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NÚCLEO DE DESENVOLVIMENTO E PESQUISA DO NAVIO

AUTOMATED BULK-CARRIER STRUCTURAL SYNTHESIS

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ABSTRACT

This work presents a bulk carrier midship section structural model to perform the synthesis of longitudinal material. The model is a part of a larger one, presently being developed, which will encompass transverse, as well as longitudinal material.

The main objective of this work is to develop a technique and a tool which will ensure a fast and efficient design of the midship section. They apply to different stages of the process of conception and design of the ship. The limits of application are quite wide, regarding the size of the ship and the type of cargo. For efficient design it must be understood one that ensures an optimum combination of advantages in initial cost plus pay-load capacity.

A study of the structural synthesis process was done, with due consideration to its place and relationships on the global problem of ship design.

The adopted model contains some aspects of local optimization. A mathematic model to represent the midship section geometry was developed, as well as a method to generate its parameters.

As a final product, a computer program was developed. Some examples of its applications are presented as well as conclusions on the influence of design variables on the longitudinal weight.

I N D E X

LIST OF SYMBOLS

L	lenght of ship
B	breadth of ship
D	draught of ship
H	depth of ship
C_B	block coeficient
Δ	ship's displacement
V	service speed of ship
SF	cargo stowage factor
SWBML	maximum still water bending moment full load condition
SWBMB	maximum still water bending moment ballast condition
A	area of continuous longitudinal material in the midship section
e_L	longitudinal stiffeners spacing
e_t	transversal stiffeners spacing

1. INTRODUCTION

One of the first works dealing with midship section automated design was presented by Evans and Kousky(1), in 1963.- It was based on A.B.S. Rules and its aim was to orient the designer in choosing the most adequate design parameters. Buxton(2), in 1966, using L.R.S. Rules, programmed the calculation of the scantlings for the structural elements in a tanker hold. In 1968, Moe e Lund(3) presented a similar work, based on D.N.V. Rules, elaborating a mathematical model for the midship section of a tanker. Aldwinckle(4), in 1970, built a mathematical model for the midship section design of a bulk carrier, based on L.R.S. Rules, valid for the range from -- 20.000 to 80.000 TDW. In his work he included an automated process for obtaining the required section modulus and also a process for selection of profiles, taken from a commercial file.

The research and development departments of Classification Societies have been developing computer programs for determining scantlings, using their own rules(5),(6).

The great majority of recent works dealing with structural synthesis emphasize optimization(7). They apply, almost invariably, to tankers.

Increasing prices for oil greatly increases the economies due to savings in structural weight. It must be remembered that, for each ton of structural weight saved in the preliminary design cycles, two or more tons may be reduced in the ship's final displacement. The consequent reduction in power and full consumption is obvious. In certain cases, simultaneous gains in structural weight, pay-load and fuel consumption may be envisaged. However, to consider so many alternatives and choosing a very good one, it does require design automation. Automated structural synthesis is, therefore, mandatory.

A good structure may be defined as the one wich combines, in adequate proportions, light weight, good arrangement, and characteristics for easy fabrication and maintenance. It can be designed by Classification Society rules or by "rational" methods. In the first case it is relatively easy to design the structure, by hand calculations or with the aid of some small and straightforward programs. However, to design a really good structure, taking full advantage of the rules, involves many interactions and optimization considerations. It does require a deep analysis of the whole problem, a mathematical formulation and a an adequate computer program.

Structural weight reductions may be obtained through: refined load prediction and structural analysis methods and/or by optimizing the structural topology. In general, the second alternative is much more promising. It is the main concern of this work.

The structural design synthesis model presented herein leads to the midship section with all its details normally found in a contract design, excluding, for the time being, the transverse structure. Besides this feature of completeness, it is fundamentally flexible, admitting, as input data:

a) only a few very preliminary ones; b) some more elaborated ones; c) a complete set of data defining the midship structure. In each case the model generates the remaining parameters, with due consideration to optimization. When all of them are given, the program acts as an evaluator of the structure. Therefore, the model presented herein applies to different situations of ship design, from the conceptual study stage up to the evaluation of an already designed (or built) structure. It serves, therefore, to shipdesigners, shipowners, government agencies, etc.

In its working condition, the model does not include the transverse structure. It uses L.R.S. Rules and considers the general arrangement shown in figure 1, including ships from - 10.000 to 250.000 TDW, and minimum stowage factor of $0.7m^3$/ton.

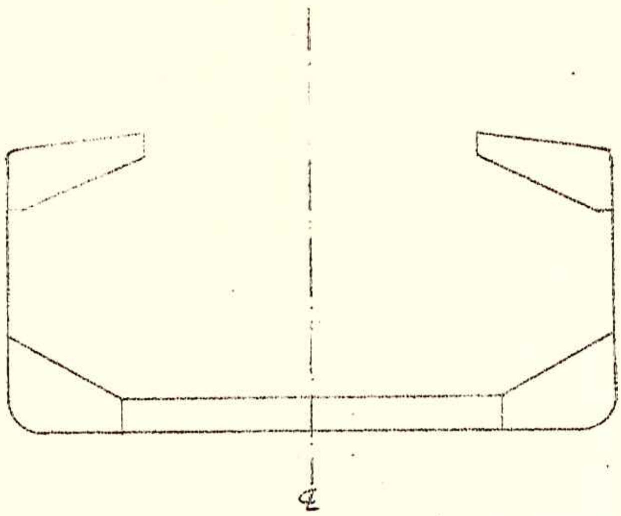


Figure 1

Presently we are extending the model to include:

a - the transverse structure;
b - other general arrangements besides that of figure 1 (ore carriers, combined bulk carriers).

In chapters 2 and 3 we will present the structural model. In chapter 4 we will present the conclusions drawn from its application to several known ships.

2. METHOD

The first step in designing the midship section structure is to define its topology, that is, to stablish its external and internal contour and the position of its main components. As a rule, when this is done, the main worries refer to general design and fabrication requirements, with heavy influence of past designs. However, fixing the topology means, to a great extent, determining the structural weight. The next steps, in a design by Societies rules, are:

a) to calculate the ship's girder minimum section modulus required;
b) to calculate minimum required plate thichnesses and stiffiners section modulus;
c) to choose plate thicknesses and stiffners sections, from

those available;

d) to calculate the resulting ship's girder section modulus;
e) to change scantlings, in order to reach the minimum required ship's girder section modulus;
f) to calculate, again, required plates thicknesses and section modulus, taking advantage of any excess in the bottom section modulus previously obtained;
g) to recycle c, d, e and f, until satisfactory convergence is reached;

After this, the original topology should be systematically modified, and the whole sequence of operations carried out, searching for reduction in weight.

Therefore a good structural synthesis requires very good orientation to start with an adequate topology, not only according to general requirements but, as well, according to structural optimization; and it also requires a high degree of automation with built-in optimization techniques.

Structure optimization may lead to very expensive procedures which, although yielding an "optimal solution", may not enlighten significantly the structural designer. In this work we go deep to investigate the relationship among the variables, and their influence, attaining a simple but efficient way to generate and optimize the structure.

Structure is just one part of the global problem of the whole ship design and optimization. On the other hand, this global problem should have a means for determining, with good accuracy, the changes in structural weight due to changes in the ship's main parameters. Therefore, concentrating in the structure, we'll consider the parameters of the ship's global optimization as constants in each case. At the end, we will vary them, sistematically, to show their influence on the structural weight.

A merit function, involving weight, construction and main tenance costs could be considered. However, only weight may be looked objectively, the latter two factors being always subjective. Besides, weight governs, to a great extent construction and maintenance costs and, for this reason, it will be considered alone in our model. However, the model was elaborated with built-in criteria of good construction and maintenance. As the parallel middle body determines most of the structural weight, only this portion of the ship will be considered.

Let P be the structural weight function to be optimized. We write:

$$P = P\ \{\alpha\}\ ,\ \{\beta\},\ \{\gamma\},\ \{\delta\}, \qquad (1)$$

where:

$$\{\alpha\} = \{\alpha_1\}, \{\alpha_2\}\ ;\ \{\gamma\} = \{\gamma_1\}\ ,\ \{\gamma_2\}$$

$\{\alpha_1\}$ defines:
- ship speed;
- payload characteristics (TDW, minimum and maximum stowage factors, angle for static equilibrium);

$\{\alpha_2\}$ defines:
- ship's parameters with heavy influence on ship's design global optimization: L,B,D, H, C_B and spacing between transverse watertight bulkheads;

$\{\beta\}$ defines the midship section contour, e.g., it positions the double bottom, the inclined bulkheads, the hatch,etc (figure 3);

$\{\gamma_1\}$ defines the position of the longitudinals (side keels and longitudinals stiffeners);

$\{\gamma_2\}$ defines the position of the transversal elements (floors, side frames, web frames and deck beams; (figure 4);

$\{\delta\}$ defines the parameters of the transverse watertight bulkheads (figure 5).

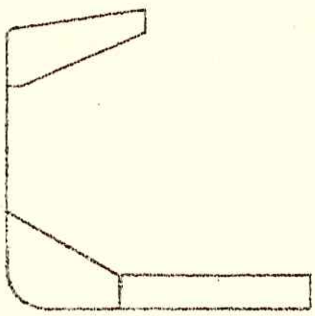


Figure 3

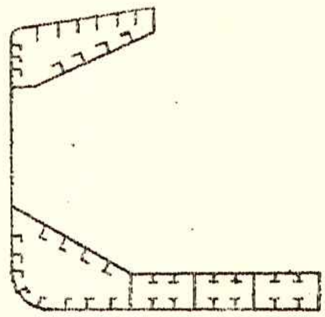


Figure 4

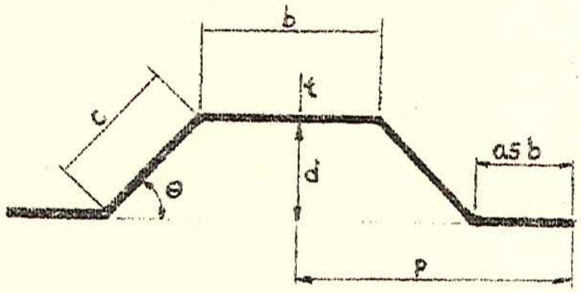


Figure 5

Equation (1) must be rewritten:

$$P = P\ (\{\alpha_1\},\{\alpha_2\},\{\beta\},\{\gamma_1\},\{\gamma_2\},\{\gamma\} \qquad (1\text{-}A)$$

$\{\alpha_1\}$ is input data for our problem. It's as constant $\{\overline{\alpha}_1\}$;

$\{\alpha_2\}$, although heavily influencing, P, pertains to the problem of ship's design global optimization. It will be considered constant, in each case. Varying it sistematically, in the model, will set its influence on the structural weight. It will be denoted by $\{\overline{\alpha}_2\}$, when kept constant.

Therefore:

$$P = P\,(\{\bar{\alpha}\}\ \ \{\beta\}\ \{\gamma_1\}\ \{\gamma_2\}\ \{\delta\}) \qquad (1\text{-}B)$$

It is convenient to consider the structural weight as:

$$P = P_1 + P_2 + P_3 \qquad (2)$$

P_1 = weight of the longitudinal structure

P_2 = weight of the transverse structure (excluding bulkheads)

P_3 = weight of the transverse bulkheads (considered corrugated).

We can write:

$$P_1 = P_2\,(\{\bar{\alpha}\},\{\beta\},\{\gamma_1\},\{\gamma_2\}) \qquad (3)$$

$$P_2 = P_2\,(\{\bar{\alpha}\},\{\beta\},\{\gamma_2\}) \qquad (4)$$

$$P_3 = P_3\,(\{\bar{\alpha}\},\{\beta\},\{\delta\}) \qquad (5)$$

P_2 is not a function of $\{\gamma_1\}$, within the scope of the Society rules.

Let us analyze $\{\gamma_1\}$. The spacing and number of side keels, in the Society rules, depend only on B which belongs to $\{\bar{\alpha}\}$. The longitudinal spacing, in the Society rules, has a "minimum value" to be adopted in the calculation of plates thicknesses, which is a function of L, only. As will be shown in chapter 4, this "minimum value" always leads to a minimum P_1, for any combination of $\{\bar{\alpha}\}$ $\{\beta\}$ and $\{\gamma_2\}$. As a matter of fact, $\{\gamma_1\}$ has some conpling with $\{\beta\}$, since the sum of longitudinal spacings has to be iqual to scalars appearing in $\{\beta\}$. However this only adjusts the "minim value" of the longitudi nal spacing, referred above, with negligible influence on P_1. Therefore it is very easy to determine the value of $\{\gamma_1\}$ which minimizes P_1. Let us denote it by $\{\gamma_1\}^*$. Therefore:

$$\{\gamma_1\}^* = \gamma_1\{\bar{\alpha}\} \qquad (6)$$

It may seem rather ilogic that $\{\gamma_1\}^*$ is independent of $\{\gamma_2\}$ but, within the Society rules, it is true.

From (3) and (6) we can write:

$$P_1 = P_1 \{\bar{\alpha}\} \{\beta\} \{\gamma_2\} \qquad (3\text{-A})$$

$$P_2 = P_2 \{\bar{\alpha}\} \{\beta\} \{\gamma_2\} \qquad (4)$$

$$P_3 = P_3 \{\bar{\alpha}\} \{\beta\} \{\delta\} \qquad (5)$$

The vectors $\{\beta\}$, $\{\gamma_2\}$ and $\{\delta\}$, above, involve many scalar variables which will vastly increase the time and cost to solve the problem of optimization. To avoid this we'll make some hypo theses, which will have to be checked when using the model:

H-1 the values of $\{\beta\}$, $\{\gamma_2\}$ and $\{\delta\}$which minimize

$P = P_1 + P_2 + P_3$ are relatively uncoupled, that is, each one of them does not change significantly, when the other two vary within practical limits; as one particular consequence, the value of $\{\delta\}$ which minimizes P is the same value which minimizes P_3;

H-2 since P_1 is predominant, in P, and $\{\beta\}$ is prevailing in P_1, the value of $\{\beta\}$ which minimizes P is very close to the value of $\{\beta\}$ which minimizes P_1 alone;

H-3 The value of $\{\gamma_2\}$ which minimizes P is very close to the value of $\{\gamma_2\}$ which minimizes $P_1 + P_2$.

Using these hypothesis, separate parts of a model may be built to generate the longitudinal structure, the transverse structure (excluding bulkheads) and the bulkheads. With given $\{\bar{\alpha}\}$ and $\{\gamma_2\}$, and using the first part of the model, $\{\beta\}$ optimum is found; with this $\{\beta\}$ and $\{\bar{\alpha}\}$, using the first and the second parts of the model, $\{\gamma_2\}$ optimum is found; and, using $\{\bar{\bar{\alpha}}\}$, $\{\beta\}$ optimum and the third part of the model, $\{\gamma\}$ optimum is found.

The scalar variables of $\{\beta\}$ are related to the areas A_1, A_2, A_3 and A_4 of figure 6. These, in turn, are associated with the ship's design general requirements (necessary volume for payload, ballast and fuel, cargo handling, and ship stability). Therefore the optimum value for $\{\beta\}$ must be found by optimizing the function P_1, subjecting the scalars of $\{\beta\}$ to constraints imposed by the above requirements. Therefore, the optimum value of $\{\beta\}$ is found from the following formulation:

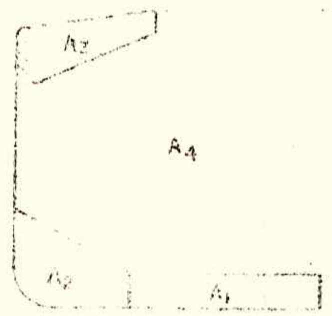


Figure 6

$$\min P_1 = \min P_1 (\{\bar{\alpha}\}, \{\beta\}, \{\bar{\gamma}_2\})$$

subjected to:

$$\underline{A}_i < a_i < \bar{A}_i \qquad i = 1, 2, \text{-------}, n \qquad (7)$$

$$\underline{B}_j < b_j < \bar{B}_j \qquad j = 1, 2, \text{-------}, n$$

$$\underline{C}_i < c_i < \bar{c}_i \qquad \text{where}$$

- A_i, $\bar{A}_i$ and a_i: represent, respectively, the minimum the maximum and the actual value of each area A_i of figure 6;

- B_j, $\bar{B}_j$ and b_j : represent, respectively, the minimum, the maximum and the actual value of the scalar variables of $\{\beta\}$;

- C_i, $\bar{C}_i$ and c_i : represent, respectively, the minimum, the maximum and the actual value of the center of gravity of each area A_i of figure 6.

A_i, $\bar{A}_i$, B_j, $\bar{B}_j$, C_i and $\bar{C}_i$ depend on $\{\bar{\alpha}\}$.

We'll summarize now our previous discussion:

$$P = P_1 + P_2 + P_3 \qquad (2)$$

$$P_1 = P_1 \ (\{\bar{\alpha}\},\{\beta\},\{\gamma_2\}) \qquad (3\text{-A})$$

$$P_2 = P_2 \ (\{\bar{\alpha}\},\{\beta\},\{\gamma_2\}) \qquad (4)$$

$$P_3 = P_3 \ (\{\bar{\alpha}\} \ \{\beta\} \ \{\delta\} \qquad (5)$$

$\{\beta\}^*$, $\{\gamma_2\}^*$,$\{\delta\}^*$ - optimum values of $\{\beta\}$, $\{\gamma_2\}$ and $\{\delta\}$ which optimize $P = P_1 + P_2 + P_3$

$\{\beta\}^{**}$, $\{\gamma_2\}^{**}$,$\{\delta\}$== "<u>near - optimum values</u>" of $\{\beta\}$, $\{\gamma_2\}$ and $\{\delta\}$ which can be taken as optimum values for practical purposes.

i) min $P_1 (\{\bar{\alpha}\},\{\beta\}, \{\gamma_2\})$ $\quad \{\beta\}^{**}$

(under constraints)

ii) min $P_1 + P_2 \ (\{\bar{\alpha}\},\{\beta\}^{**},\{\gamma_2\})$ $\quad \{\gamma_2\}$

iii) min P_3 $(\{\bar{\alpha}\},\{\beta\}^{**}, \{\delta\})$ $\{\delta\}^{**}$

According to the foregoing ideas, the work to ge an "automated, self-optimized, bulk carrier structural model" comprises the following stages:

1. elaboration of a model for automatic generation of the longitudinal structure, including "local optimization features" such as the selection of the ideal $\{\delta_1\}$ (equation (6)) and area distribution to get the section modulus;

2. elaboration of a model for automatic generation of the transverse structure (excluding bulkheads).

3. elaboration of a model for automatic generation of the transverse watertight bulkheads;

4. Selection and inplementation of techniques to perform the optimizations of P_1, $P_1 + P_2$ and P_3, using the models developed in the preceding steps:

5. Checking the hypotheses H-1, H-2 and H-3, previously stated.

Presently, stage no.1 is completely developed and tested. Stages 3,4 and 5 are underway. In chapters 3 and 4 we'll present the results already obtained.

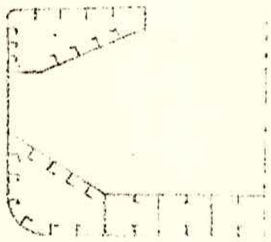
3. LONGITUDINAL STRUCTURE AUTOMATIC GENERATION.

This corresponds to phase 1, referred to at the end of the previous chapter. It is such that enables the program to be used in the following cases:

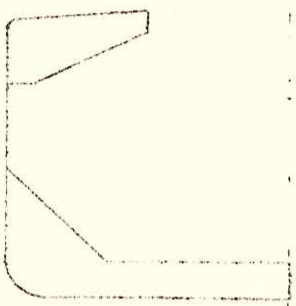
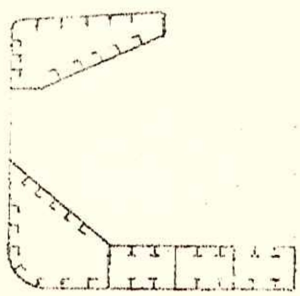
CASE 1

D A T A	OUT PUT
Δ or TDW V SF minimum	for each generated ship: L, B, H, D, C_B longitudinal material sectional area.

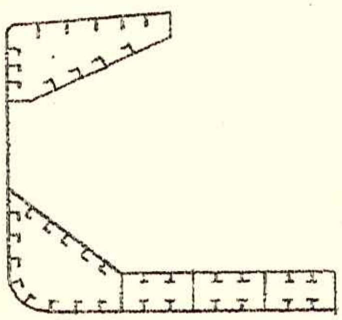
CASE 2

D A T A	OUT PUT
Δ or TDW V, SFminimum, L,B,H,D,	 Section geometry, with complete scantlings.

CASE 3

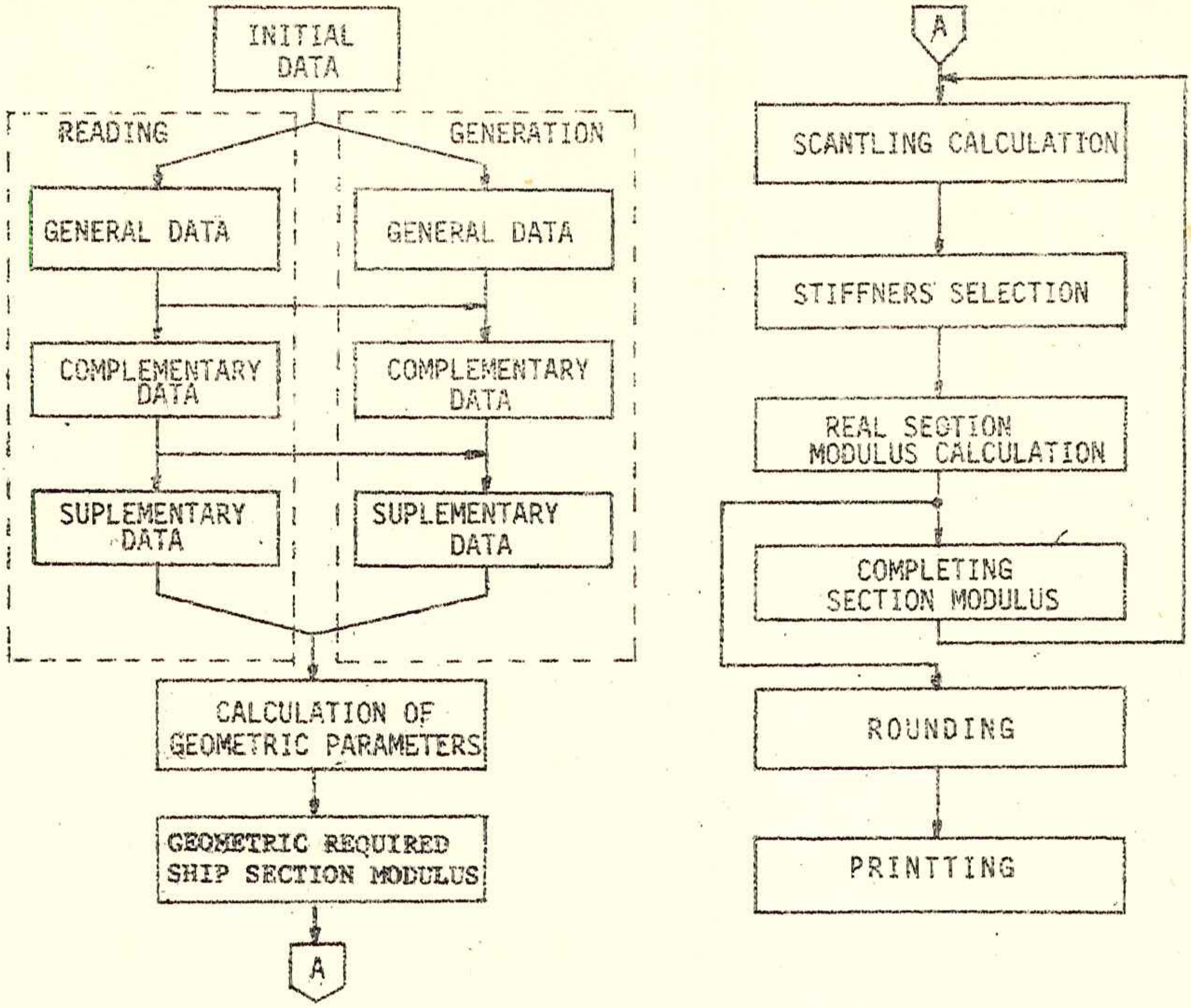
D A T A	OUT PUT
Δ,TDW,V, $SF_{minimum}$, L,B, H, D, C_B, yield stresses, configuration below,SWBML and SWBMB (These last two are optional) 	 Section geometry, with complete scantlings.

CASE 4

D A T A	OUT PUT
Δ or TDW, V, $SF_{minimum}$, L,B, H,D, C_B, yield stresses, the section geometry with all scan tlings, SWBML and SWBMB . 	Minimum thicknesses and stif- feners scantlings

The generation is done through a computer program made up of a "master program" plus 14 subroutines, organized in form groups. This structure is presented below.

GROUP	SUBROUTINE	F U N C T I O N
1	01	reading initial data
	02	reading general data
	03	reading complementary data
	04	reading suplementary data
	05	generation of general data
	06	generation of complementary data
	07	generation of suplementary data
2	10	computation of geometrical parame- ters for scantling calculations.
	11	required ship's sections modulus calculations
	12	scantling calculations
3	13	ship's section modulus calculation
	14	completing ship's section modulus
4	15	selection of stiffners
	16	rounding of thicknesses



Formal optimization of P_1, through extremals for {B}, is now being introduced, according to the lines presented in Chapter 2.

4. CONCLUSIONS

In this chapter some conclusions are presented, drawn from analysis of systematic longitudinal structure generation. 15 "families" of ships were considered, each one having a "referen ce ship" These range from 20.000 TDW to 200.000 TDW. For each family 100 different structural configurations were generated. To abreviate this presentation, we'll restrict ourselves to 5 families, represented by their "reference ships" in table 7, below.

SHIP	TDW (tons)	L (m)	B (m)	H (m)	D (m)	C_B
1	21 545	150.90	22.82	9.54	12.80	0.780
2	37 650	186.08	26.50	11.38	15.40	0.793
3	44 567	184.50	29.00	11.80	16.00	0.884
4	50 500	205.50	30.50	12.00	17.00	0.805
5	159 250	280.42	42.67	18.21	24.69	0.833

TABLE 7

a. Table 8 shows the influence of longitudinal stiffners spacing in P_1. It is seen that the minimum weight corresponds very closely to the minimum spacing allowed by the rules for the calculation for shell plate thicknesses.

TABLE 8

NAVIO 1 e_{LRS}=721,50 mm			NAVIO 2 e_{LRS}= 780.13 mm			NAVIO 3 e_{LRS}=777,5 mm			NAVIO 4 e_{LRS}=812.50 mm			NAVIO 5 e_{LRS}=886.66 mm		
e (mm)	A (cm^2)	+%A_o	$\bar{e}$ (mm)	(cm^2)	+%A_o	e (mm)	A (cm^2)	+%A_o	e (mm)	(cm^2)	+%A_o	e (mm)	(cm^2)	+%A_o
665	17840	0.02	700	24896	-0.5	705	27604	-1.0	735	31355	-0,4	820	59109	-2.1
720	17837	-	755	24861	-0.7	755	27734	-0.5	785	31309	-0,6	870	59661	-1.2
785	18230	2.2	815	25031	-	810	27869	-	845	31491	-	920	60406	-
865	18734	5.0	890	25438	1.6	880	28439	2.0	915	32054	1.8	985	61542	1.9
960	19102	7.1	890	26013	3.9	920	29090	4.4	10^3	32902	4.5	1050	62691	3.8

b. The influence of each scalar of vector B on P_1 is shown in graphs 1 to 6 in pages 16 and 17. From them, we conclude that the important scalars of B to be varied in the optimization procedure are:

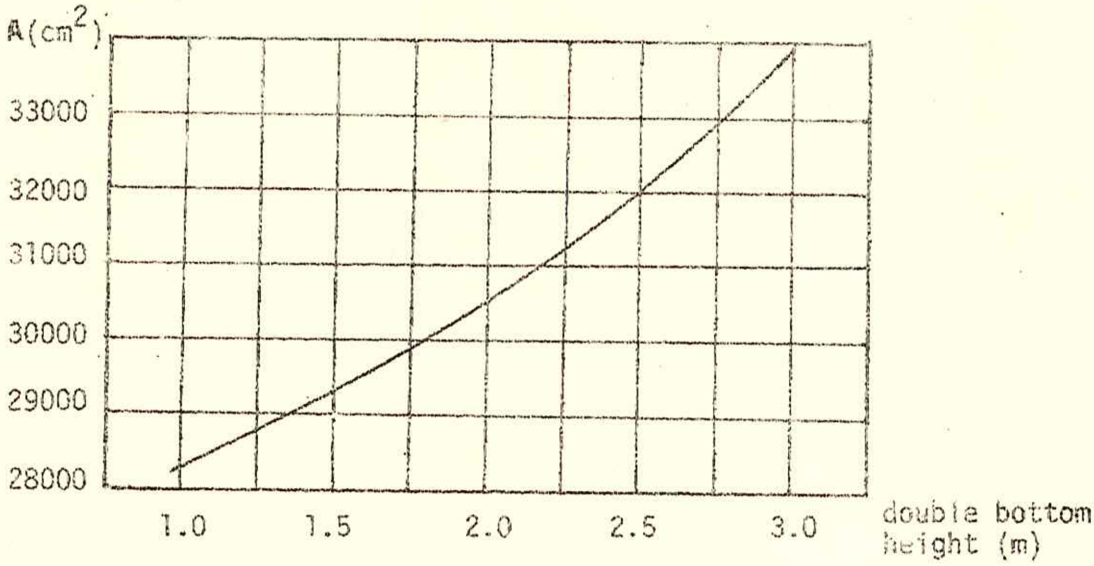
1-b double bottom height

2-b hatch width

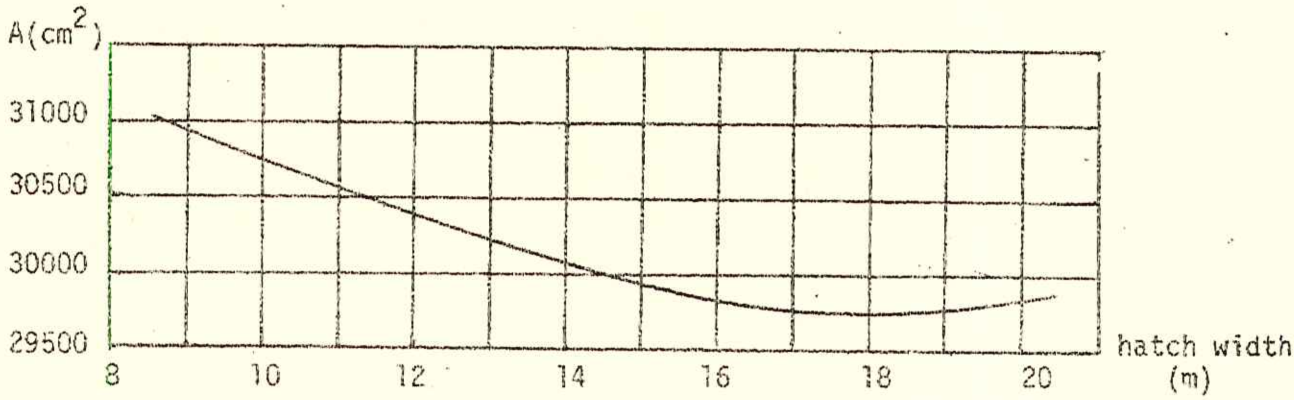
3-b double bottom breadth

4-b angle of longitudinal bulkheads in hopper tank
and saddle tank.

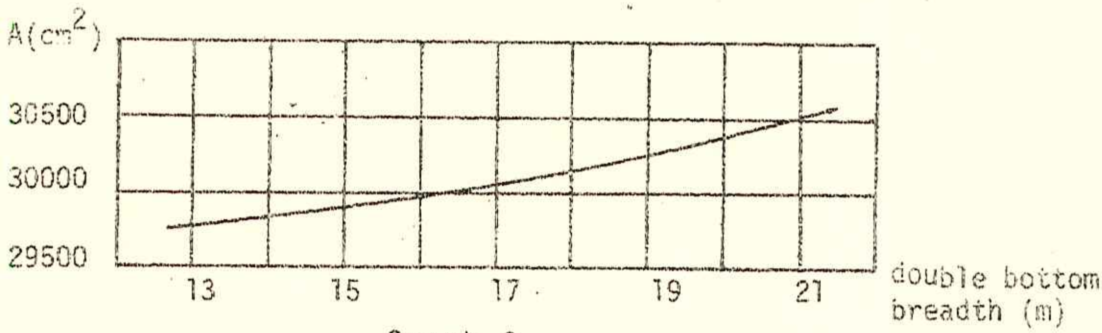
5-b deck sheer.



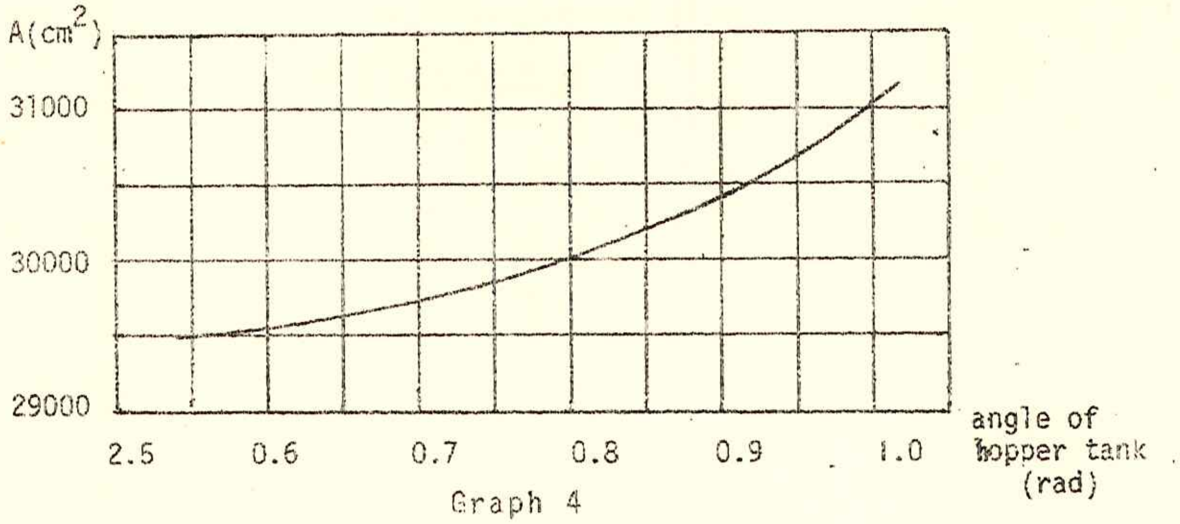
Graph 1



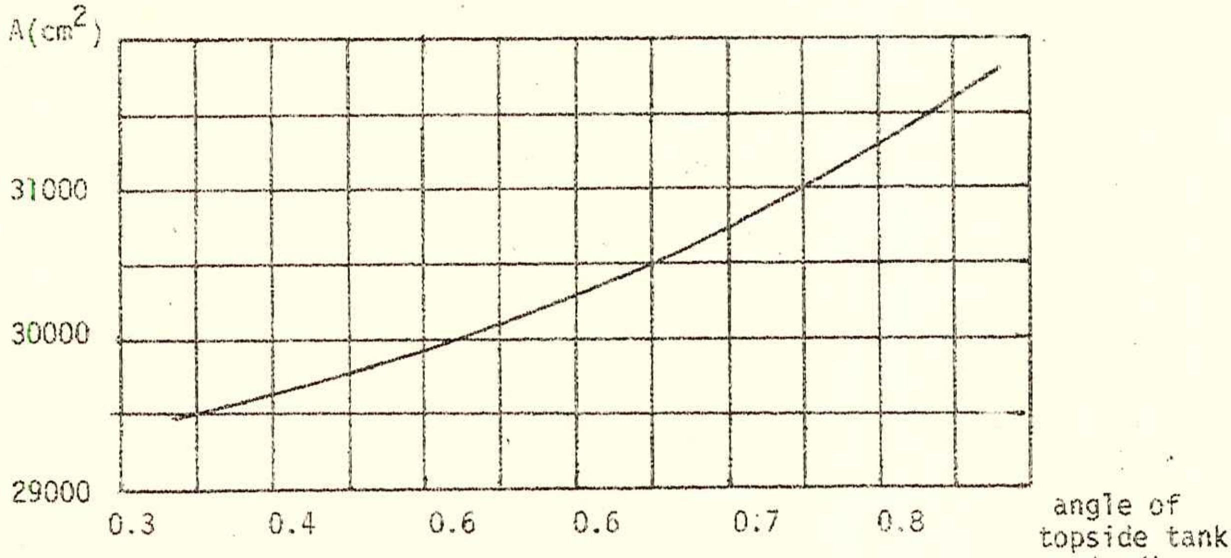
Graph 2



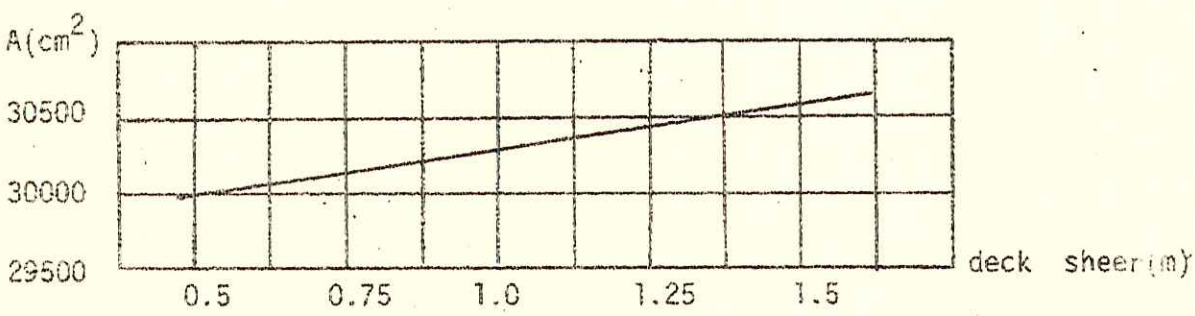
Graph 3



Graph 4



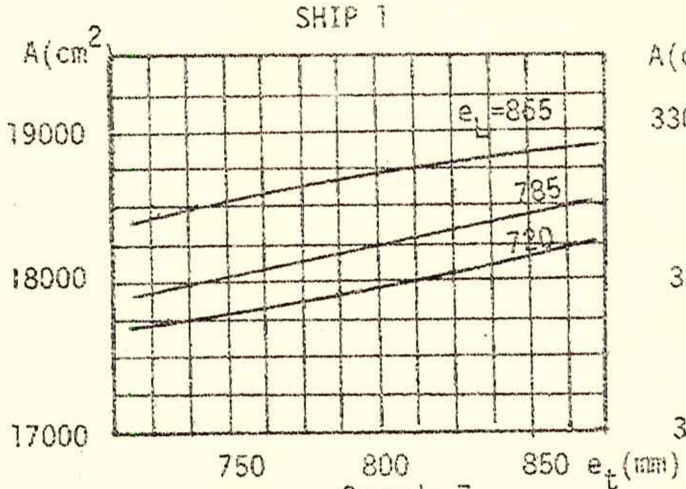
Graph 5



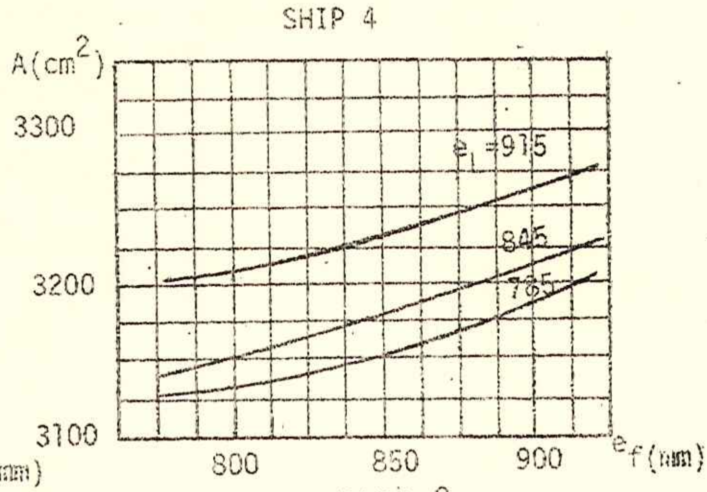
Graph 6

NOTE: The graphs above refer to ship 3.

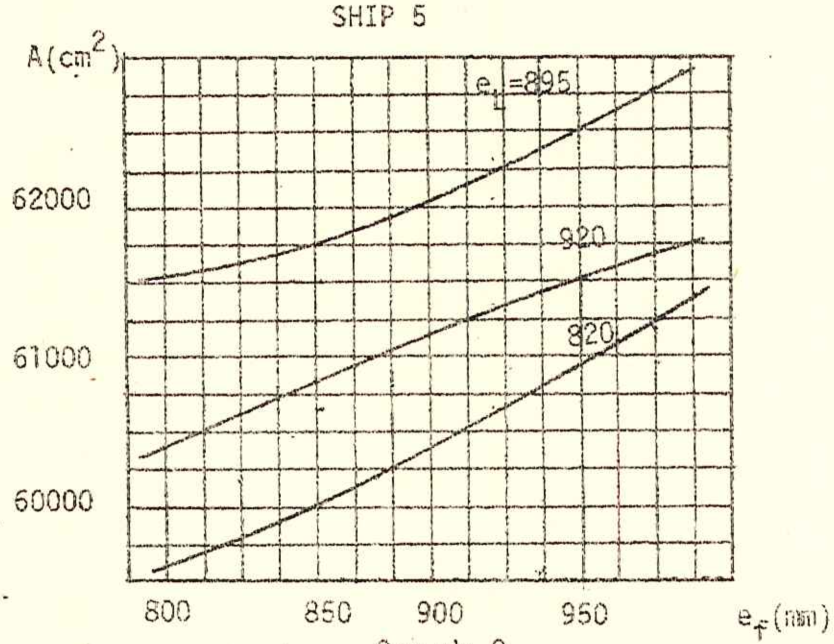
c- A first look on the influence of transverse spacing in P_1 is made possible through graphs 7, 8 and 9. It is seen that P_1 decreases, as the transverse spacing decreases.



Graph 7



Graph 8



Graph 9

d- Finally, an analysis of reduction of P_1 through the use of higher tensile steel was made, using AH32 steel, as found in chapter P of the Rules. It revealed that 7,0% to 8,5% reduction in P_1 is to be expected, using HTS in the deck. If higher tensile steel is also used in the bottom, that reduction increases to 10,5% to 11,5% . On the other hand, using HTS in deck plating means having about 25% to 30% of the section made up of this steel.

while using it also in the bottom increases that percentage to 50% to 55%.

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