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An Expert System for Design Ship Structures

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SUMMARY

This work contains the basic hypothesis used for developing an expert system to synthesize automatically the transverse frame of ship structure. The system is composed by a Finite Element module, a Graphic Display module and a User Friendly Data Entry and Management Module. It can be used for synthesis or for analysis of ship structures or any two-dimensional frame structure as well. The Finite Element module has in its library spar, beam and shear elements. With the last one is possible to calculate the primary shear stress among the ship cross section. The Graphic Display module can plot the model characteristics as mesh, loads, boundary conditions and the results as deformed shape, stress and force diagrams. The system was used to synthesize a transverse frame for ship structure that was former designed and optimized by using three-dimensional finite element model. The results are similar but with one significant difference: the time dispensed by the using the synthesis system, few hours, is much less than the days spent by using three-dimensional models.

INTRODUCTION

In present day the ship structure is designed initially on the basis of experience with similar types of structures, using perhaps, some simple analitical calculations. Then the structure is analysed in detail by numerical methods, and subsequentilly the structure is modified by the designer after examination of the numerical results. The modified structure is then re-analyzed, the analysis examined, and the structure modified, and so on, until a satisfatory structural design is obtained.

With the development and spreading of computer systems this situation had its horizon line expanded. Today is possible, once established the design criteria, rationally synthesize the ship structure in optimum levels as never done before. These synthesis systems are highly interactive with the designer, flexible and able to generate data for a detailed structural analysis by others, more sophisticated, structural programs, like finite element programs.

We are sure that only by these systems the designer can use his total creation capacity, trying new forms and solutions for his problems that were prohibitive before because the amount of calculation and the time usually spent out to achieve one solution. Nevertheless using expert systems, the designer, with his previous knowledge and experiences, gives to computer the seed and the later, after an uncountable number of calculations, gives back the structure based on the launched seed. Unlike in the past where, in a not to short time space, the designer would find only one satisfactory solution, today several of them are found, making him able to chose the best one, enriching his experiences about causes and effects, exploiting frontiers that in the past were beyond his imagination.

Present here is an expert system that is able to tell what are the convenient transverse frame cross section to resist a particular load. The system was developed to be used in ship structures but this is not a limitation because it can be used in any kind of two-dimensional frame structures. It is composed by three modules. One, for user friendly data entry and management module, one finite element module and another, graphics module, able to plot in a display and in a graphic printer many problem characteristics as

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the structure nodal points, elements, loads, deformed shape, stress and forces beam diagrams. The system is highly user interactive and was developed as a PC-DOS compatible. The only thing to do is describe the geometry and loads, set a table of beam cross section and the system will choose which one is adequate to each beam in the model.

THE SHIP STRUCTURE

The ship structure is classified in what the engineers call *Light Structures,* which are composed by thin plates and stiffeners, making the panels. The most of ships has, in the longitudinal direction, light and heavy longitudinal stiffeners and, in the transverse direction, the transverse frames and the bulkheads. The later, with exception of corrugated bulkheads, are formed by panels too.

In its entire life this complex structure will be submitted to distinguished load conditions beginning with the ship launching and continuing with each trip and interval docking. To handle a structural design with this complicated load situations the engineer uses a fictitious load, a hydrostatic equivalent load, by which they can design the structure in a simple way and can be sure that this structure will resist real loads in a safe condition.

It is supposed that when submitted to a simple hydrostatic load the ship structure will suffer three kinds of basic deformations:

Primary: Ship structure bends as a beam in its overall length, with the transverse sections remaining at the same shape as before the load is applied. The load is resulted from a local difference between ship buoyancy in a fictitious wave and weight distribution among its length;

Secondary: The secondary deformation is formed by two components: the first one corresponds to the panels being deformed, with continuos slop, between bulkheads or another kind of transverse heavy structure, like heavy frames and pillars; and the second one corresponds to the light stiffener bending between two adjacent transverse frames. The load is token as equivalent hydrostatic pressure.

Tertiary: This last one corresponds to the shell plate unit bending between adjacent transverse and longitudinal stiffeners. As in the secondary case, the plate is submitted to equivalent hydrostatic pressure.
Considerations about strain symmetry between continuous parts of the structure permit that one part being extracted from the whole structure and been calculated with simple models from structural mechanics. One example of this is the light stiffener that can be cut out the structure and be considered as a beam with both ends fixed and submitted to uniform load.

The stresses resulting from those three kinds of deformations are finally superimposed, composed by a stresses' criterion and compared with adequate limits, established for the material and each stress composition at each structure critical point.

Those hypothetical behaviors have been used successfully in the structure ship design and we think they must be used, at least, as a first approach, even in those cases where we are not sure about the use of this approach.

THE FRAME STRUCTURE MODEL

There are many models to calculate the transverse structure of the ship. All of them have advantages, disadvantages and some kind of limitations. Some are simple others really complicated.

We all engineer know that engineering art is closely linked with abstraction capacity. The engineer handles with approximations, abstract models of the reality and never with the reality itself. A good model is that one which with all its limitations furnishes results with sufficient quality to the engineer, by the model, well represent the reality.

The model for the transverse structure calculations, inside the classifications given in the previous chapter, can be classified as with secondary deformations. In this model the ship structure is supposed to bend between bulkheads.

Happening in this way the model widely accepted to calculate secondary stress is the three-dimensional model composed by the heavy longitudinal stiffeners and the transverse frames modeled as beams and the shell plating modeled as membranes. By this model the engineers get the beams stress and deflections only. The plating is there only to simulate the shearing between adjacent transverse frames. A model with the beams only is not adequate because the interaction of transverse frames will be done only by the longitudinal stiffeners and this may be not true. The three-dimensional model is complex and its calculation is possible only by finite element programs. A simpler model consists in cutting out from the ship structure a slice that contains the frame to be calculated and transfomr it in a two-dimensional one. This advance is more complicated because it involves a lot of hypothesis about the slice interaction with the remaining structure. The engineer must find answers to question like that: *how do the longitudinal stiffeners and the shell plating interact with the transverse frame?*

The first doubt has easy answer when we talk about the light longitudinal stiffener and the transverse frame interaction. We can adopt the frame as a rigid support for the longitudinal stiffener because the former is stiffer than the later. To handle this problem is better to admit the heavy longitudinal acting as elastic support for the frame. The model simplifies itself nevertheless the further problem becomes: *what will be the support elastic constant?*

The remaining structural part that interacts with the transverse slice is the shell plating. For a better understanding of how it works let us admit that the overall compartment, under the equivalent hydrostatic load, deforms in two different phases. At first, the compartment between bulkheads bends as a beam. In this case all transverse sections remain rigid suffering only rotations and vertical displacements. In sequence the transverse frames bend itself in their own planes.

Though in this way, the first deformation component is due beam under variable bending moment from which we cut out the transverse frame that we must calculate. Alike in simple beam theory, the resulting forces in the isolated slice must be balanced by resulting shear stress forces. The loads acting in the slice are not only due the equivalent hydrostatic pressure. We must consider those resulting from shear stress along the cut edges, along the shell platting. The resulting shear force must balance, in the vertical direction, the resultant of hydrostatic forces. Because the shear stress comes from the beam model their distribution follows the same as in the primary shear stress distribution. The difference is that in the later the resultant must be equal the shear force and in the former the resultant must equilibrate the hydrostatic loads acting in the sliced section. Another regarding about the shell plating, when we analyze two-dimensional transverse ship structures, is the own enplane plate stiffness. It is so high and we must consider this putting some adequate support in the model.
The second strain component, the more usual, comes from the bending of frames itself in the slice plane.

Concluding we propose a physical model for the transverse frame structural calculus based in the following assumptions:

1. the model is two-dimensional, gotten from a slice cut out from the ship structure that contains the frame.
2. the slice, with the equivalent hydrostatic loads, musts contains the resulting shear loads which comes from its equilibrium as in the simple beam theory.

3. the frame has elastic supports, whenever it intercepts the heavy longitudinal stiffener.

Based in this model we develop a the expert system able to make the synthesis (that is, able to search in a stiffener's table and say which one is adequate to that part of the structure) the transverse ship structure.

ANALYSIS AND DESIGN CRITERIA

All engineering project must be based in a design criterion. This criterion, unless one or another specialty particularization, is composed by a tripod making a non dismembering set that makes sense. The tripod legs are: *the physical model*, *the loads* and *the admissible values*. There's no sense in saying that one structure was designed with a safety factor 5 and saying nothing about the loads and the model by which that structure was calculated.

In the developed expert system we adopted the following design criterion:

Physical model. The physical model used is that described in the previous chapter. The model is two-dimensional composed by the slice that involves the transverse frames to be synthesized or analyzed. The heavy longitudinal stiffeners are taken into account as elastic supports with elastic constant calculated, by example, from a beam with both ends fixed with the same length of the ship compartment between bulkheads and inertia calculated from the transverse area stiffener plus an effective plate. The load may be concentrated or distributed along the span. As mathematical model to solve the physical model and get the stress in the frames we use a finite element program developed exclusively for the synthesis system. By using a particular finite element program we are limited by the following:

1. the transverse structure shall be made discrete in straight or curved beam elements;
2. the span load on the beams shall be, at maximum, linear distributed;

Loads. As loads we adopted those generated by the equivalent hydrostatic pressure acting upon the transverse frames. The span load intensities are gotten by multiplying the pressure acting in the ship slice by the slice width. The shear loads are intrinsic because their distribution and intensity are hydrostatic load consequence.

Limit Stress. As limit state of stress we adopted that in any point of the frame the equivalent stress, based in the Henky-Von Mises criterion, must not exceed the limit stress given by the designer.

THE EXPERT SYSTEM: TRANSEC

Based in the design criteria discussed in the previous item we developed an expert system named TRANSEC able to synthesize the transverse structure of a ship. To accomplish this by the system the designer must do the following:

1. Divide the section to be synthesized in nodal points and beam elements. Each beam element to be synthesized must have its own section property (the designer gives only the effective plate dimensions, thickness and width) and its own span normal load.

2. Establish the boundary conditions. Within the boundary conditions must be included the support springs elastic constants provided by the heavy longitudinal stiffeners.

3. Set a stiffeners table from which the system will search the optimum stiffener for each beam to be synthesized.

With these data the system follows the flow diagram steps showed in figure 1. If the user doesn't have initial values (stiffener) associated with a particular beam the system starts with the weaker stiffener in the stiffener's table. Further the system calculates the shear distribution in the sliced section. The system uses the mesh given and the effective plate data to assemble a model based in shear elements. It calculates the shear stress distribution in the compartment cross section adopting that the compartment is being bent between bulkheads under a unit shear force and transforms these stresses in tangential load onto the beams [7]. The intensity of the loads is corrected in way the shear force resultant balances the pressure load resultant in vertical direction.

Following these steps the system has a structure that can be analyzed. It has the nodal points, the boundary conditions and the beams with their loads and sectional properties. Then the system calculates the beams stress, running the finite element module.

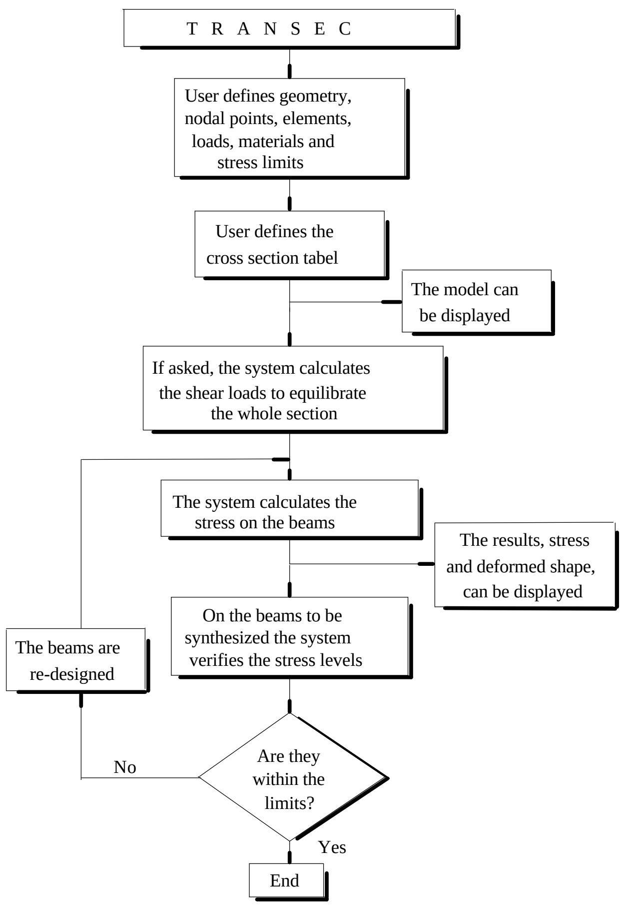

Figure 1 - The system flow chart diagram

In sequence, the system verifies:

1. which beams had their stress limit exceeded;

2. If one exists, the system, knowing the beam end forces, try to find a section property, in the stiffenner's table, which is adequate to the stress limit (this is named re-design process). If it doesn't find any, a message is sent and that beam is aborted off the search.
3. with new beam properties the system runs over.

These steps are followed up to all beams had stress bellow the stress limit and above, if possible, an under stress level defined by the user.

SYNTHESIS EXAMPLE

We will show a structure example that had their scantlings calculated by the system. The structure is the transverse frame that belongs to a ship backward compartment, showed in the figure 2, and was former designed using three-dimensional finite element models. The maximum stress in each frame should be 157 MPa (steel with Yield Stress = 235 MPa and E = 2100000 MPa). We use the system to calculate the same frame and the results are shown in the figures 3 and 4. In despite of little differences we can say that the sections have almost the same scantlings.

CONCLUSIONS

By using the expert system we have some advantages. First of all is about the time consumed in the design that is less than when three-dimensional models are used. The second is the automatic synthesis itself. By the conventional methods you must find the adequate scantlings by a trial-error basis which are time consuming. Even in those cases that you are not sure if the two-dimensional models will work well you can use the system to give you a first estimating of the scantlings for further use in the three-dimensional models.

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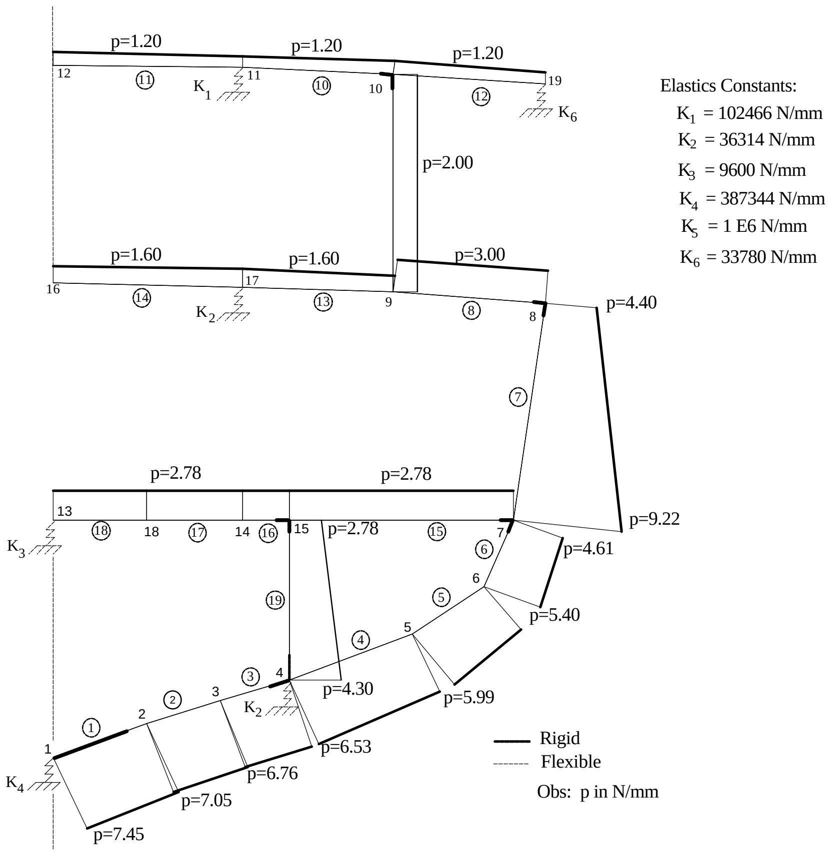


Fig.2 - Transverse structure

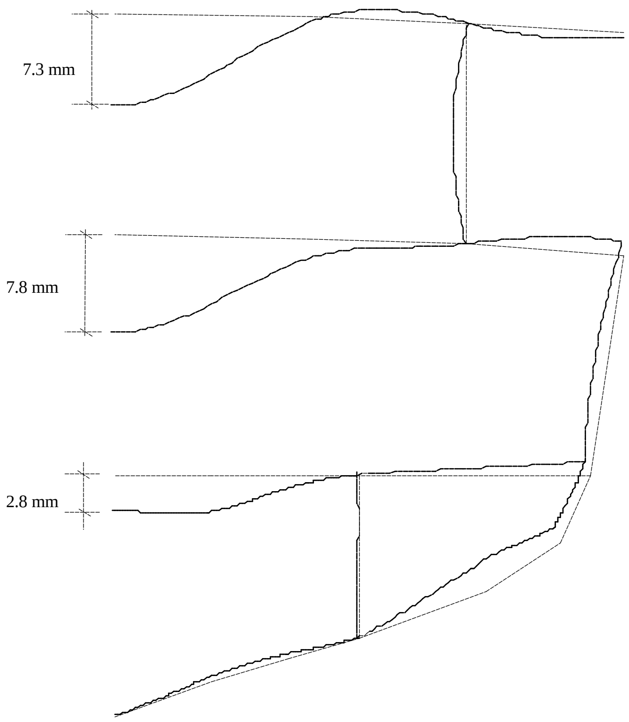
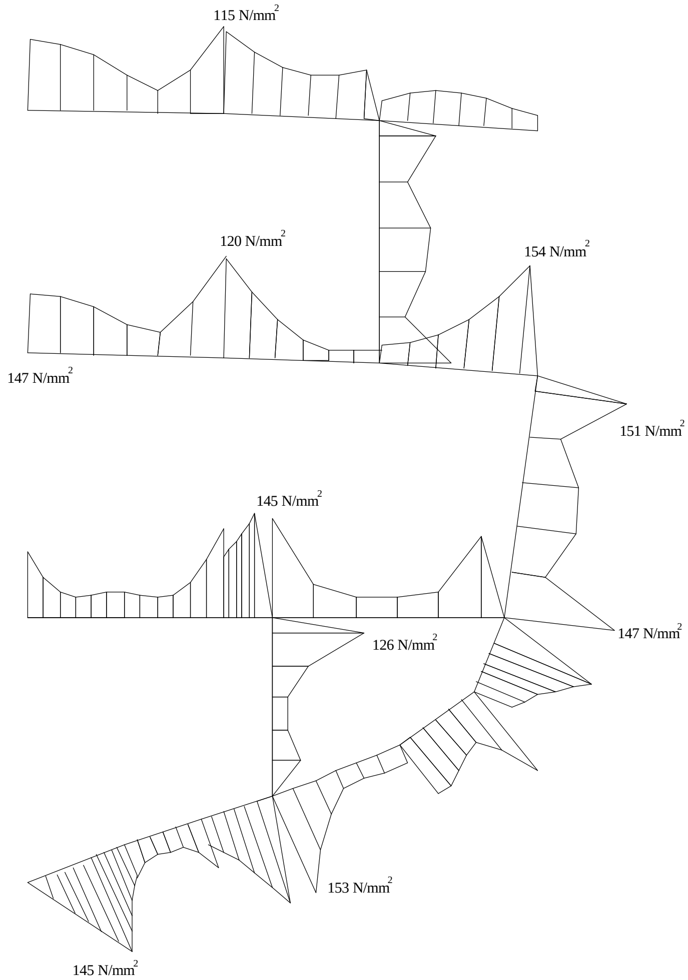


Fig.3 - Deformed shape structure



Beam cross section dimensions after synthesis by the system TRANSEC(mm)

Beam	*Modelo Tridimensional*			*T R A N S E C*		
N.	bxtb *1	hxth	fxtf	bxtb	hxth	fxtf
1	1030x8.0	700x6.3	180x8.0	1030x8.0	140x6.3	70x12.5
2	1030x8.0	550x6.3	180x8.0	1030x8.0	100x6.3	70x12.5
3	1030x8.0	430x6.3	180x8.0	1030x8.0	230x6.3	70x12.5
4	1030x8.0	300x6.3	100x8.0	1030x8.0	240x6.3	70x12.5
5	1030x8.0	275x6.3	100x8.0	1030x8.0	100x6.3	70x12.5
6	1030x8.0	250x6.3	100x8.0	1030x8.0	190x6.3	70x12.5
7	1030x6.3	180x6.3	100x8.0	1030x6.3	210x6.3	70x12.5
8	1030x5.0	180x6.3	100x12.5	1030x5.0	200x6.3	70x12.5
9	1030x6.3	160x5.0	100x8.0	1030x6.3	100x6.3	70x12.5
10	1030x8.0	180x6.3	100x9.5	1030x8.0	100x6.3	70x12.5
11	1030x8.0	180x6.3	100x9.5	1030x8.0	100x6.3	70x12.5
12	1030x8.0	180x6.3	100x9.5	1030x8.0	100x6.3	70x12.5
13	1030x5.0	180x6.3	100x12.5	1030x5.0	120x6.3	70x12.5
14	1030x5.0	180x6.3	100x12.5	1030x5.0	120x6.3	70x12.5
15	1030x6.3	160x6.3	100x12.5	1030x6.3	100x6.3	70x12.5
16	1030x6.3	160x6.3	100x12.5	1030x6.3	150x6.3	70x12.5
17	1030x6.3	160x6.3	100x12.5	1030x6.3	100x6.3	70x12.5
18	1030x6.3	160x6.3	100x12.5	1030x6.3	100x6.3	70x12.5
19	1030x7.2	180x6.3	100x8.0	1030x7.2	100x6.3	70x12.5

1. Effective plate dimenisons given by the user.

Fig.4 Results for Ship Transverse Structure