service reasons. The straightening process involves non-negligible labor cost; it is thus interesting to estimate the straightening impact on the production workload in order to improve the research of an optimal solution. The cost assessment of the plate straightening is done by using a general formula linking the straightening cost to the scantlings and to other section characteristics (Caprace *et al.* 2006). This formula was obtained through a data mining method, using statistical

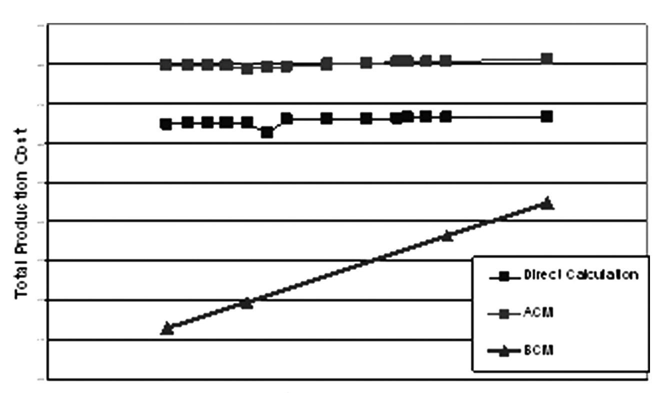

Figure 4 Total production time versus plate thickness.

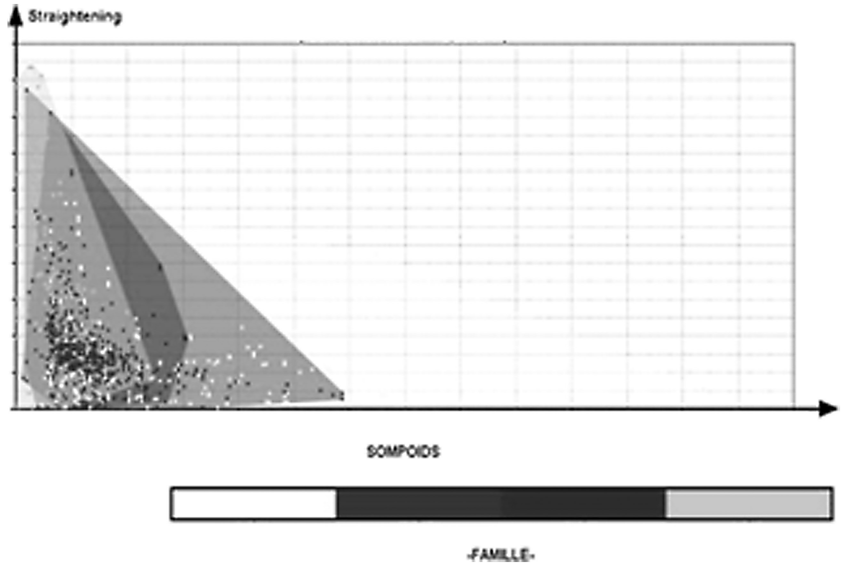

Figure 5 Straightening costs for different regions of the ship.

data on straightening costs for a number of 12 ships built by Aker Yards, France. Figure 5 illustrates the variation of the straightening costs (in hours/m^2), for different regions of the ship, as a function of the weight of the defined lots.

STRUCTURAL MODEL

The ACM will be applied to study the cost minimization of a large passenger vessel. With an overall length of over 300 meters and a breadth of more than 32 meters, this is an "over-panama" class cruise ship.

The LBR-5 model of the ship's mid-section was imported from an existing Mars2000 (scantling verification software based on Bureau Veritas Rules) model prepared by Aker Yards, France. LBR-5 disposes of a data-transfer module allowing the importation of Mars2000 geometry and loads. Figure 6 shows an imported mid-ship section (transversal members and pillars were added manually). A number of 98 LBR-5 panels were used to define the model (77 LBR-5 plates and 21 pillars). Based on structure symmetry, only half of the structure was modelled.

Five load cases were considered for the calculation:

- sagging wave vertical bending moment with a probability of 10^{-8}; still water pressures; static deck loads;
- hogging wave vertical bending moment with a probability of 10^{-8}; still water pressures; static deck loads;
- sagging wave vertical bending moment with a probability of 10^{-5}; still water and wave pressures; static deck loads;
- hogging wave vertical bending moment with a probability of 10^{-5}; still water and wave pressures; static deck loads;
- no bending moments; still water and wave pressures; static and inertial deck loads.

Bending efficiency coefficients were considered in order to take into account the participation degree of each deck

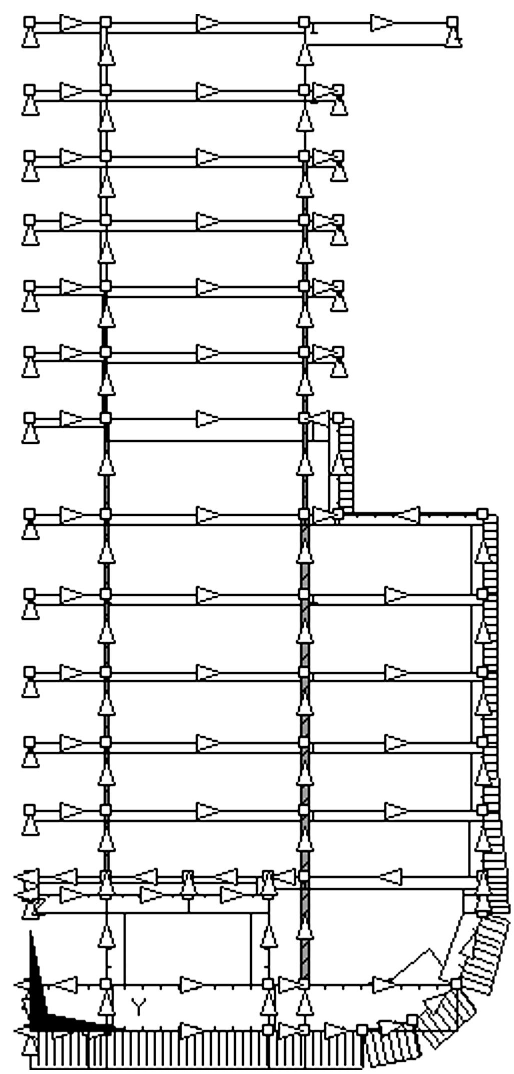

Figure 6 LBR-5 model of the mid-ship section.

to the longitudinal bending. These coefficients are directly imported from the Mars2000 model.

Other load cases including shear forces must be considered when shear stresses are significant in the considered section.

OPTIMIZATION MODEL

The design variables used in the optimization are (for each LBR-5 stiffened panel):

- plate thickness;
- web height (longitudinal and transversal members);
- web thickness (longitudinal and transversal members);
- flange width (longitudinal and transversal members);
- spacing (longitudinal and transversal members).

Technological restrictions were assigned to the design variables in order to define the search space for the optimization problem. These restrictions are formulated on the basis of technological limitations, like minimum plate thickness considering corrosion, or the maximum size or thickness of plates and members with respect to welding process.

The structural restrictions imposed throughout the model to satisfy the limit states are related to:

- plate buckling based on Hughes formulations (Hughes 1988);
- ultimate strength of beam column (Paik and Thayamballi 2003);
- yielding in plates and longitudinal stiffeners;
- yielding in transversal members at web-plate and web-flange junction.

The structural restrictions are imposed for each load case, and when needed, on more than one point of the LBR-5 panel.

In order to preserve rational proportions between the different design variables, the following geometrical restrictions were applied, for both longitudinal and transversal members:

- plate thickness/web thickness ratio

$$\delta \leqslant 2 \times T_w \tag{10}$$

- flange width/web height ratio

$$0.625 \times D_f \leqslant D_w \leqslant 2.5 \times D_f \tag{11}$$

Table 1 **Size of the optimization problem**

Type of constraints	Number of constraints
Technological	627
Structural	4109
Geometrical	622
Equality	137
Global	1

- plate thickness/web thickness ratio

$$0.5 \times T_w \leqslant \delta \leqslant 2 \times T_w \tag{12}$$

- web slenderness

$$D_w \leqslant 120 \times T_w \tag{13}$$

- flange thickness/web thickness ratio

$$T_f \leqslant 2 \times T_w \tag{14}$$

- flange width/flange thickness ratio

$$8 \times T_f \leq D_f \leq 32 \times T_f, \tag{15}$$

where δ is the plate thickness, T_w is the web thickness, D_f is the flange width, D_w is the web height, T_f is the flange thickness.

Obviously the results will change if we select other geometrical constraints, but not significantly.

A number of equality constraints between design variables belonging to different panels were also imposed in order to reach a rational and exploitable solution. For instance, transversal member's spacing is considered equal all over the midship section, and plate thickness and transversal members web thickness are supposed to be constant on each deck. These constraints are imposed by the shipyard to standardise the production.

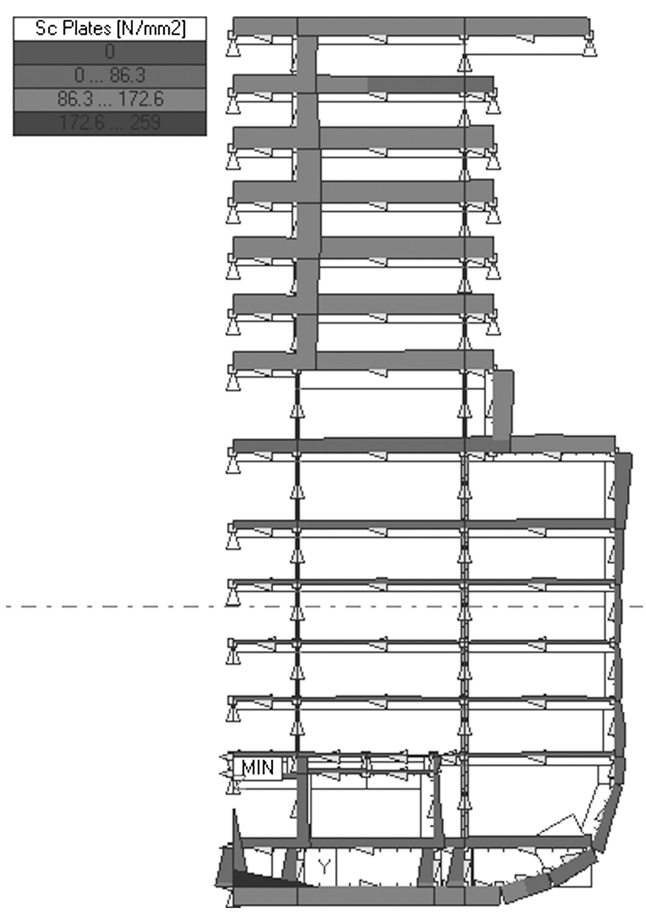

Figure 7 Structural result—von Mises stress.

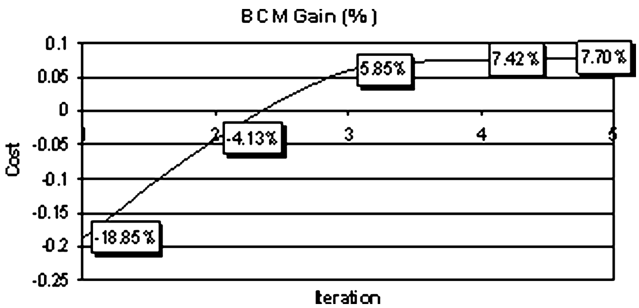

Figure 8 Gain obtained with the BCM.

A global restriction relative to the gravity centre vertical position was imposed to restrict its variation between fixed lower and upper limits.

The size of the optimization problem is illustrated in Table 1.

CALCULATIONS

Due to the international competition between shipyards, a lot of valuable information will not be mentioned in the present paper. Nevertheless, the authors acknowledge Aker Yards, France for its courtesy for allowing use of their results. In this paper, data are mainly presented in terms of ratios to avoid publishing sensitive confidential quantitative data.

The structural optimization was performed with both the BCM and ACM, and a comparative analysis has been carried out on the optimal configurations. These configurations (scantlings) are "feasible" solutions, which mean that all the constraints imposed to optimization are satisfied. An example of structural result (von Mises stress) given by LBR5 graphical user interface is shown in Figure 7. The convergence of the cost objective function required only five iterations for both cost modules (Figures 8–9).

The results revealed differences between cost assessments of the two modules, but also in terms of cost savings, which was expectable as the sensitivities of the design variables are less realistic with the BCM, compared to direct cost calculation. Figures 8 and 9 show the BCM respectively ACM gains in terms of production costs, considering as reference the initial design cost assessments.

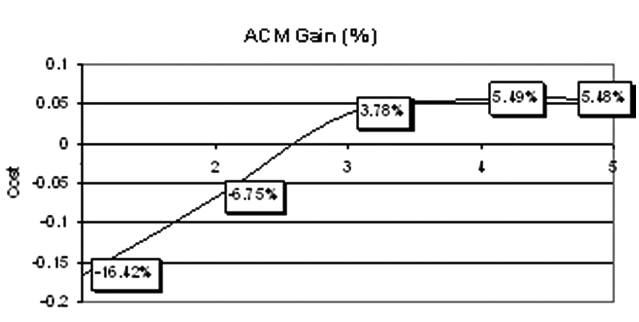

Figure 9 Gain obtained with the ACM.

Table 2 **Scantlings comparison**

Structural item	Ship region	BCM %	ACM %
Plate thickness	Upper deck	−100	−80
	Double bottom	−30	−31
Stiffener modulus	Upper deck	−183	−286
	Double bottom	−262	−260
	Neutral axis	+32	+32
Stiffener spacing	Upper deck	+38	+38
	Lower decks	+20	+20
	Double bottom	−34	−34
Transversal spacing	Overall	+20	+20

The initial cost assessment shows a difference of 20.4% between the BCM and the ACM calculations. The optimal solutions present a 7.7% gain for the BCM and a 5.5% gain for the ACM, meaning a 2.2% difference in gain. This gap is given by the different cost assessments on one hand and the different sensitivities on the other. A way to evaluate the effect of sensitivities alone is to assess the costs of BCM-based optimal scantlings using the ACM approach and then compare it with the ACM optimal solution. This comparison resulted in a 0.93% gap, which means that 42% of the difference between gains with BCM and ACM is due to the optimization process.

The general tendency for the ACM-based optimization was to increase the plate thickness with ∼80% on the upper decks and ∼31% on the double bottom. The longitudinal member's section modulus also increased up to ∼286% on the upper deck and ∼260% on the double bottom, while it was reduced with ∼32% in the neutral axis region. The plate and longitudinal members general increase is fully compensated by a reduction of the number of stiffeners (∼27% for the transversals members respectively 20–38% for the longitudinal members), as well as a reduction by ∼20% of the transversals section.

The same trend was observed with the BCM-based optimization, the main differences in terms of scantlings are found for the plate thickness and stiffener scantlings. The plate thickness was increased with ∼100% on the upper decks and ∼30% on the double bottom. The section modulus for the longitudinal stiffeners increased with ∼183% on the upper deck and ∼262% on the double bottom; in the neutral axis region a 32% reduction is noted. The spacing of transversal members is the same for both methods, as it reaches each time the maximum limits of the technological restrictions. Table 2 resumes the differences between the two calculations in terms of final scantlings.

CONCLUSIONS

This paper presents an example of scantling optimization performed with the LBR-5 software. The goal was to minimise the production costs for a large passenger vessel using the two available cost assessment tools. Plate straightening was taken into account with both BCM and ACM.

A comparison was made between solutions found with the two cost modules. The cost assessment made with the ACM-based optimization was found to be about 20% less optimistic than the BCM approach. The ACM optimization found a 5.5% gain compared to the initial cost assessment, while the BCM found a 7.7% gain. The difference between these two ratios is the result of a more realistic cost assessment and calculation of sensitivities for the ACM.

Nevertheless, the general optimization trend is similar to the two approaches, as plate thickness and longitudinal stiffeners section modulus grow, while the number of longitudinal and transversal members decreases.

ACKNOWLEDGMENTS

The present research was achieved with the funding and support of MARSTRUCT, Network of Excellence in Marine Structures (www.mar.ist.utl.pt/marstruct/), IMPROVE (FP6 project - 031382 - funded by EU, www.anast-eu.ulg.ac.be) and AKER YARDS, France.

REFERENCES

Caprace JD, Bair F, Losseau N, Rigo P. 2006. A data mining analysis applied to a straightening process database. *COMPIT'07 Proceedings*, pp. 186–196

Fleury C. 1989. CONLIN, an efficient dual optimizer based on convex approximation concepts. *Structural Optimization* 1; 81–89.

Hughes OF. 1988. Ship structural design: a rationally-based, computer-aided optimization approach, (Ed.) SNAME, New Jersey, p. 566.

Paik JK, Thayamballi AK. 2003. Ultimate limit state design of steel-plated structures, John Wiley and Sons, Chichester, UK.

Rigo P. 2001. A module-oriented tool for optimum design of stiffened structures. Marine structures, vol. 14/6, Elsevier pp. 611–629.

