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AN IMPROVED NUMERICAL MODEL FOR CALCULATING SHIP HULL FRAME TRANSVERSAL STRUCTURE

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Abstract. *Reinforced panels basically compose a ship structure like many other light structures. Nowadays the most usual method for stress calculating of these structures is the Finite Element Method, where the hull plating are modeled as shells elements and stiffener beams as membrane elements as well as beam elements with attached plate. These models are convenient when used for analysis problems where generally few simulations are done to diagnostic any structure. Nevertheless when the problem is design or synthesis high accuracy simpler models are necessary because in despite of the search or optimization algorithm used hundred of simulations are often necessary until the final design is attained. For these situations we have proposed a two dimensional simplified model to calculate stress and deflections of the transverse ring frame of a hull structure, trying to reduce the simulation time and consequently the total time in the optimizing global process. The model consists in calculating an isolated ring frame of the hull structure prescribing adequate boundary conditions that will reconstruct the main behavior of the isolated structure when it was with the whole structure. The results were compared with those obtained by three-dimensional models and the accuracy attained is compatible even for analysis problems.*

1 INTRODUCTION

Ship structure design is commonly performed in a cyclic approach, beginning from similar structures and loads. The initial structure is analyzed and re-jobs are done in those parts where the allowable stresses are reached. This process drives the designer to a satisfactory configuration, since it is not necessarily the best one in terms of weight. The variant shape of hull along the ship length enforce the transverse frames to different shapes, hence it is a difficult task to determine which new frames and plates are needed in order to get a suitable structure. The complex and gigantism of ship structure turn the analysis of 3d compartments very time expensive, even when finite element (FE) programs are used. With the increase of ship dimensions, the structural weight also increased and the structure optimization became important. To accomplish that task, specialized computer programs appeared (see Hughes[1]) getting more and more usefulness with the development and spreading of computer systems.

Today is possible, once established the design criteria, rationally synthesize the ship structure in optimum levels as never one 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. However 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 between causes and effects, exploiting frontiers that in the past were beyond his imagination.

In this paper we describe a two dimensional model to evaluate transverse hull frame structure that were used in a synthesis system (see Augusto[2]) instead of expensive three-dimensional models. Comparative tests show the accuracy of the model and the adequacy of the hypothesis admitted.

2 THE SHIP STRUCTURE BEHAVIOR

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 stiffeners and, in the transverse direction, the transverse frames and the bulkheads. Panels also form the later, with exception of corrugated bulkheads.

In its entire life this complex structure will be submitted to outstanding 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 he can design the structure in a simple way and can be sure that this structure will resist to real loads in a safe condition.

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

Primary: Ship structure bends as a girder 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 an 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 one part being extracted from the whole structure and calculated with simple models from structural mechanics. As example one can take the light stiffener which can be cropped off the structure and be considered as a beam with both ends fixed and submitted to a uniform load.

The stresses resulting from those three kinds of deformations are finally superimposed, composed by a stress' 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.

3 THE HULL FRAME STRUCTURE

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 other really complicated.

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

The model for the transverse structure calculations, inside the assortment given in the previous item, 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 beams only is not adequate because the longitudinal stiffeners alone will do the interaction of transverse frames only and this mode rarely occurs.

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 hull structure a slice containing the frame to be calculated and transform 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 deal with iteration between heavy longitudinal stiffener and the transverse frame is better to admit the heavy longitudinal acting as elastic support for the frame. The model simplifies itself nevertheless the further problem arises: *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 girder. In this case all transverse sections remain rigid suffering only rotations and vertical displacements. In sequence the transverse frames bend themselves in their own planes.

Divided in this fashion, the first deformation component is due to a beam under variable bending moment from which we cut out the transverse frame that we must calculate. Resembling the simple beam theory, the resulting forces in the isolated slice must be balanced by the resulting shear stress forces. The loads acting in the slice are not due the equivalent hydrostatic pressure only. We must consider those resulting from shear stresses along the trimmed 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 hull girder 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.

Regarding to shell plating, when we analyze two-dimensional transverse ship structures, is its own enplane stiffness. It is so high and we must consider this stiffness putting some adequate support in the model.

The second strain component, the more usual, comes from the bending of frames themselves 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) of the transverse ship structure.

3.1 The Elastic Support Constants

The elastic constant, k_e, can be estimated admitting the flexibility of a clamped beam with span L, corresponding to distance between bulkheads or other rigid support for the heavy longitudinal. A unit force is applied web direction at the intersection longitudinal beam and transverse frame. For a ring frame located at compartment center, as shown in figure 1, the elastic constant is

$$k_e = 192 \frac{EI}{L^3} \tag{1}$$

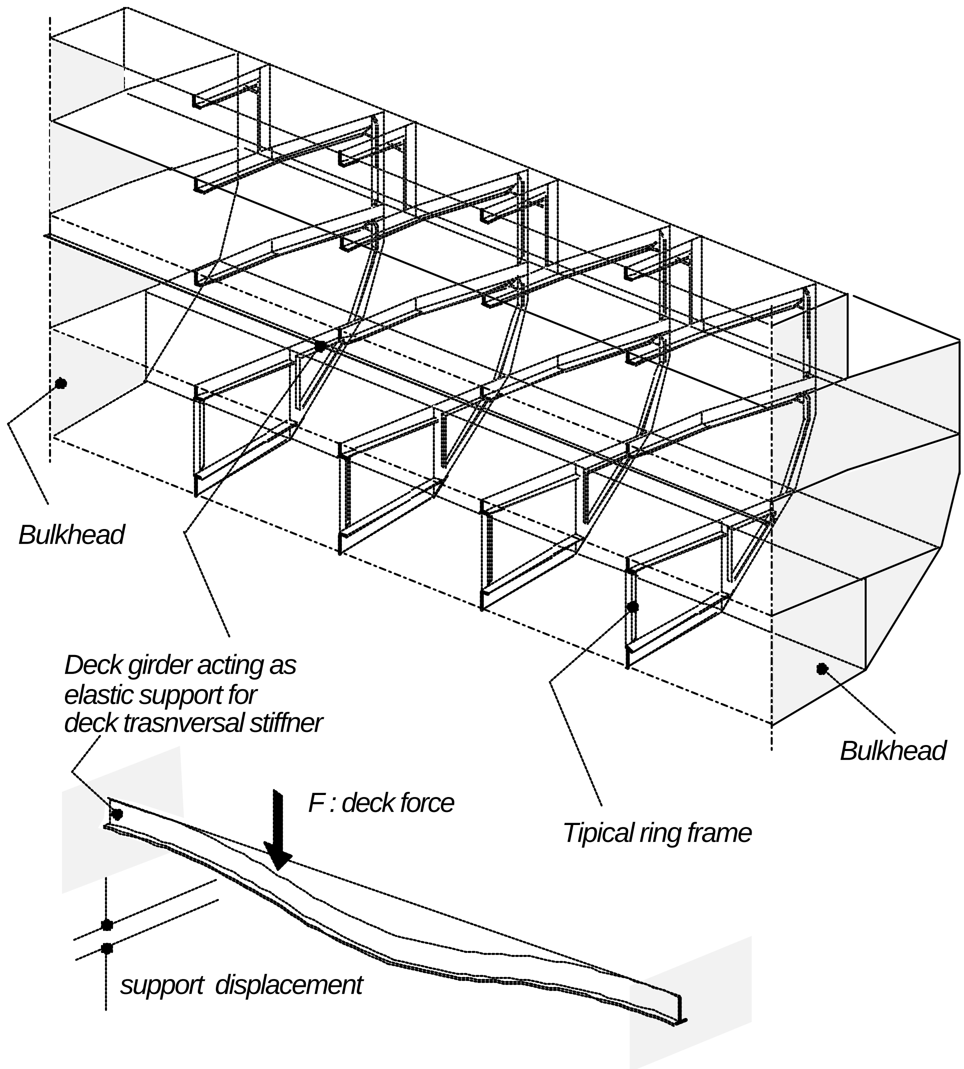

Figure 1 – Elastic constant support for the frames

This procedure can be not adequate in some case as shown by Cardoso[3] since adjacent ring frames also interact whit heavy longitudinal. Each frame along the compartment imposes a displacement at the point in study. In these conditions, the elastic constant can be calculated admitting that each frame have the same interaction with the longitudinal as shown in figure 2. Distributing the concentrated load as uniform load along the beam span L it can be proved for a compartment having m equal spaced frames, that the elastic constant at position frame n is given by

$$k_e = 24\frac{EI}{s^3 n^2 (m-n)^2} \tag{2}$$

$$Slopedeflection:\ \frac{q}{24EI}(x^4 - 2Lx^3 + L^2x^2)$$

Force position x=ns

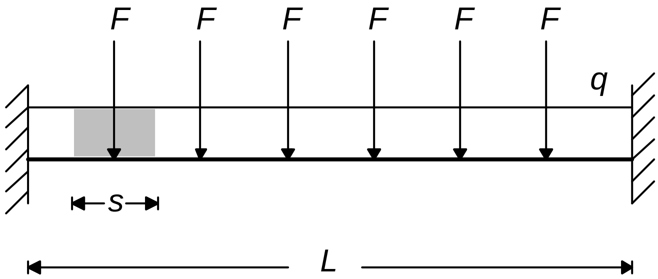

Figure 2 – Interaction between frames and longitudinal stiffener

3.1 Hull Platting Shear Stress Distribution

The shear stress distribution along the shell platting can be calculated admitting the hull compartment working as a thin walled girder with the cross section defined by the shell platting.

To calculate the shear stress distribution for sections statically determinate, we can use the well know relation from beam theory

$$t = \frac{Qm_s}{It} \tag{3}$$

where

m_s is the area moment for the part section beyond the cut where the stress is being calculated;

t is the cut width;

I is the whole cross section area inertia;

Q is the shear force.

Otherwise if the cross section is statically indeterminate, see figure 3, the equation 3 no longer can be applied. The indetermination number is related with the number of cells and a numerical solution will be necessary to carry out the solution.

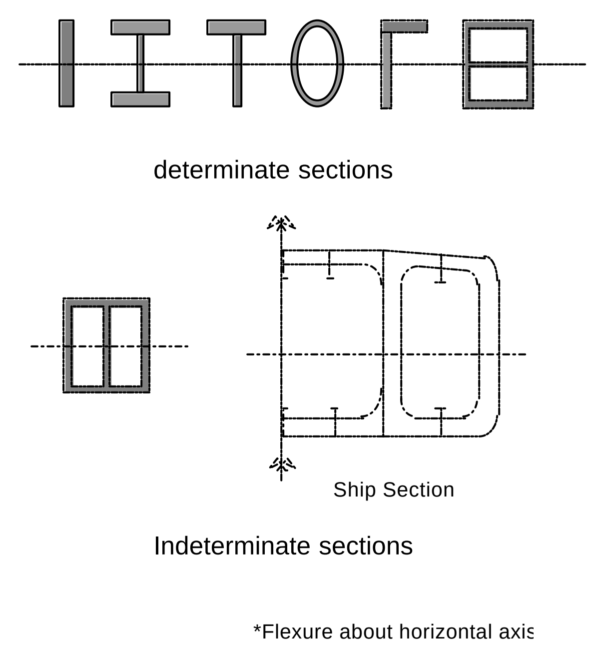

Figure 3 – Examples of beam cross sections

Multiple cell beams, such as those generally found in ship cross sections, are statically indeterminate. To calculate the shear stress distribution in these cases we decide to use a special finite element, as described in Augusto[4].

In this way, the hull cross section is discretized in one-dimensional shear elements and the sear stress distribution is calculated for a unit shear force. The shear flow $\bar{q}_1$ is gotten multiplying the shear stress by the local shell plate thickness

$$\vec{q}_1 = tt \tag{4}$$

where the subscript 1 stands for unit shear force

Since the resultant of this load in the vertical direction is the shear force Q_1=1 is easy to find a scale factor a so the hypothesis of vertical shear balancing the vertical resultant of hydrostatic load can be accomplished:

$$\vec{P} + a\vec{Q}_1 = 0 \tag{5}$$

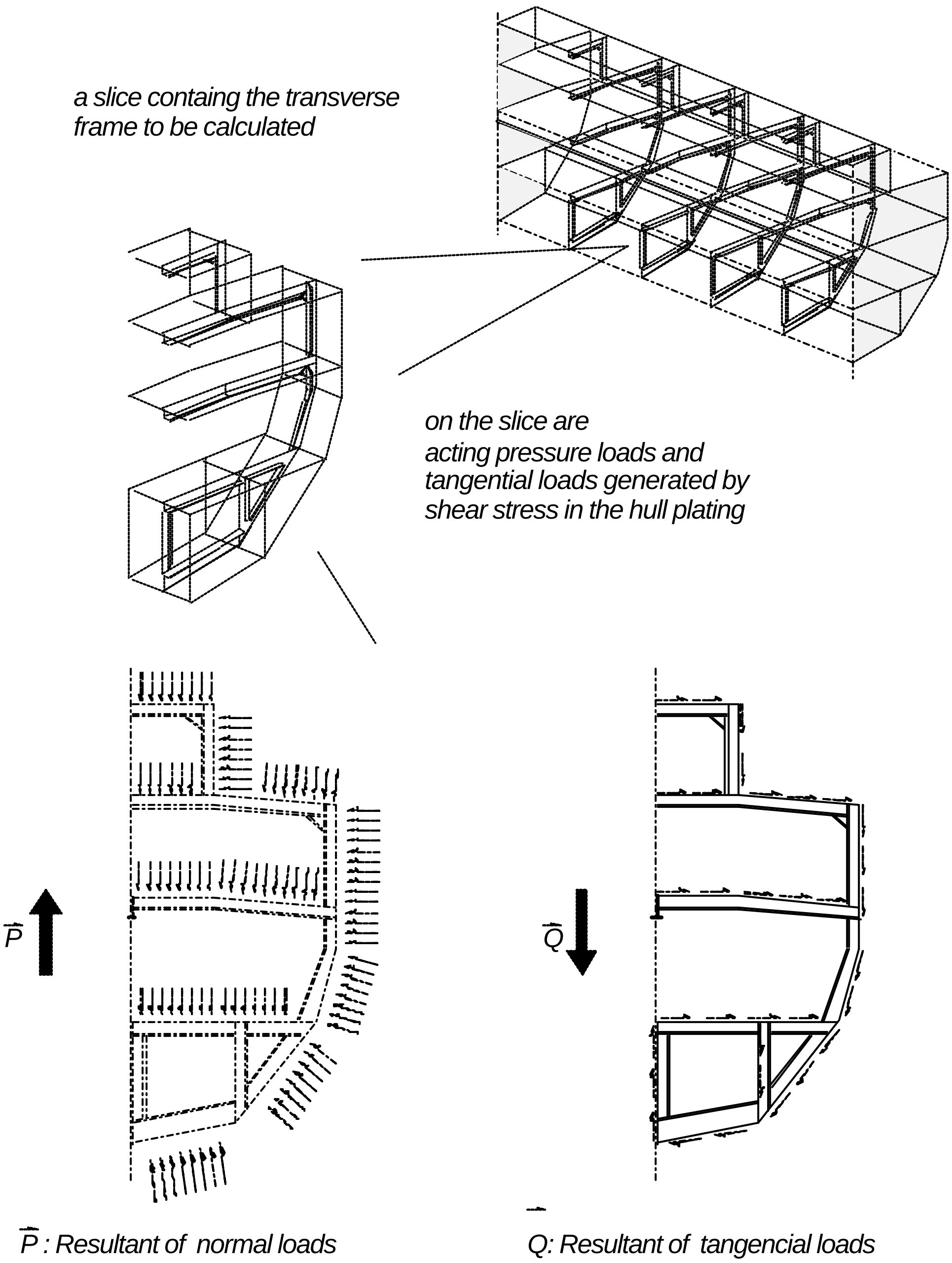

Figure 4 – Equilibrium Hypothesis

4 RESULTS

To test the model proposed we used the hull shown in figure 5.

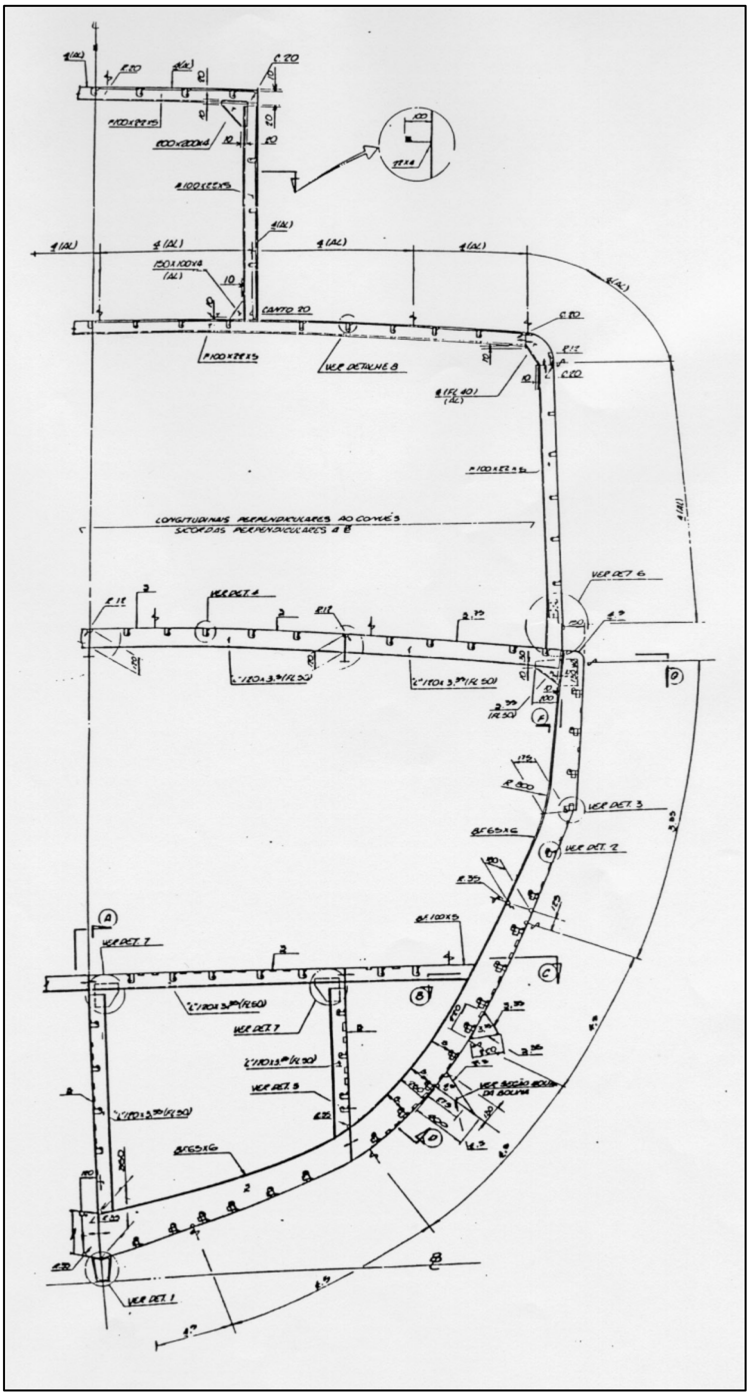

Figure 5 - Patrol Boat Structure

The model was submitted to a prismatic hydrostatic load as shown in figure 6.

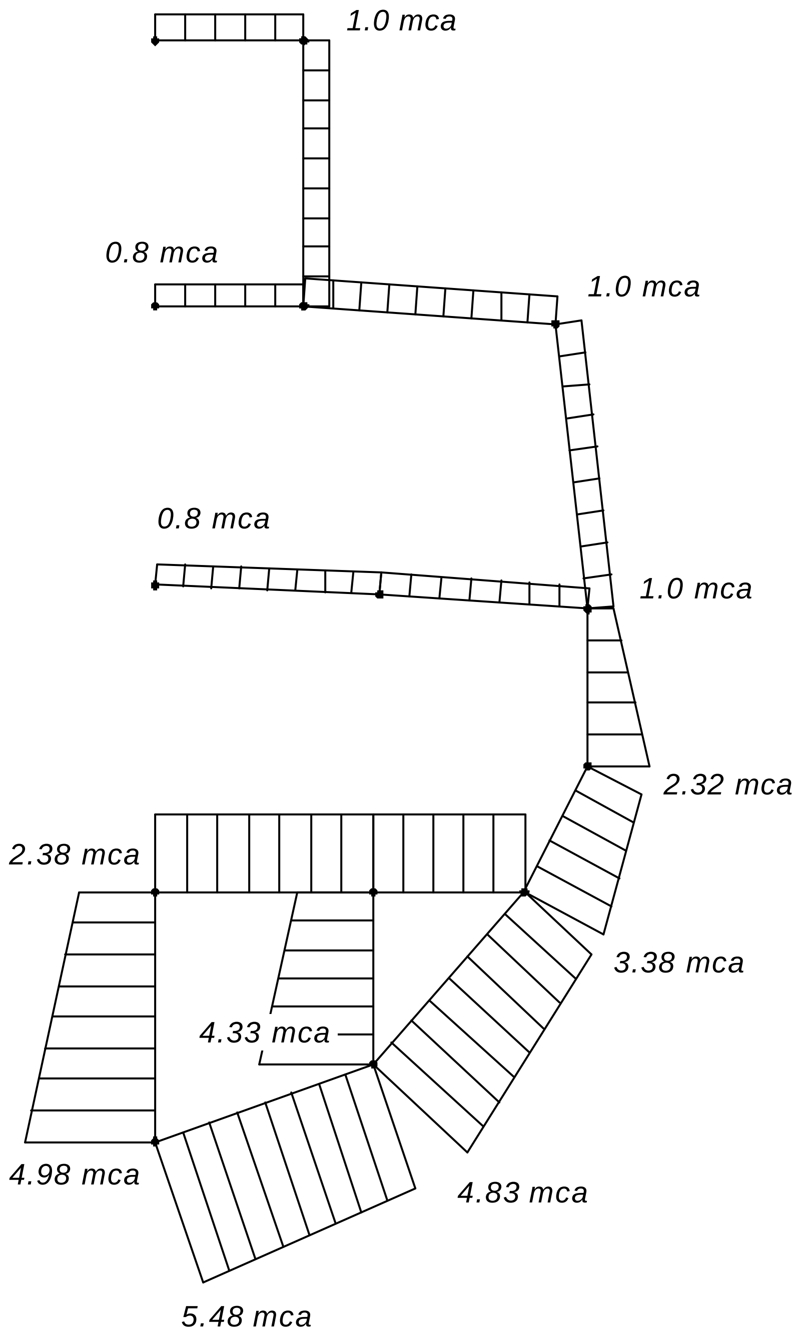

Figure 6 – Hydrostatic load used on the three dimensional model

A three dimensional model of the compartment, using membrane elements plate is shown in figure 7.

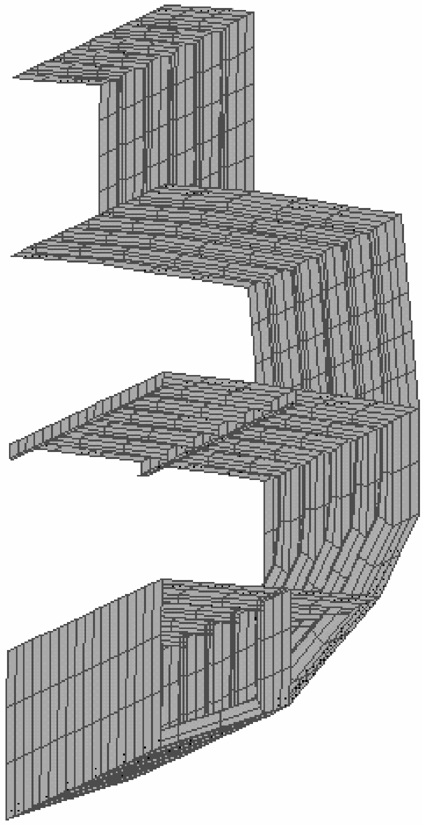

Figure 7 – Three dimensional model using shell elements

Symmetry boundary conditions in the symmetry longitudinal plane and total restrain in the ending bulkheads where used. The model was calculated by Algor[5] Finite Element Program with results shown in figures 10and 11.

For the two dimensional model we chose the transverse frame number 3, positioned at center of compartment. To calculate the 2D model, figures 8 and 9, we use the PROTEUS system, with results shown in figure 10.

As it can be seen comparing, in figure 10, the results from 2D and 3D models are similar corroborating the idea proposed.

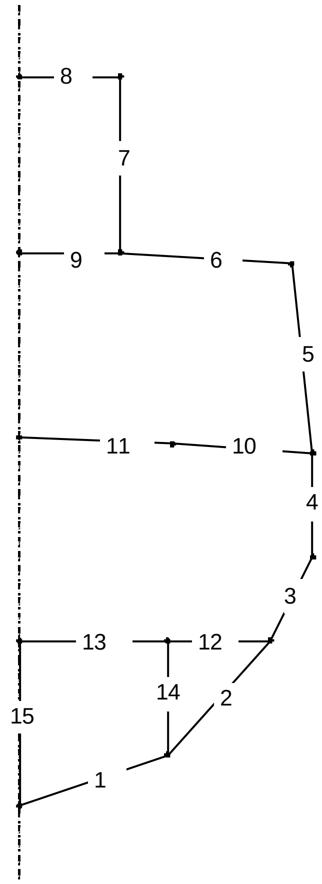

Figure 8 – Two-dimensional beam model.

beam	h	t_h	f	t_f	t_c
1	260	5.00	65	6.00	4.50
2	260	5.00	65	6.00	4.50
3	260	5.00	65	6.00	4.50
4	170	5.00	65	6.00	4.50
5	100	5.00	22	5.00	4.00
6	100	5.00	22	5.00	4.00
7	100	5.00	22	5.00	4.00
8	100	5.00	22	5.00	4.00
9	100	5.00	22	5.00	4.00
10	120	3.35	50	3.35	3.75
11	120	3.35	50	3.50	3.50
12	120	3.50	50	3.35	3.00
13	120	3.50	50	3.35	3.00
14	120	3.50	50	3.35	3.00
15	120	3.50	50	3.35	3.00

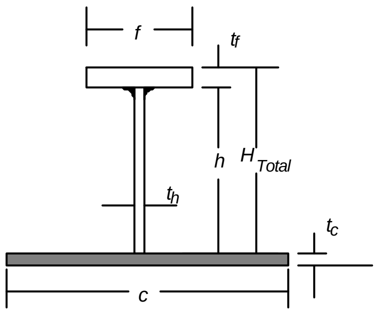

Figure 9 – Beam cross section characteris tics

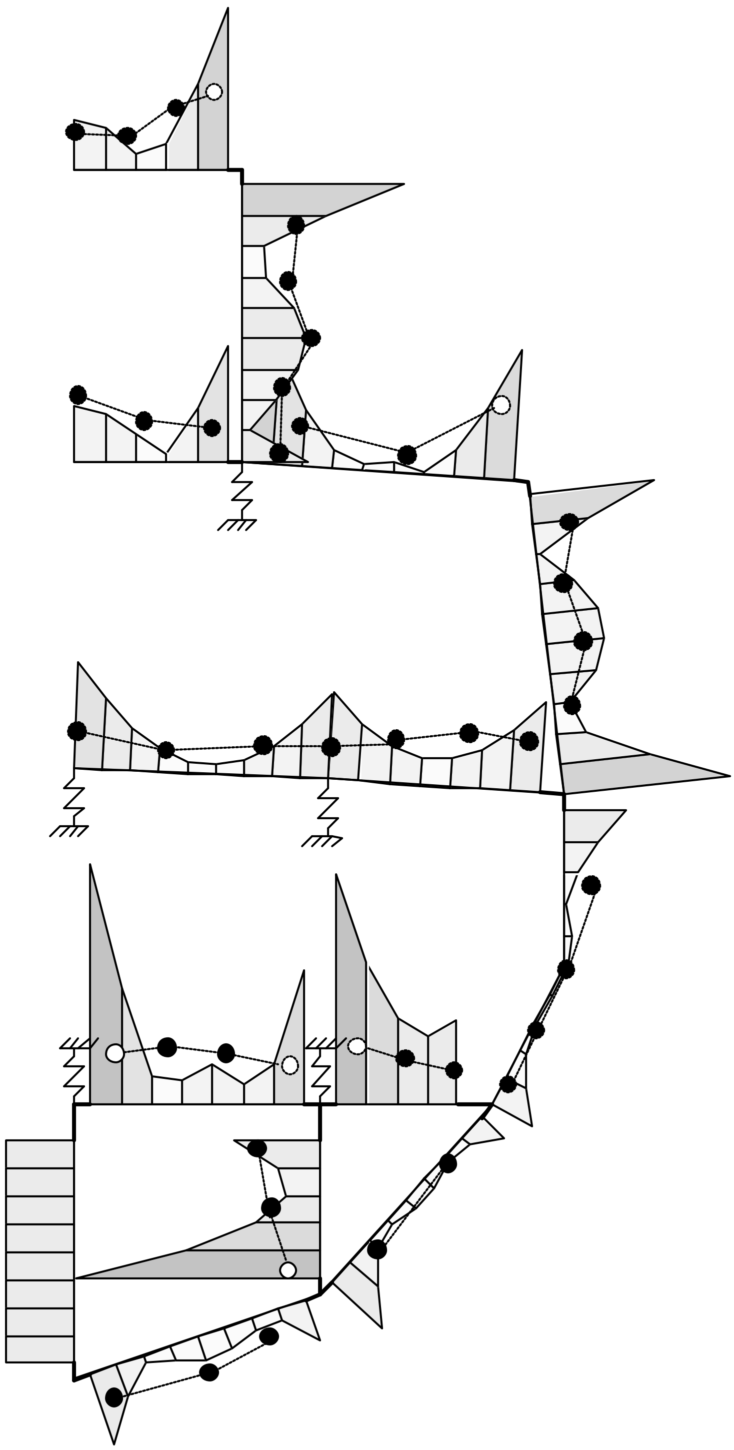

Figure 11 – Von Mises Stress at flange frame location

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