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DEFENCE RESEARCH ESTABLISHMENT ATLANTIC

Contractor Report
DREA CR 1999-019
March 1999

National Defence Défense nationale

Canada

National Defence
Research and
Development Branch

Défense nationale
Bureau de recherche
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W7707-7-4749
Contract Number

March 1999

CONTRACTOR REPORT

Prepared for

Defence Research Establishment Atlantic

Centre de Recherches pour la Défense Atlantique

Canada

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Abstract

This report describes a simple ship structural model and its use in testing the computer program MAESTRO for balance on a wave loading. Using the structural optimization features in MAESTRO, the model was optimized for the given loading. The structural stresses and MAESTRO adequacy parameters resulting from the loading of the original model and the optimized model are predicted and compared.

Résumé

Ce rapport décrit un modèle de structure de navire simple et son utilisation dans la mise à l'essai du programme informatique MAESTRO d'équilibre sur une charge de houle. À l'aide des caractéristiques d'optimisation de la structure contenues dans MAESTRO, le modèle a été optimisé pour le chargement donné. Le rapport contient les prédictions et les comparaisons des contraintes structurales et des paramètres d'adéquation MAESTRO résultant du chargement du modèle original et du modèle optimisé.

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1 Introduction

MAESTRO[1] is a computer program developed for rationally-based optimum design of large complex structures such as ships. To test its capability, a simple MAESTRO ship model was created and subjected to a balance-on-a-wave hogging load wherein the ship is balanced on a unit wave, equal to the length of the ship, with the wave troughs located at the fore and aft perpendiculars. The model scantlings were initially selected intuitively and displacements and stresses were obtained by performing a MAESTRO analysis. The most heavily stressed module of the model was then optimized for weight using the optimization routines available in MAESTRO. The sizes of the original scantlings were then compared with the sizes of the optimized scantlings and the stresses from the analysis of the original model were also compared with those from the optimized model. The adequacy of the optimization is evaluated.

2 The Simple MAESTRO Model

The simple MAESTRO model created to examine the optimization routines is shown in Figure 1. It was based on the hull form of a DDH280 destroyer so that a realistic wave load could be applied. The axis system selected was right-handed with the X-axis running the length of the ship, with zero located at the forward perpendicular. The Y-axis was vertical, with zero at the keel. The Z-axis was positive to port.

The model was made up of three MAESTRO substructures as shown in Figure 2. The substructures were divided into modules with the strakes of the modules divided into 10 sections, as shown in Figure 3. The main emphasis was on the equivalent beam strength of the hull, and girders and bulkheads were added as required. The distribution of the longitudinal girders is shown in Figure 4 and the frames in Figure 5.

3 Loading Applied to the Model

For any analysis, MAESTRO requires a weight distribution for the ship. The simple basic weight distribution selected is shown in Figure 6. It was used to represent the approximate structural plus non-structural weight of a typical destroyer. The weight was distributed automatically, as values of uniformly distributed forces in units of force per unit length, to the MAESTRO strake sections by interpolation. The model was subjected to a balance-on-a-wave hogging load based on a design wave height of 24 feet from crest to trough. MAESTRO distributed the loads longitudinally as shown in Figure 7 and transversely as shown in Figure 8.

Table 1: The Maximum Stresses in the Deck and Bottom from the Initial MAESTRO Analysis

	Stress (ksi.)	
Location	Von Mises	X Axis
Deck	23.2	25.4
Bottom	21.7	-22.6

4 Results of the Initial MAESTRO Analysis

The initial structural model was subjected to a MAESTRO analysis. The deflected shape, plotted using MAESTRO/DSA[2], is shown in Figure 9, and a fringe plot of the displacements is shown in Figure 10. The distribution of the stresses in the deck is shown, in the form of a fringe plot, in Figure 11. The distribution in the bottom is shown in Figure 12. The maximum stresses in the deck and bottom, obtained using the MAESTRO/DSA "Inquire" cursor option on the highest stress fringe, are listed in Table 1. They occured at section 10 of module 2 in substructure 2.

5 Optimization of the Mid Section Module

In order to assess the optimization routines in MAESTRO, the second module of the second substructure was optimized for weight. The symmetry of the module enabled equal and opposite strakes to be linked for the optimization procedure. This guaranteed that scantlings were sized so as to preserve the symmetry. Maximum and minimum limits were set for plate thicknesses and for girder and frame cross-section dimensions. To guarantee reasonable stability, the ratios of scantling cross-section proportions were chosen from those used in an example in Appendix A of the MAESTRO Modeler Tutorial. The bending moments for the hull sections, obtained from the original MAESTRO analysis, are shown in the form of a bending moment diagram in Figure 13. It is recommended in the MAESTRO User's Manual that the value for the minimum allowable section modulus for the module, MIN.ZMOD, be obtained from the following equation.

$$(Z_{module})_{min} = \frac{M_{hog} + M_{sag}}{(S_c)_L}$$

where M_{hog} is the maximum hogging moment, M_{sag} is the maximum sagging moment, and S_{cL} is the maximum permissable stress.

To reduce the complexity of the optimization, M_{hog} was made equal to M_{sag}. The maximum permissable stress was set at 21.3 ksi, which is based on a safety factor of 1.5 on the yield strength of the steel used. As MIN.ZMOD was imposed by the user, a dual optimization was carried

Table 2: Limit State Checks and Definitions

Limit State Acronyms	Definition	Comments
PCSF	Panel Collapse - Stiffener Flexure	
PCCB	Panel Collapse - Combined Buckling	
PCMY	Panel Collapse - Membrane Yield	
PCSB	Panel Collapse - Stiffener Buckling	
PYTF	Panel Yield - Tension, Flange	
PYTP	Panel Yield - Tension, Plate	
PYCF	Panel Yield - Compression, Flange	
PYCP	Panel Yield - Compression, Plate	
PSPBT	Panel Serviceability - Plate Bending	Tranverse
PSPBL	Panel Serviceability - Plate Bending	Longitudinal
PFLB	Panel Failure - Local Buckling	
GCT	Girder Collapse - Tripping	
GCCF	Girder Collapse - Compression, Flange	
GCCP	Girder Collapse - Compression, Plate	
GYBF	Girder Yield - Bending, Flange	
GYBP	Girder Yield - Bending, Plate	
GYTF	Girder Yield - Tension, Flange	
GYTP	Girder Yield-Tension, Plate	
FCPH1,2,3	Frame Collapse-Plastic Hinge	1 = Strake Edge 1 2 = Strake Edge 2 and 3 = midlength of frame section
FYCF1,2,3	Frame Yield-Compression, Flange	
FYTF1,2,3	Frame Yield-Tension, Flange	
FYCP1,2,3	Frame Yield-Compression Plate	
FYTP1,2,3	Frame Yield-Tension, PLate	

out. There was an initial module level optimization, where the design variables are the cross-sectional areas of the strakes, followed by a strake level optimization, where the design variables are the scantlings. The sectional areas of the strakes were identified as deck and bottom strakes to control the primary bending of the module cross-section. Fifteen cycles were used for the optimization. During the optimization, checks for the design code limit states shown in Table 2 were made.

6 The Results of the Optimization

The scantling sizes from the optimization are compared with the original sizes in Table 3. The strake locations are shown in a half view of module 2 in Figure 14. A comparison of the original girders with the optimized girders is shown in Table 4.

where

HSW	Height of stiffener web
TSW	Thickness of stiffener web
BSF	Breadth of stiffener flange
TSF	Thickness of stiffener flange
HFW	Height of frame web
TFW	Thickness of frame web
BFF	Breadth of frame flange
TFF	Thickness of frame flange
HGW	Height of girder web
TGW	Thickness of girder web
BGF	Breadth of girder flange
TGF	Thickness of girder flange

6.1 Adequacy of the Optimization

MAESTRO compares finite analysis results against design code limit states using adequacy parameters,g, which are defined by the following equation.

$$g = \frac{1 - s.f.\frac{Q}{Q_l}}{1 + s.f.\frac{Q}{Q_l}}$$

where $s.f.$ is the safety factor, Q is the stress due to the loading, and Q_l is the allowable limit.

A safety factor of 1.5 was used for the optimization. A summary of the adequacy parameters for module 2 is shown in Table 5. Adequacy parameters less than 0.0 are less than satisfactory indicating a high possiblity of failure as g approaches -1.00. Of the constraints based on minimum and maximum values such as plate thicknesses, and constraints based on the proportions of frames and girders and failure constraints such as panel collapse, three hundred and ninety four constraints were satisfied and thirty three were unsatisfied. The original weight of the model was 142,000 pounds. The optimized weight was 168,000 pounds. The increase in weight was probably due to the requirement to meet the minimum section modulus MIN.ZMOD.

During the optimization, a number of warnings were given. Typical warnings were:

Table 3: Comparison of the Original Scantlings with the Optimized Scantlings of Module 2 of Substructure 2

Strake		No. of	Plate	Stiffeners				Frames			
No	Struct	Stiff	Thick	HSW	TSW	BSF	TSF	HFW	TFW	BFF	TFF
1	Orig	2	.250	4.50	.234	1.75	.234	12.0	.300	4.00	.375
1	Optm	1	.500	11.750	.383	1.25	.250	6.00	.187	2.00	.187
2	Orig	3	.250	4.50	.234	1.75	.234	12.0	.300	4.00	.375
2	Optm	2	.250	4.00	.187	1.00	.1875	6.00	.187	2.00	.187
3	Orig	3	.250	4.50	.234	1.75	.234	12.0	.300	4.00	.375
3	Optm	4	.250	4.00	.187	1.00	.187	6.00	.187	2.00	.187
4	Orig	3	.250	4.50	.234	1.75	.234	12.0	.300	4.00	.375
4	Optm	3	.250	4.00	.187	1.00	.187	6.00	.187	2.00	.187
5	Orig	3	.300	4.50	.234	1.75	.234	12.0	.300	4.00	.375
5	Optm	4	.250	4.25	.187	1.00	.187	6.00	.187	2.00	.187
6	Orig	3	.300	4.50	.234	1.75	.234	12.0	.300	4.00	.375
6	Optm	6	.394	7.00	.187	1.00	.500	12.0	.470	6.00	.500
7	Orig	3	.300	4.50	.234	1.75	.234	12.0	.300	4.00	.375
7	Optm	6	.462	6.25	.250	5.75	.391	12.0	.375	6.00	.425
8	Orig	2	.300	4.50	.234	1.75	.234	12.0	.300	4.00	.375
8	Optm	6	.410	6.75	.187	4.75	.250	11.5	.386	5.00	.406
9	Orig	3	.250	4.50	.234	1.75	.234	12.0	.300	4.00	.375
9	Optm	3	.125	4.00	.187	1.00	.187	9.00	.187	3.50	.187
10	Orig	2	.250	4.50	.234	1.75	.234	12.0	.300	4.00	.375
10	Optm	1	.187	4.00	.187	1.00	.187	7.50	.187	3.00	.187
21	Orig	0	.250	.000	.000	.000	.000	12.0	.300	4.00	.375
21	Optm	0	.125	.000	.000	.000	.000	6.00	.187	2.00	.187

Table 4: Comparison of the Original Girders with the Optimized Girders of Module 2 of Substructure 2

Girder	Structure	Girder Dimension			
No		HGW	TGW	BGF	TGF
1	Orig	33.00	.500	8.75	.500
1	Optm	33.00	.660	11.00	1.00
2	Orig	33.00	.500	12.00	.500
2	Optm	18.50	.375	4.00	.551
3	Orig	24.00	.425	9.00	.500
3	Optm	21.75	.436	4.25	.375
8	Orig	24.00	.425	9.00	.500
8	Optm	22.50	.552	8.00	.688
10	Orig	12.00	.300	4.00	.375
10	Optm	12.00	.375	4.00	.375

```
NONCYCL TROUBLE VAR/CON/INT IER
  14       4        5   10  100
NO FEASIBLE SOLUTION IN OVROPT
DESIGN SPACE HAS BECOME ECLIPSED
```

The optimization process often could not satisfy the limit of .500 inches set for the frame web thickness although it came very close at times. When the frame web thickness limit was set to .700 the optimization process still had trouble meeting the limit. In one cycle, in order to prevent girder collapse, the optimization warned that the frame web rather than the girder web should be 0.9822 inches. In an attempt to improve the optimization results the number of cycles were increased to 20 and then to 30. Although some of the scantling sizes were changed, the the number of unsatisfied adequacy parameters were not significantly reduced.

A plot of the mimimum adequacy parameters for the load case is shown for the entire hull in Figure 15. The mininum adequacy parameters for the deck in module 2 of substructure 2 is shown in Figure 16. The parameters for the bottom are shown in Figure 17. The most likely failure is panel collapse-combined buckling (PCCB) in the longitudinal bulkhead shown in Figure 18. The minimum adequacy values for the strakes, without the longitudinal bulkhead included, are shown in Figure 19 showing a possible panel failure in local buckling of the strake panel (PFLB). A plot of the minimum adequacy parameters for the girders is shown in Figure 20, where yielding of the girder flange (GYTF) is indicated. The minimum adequacy parameters for the frames are shown in Figure 21 indicating a possiblity of frame collapse by a plastic hinge (FCPH).

Table 5: Adequacy Parameters for Module 2 Substructure 2

Range	Adequacy
0.95 TO 1.00	14
0.85 TO 0.95	28
0.75 TO 0.85	46
0.65 TO 0.75	45
0.55 TO 0.65	41
0.45 TO 0.55	31
0.35 TO 0.45	31
0.25 TO 0.35	37
0.15 TO 0.25	39
0.05 TO 0.15	53
0.01 TO 0.05	18
	Transition
-0.01 T0 0.01	11
	Unsatisfied
-0.05 TO -0.01	7
-0.15 TO -0.05	6
-0.25 TO -0.15	10
-0.35 TO -0.25	2
-0.45 TO -0.35	0
-0.55 TO -0.45	0
-0.65 TO -0.55	0
-0.75 TO -0.65	0
-0.85 TO -0.75	1
-0.95 TO -0.85	0
-1.00 TO -0.95	7

Table 6: The Maximum Stresses in the Deck and Bottom of the Optimized Model

	Stress (ksi.)	
Location	Von Mises	X Axis
Deck	19.4	21.2
Bottom	12.0	-13.9

6.2 Stresses in the Optimized Model from Balance-on-a-Wave Load

The Von Mises stresses in the deck of the optimized model are shown in Figure 22. The highest stresses in module 2 of substructure 2 are in the deck as shown in Figure 23. The stresses in the bottom are shown in Figure 24. The maximum stresses in the deck and bottom of the optimized model are listed in Table 6. All four of these stresses are less than the stress of 21.3 ksi used to calculate the minimum section modulus MIN.ZMOD.

The the maximum combined stresses in the girder flanges are shown in Figure 25 with a maximum compressive stress of -25.0 ksi. The maximum combined stresses in the frame flanges are shown in Figure 26 with a maximum value(negative) of -41.0 ksi, which is approaching the ultimate strength of the material of 46.5 ksi, confirming the possibility of the formation of a plastic hinge.

7 Discussion

The simple ship model, generated using the MAESTRO Modeller, was shown to be suitable for carrying out a MAESTRO structural analysis. The optimization of module 2 of substructure 2 of the model, using the MAESTRO optimization option, was not totally satisfactory. The optimization of the strake panels was mostly satisfactory except for the longitudinal bulkhead. The lack of success in that region may have been due to not initially specifying panel stiffeners. Some of the girders and the frames were also not satisfactorily optimized. This may explain the reasons for the warnings given in the output data file. Due to the large number of unsatisfied adequacy parameters, a much simpler model should have been used initially, to more easily examine the optimization process.

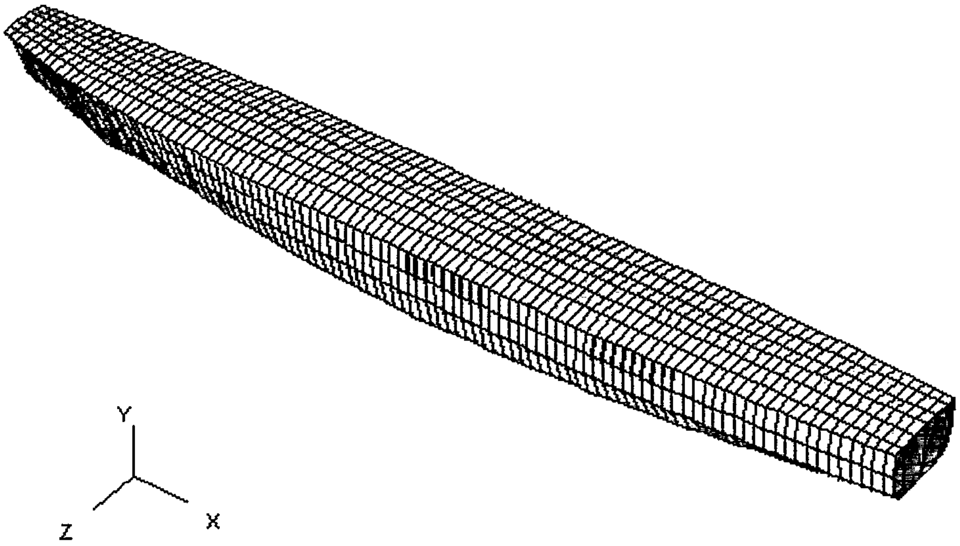

Figure 1: Simple Ship MAESTRO Model

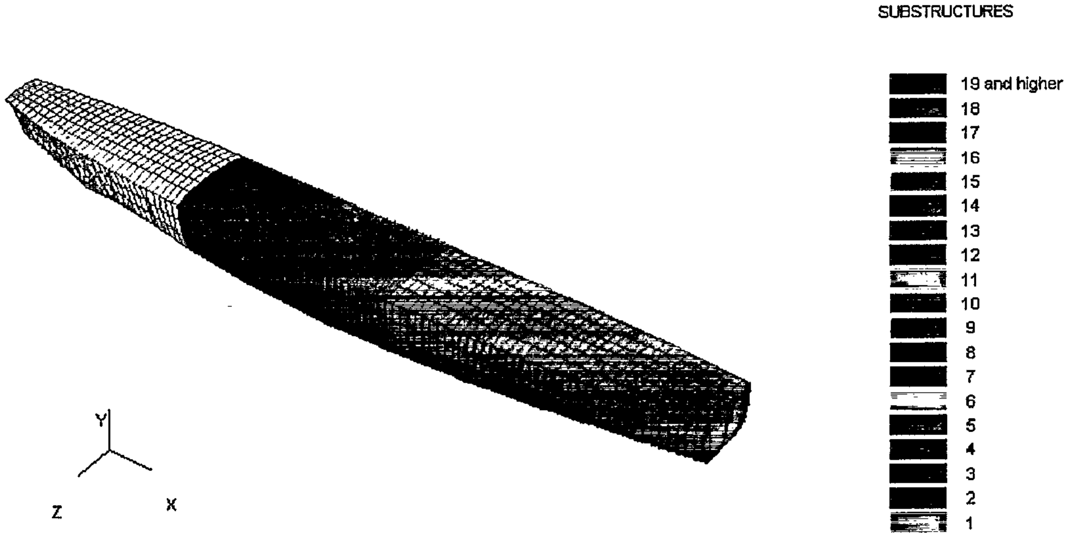

Figure 2: MAESTRO Model Substructures

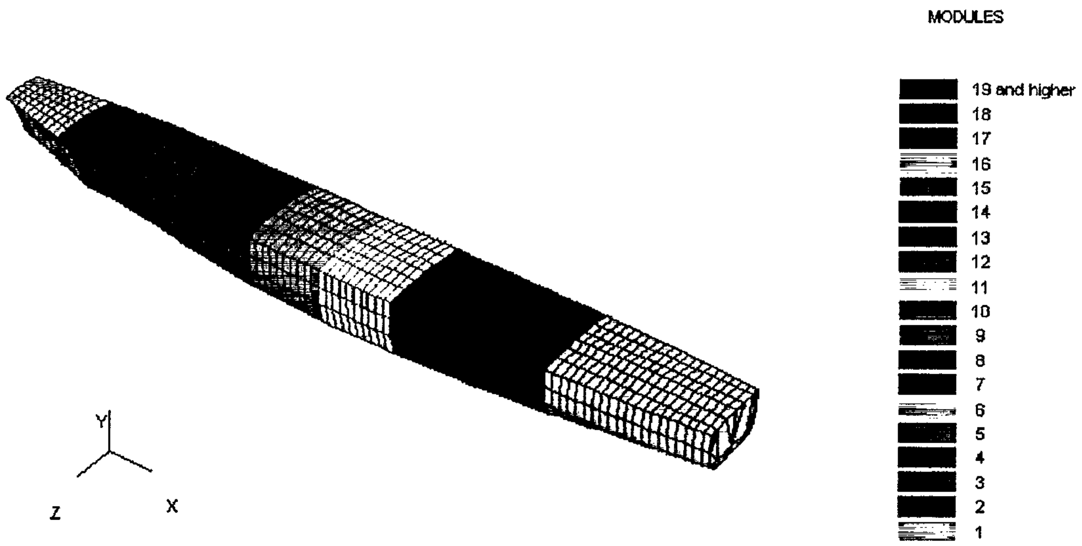

Figure 3: MAESTRO Model Modules

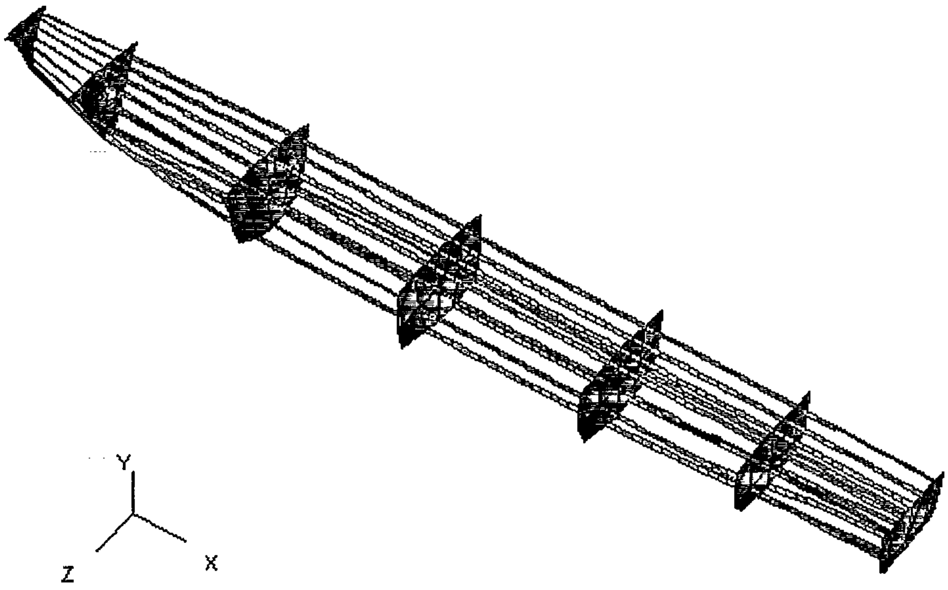

Figure 4: MAESTRO Model Girders

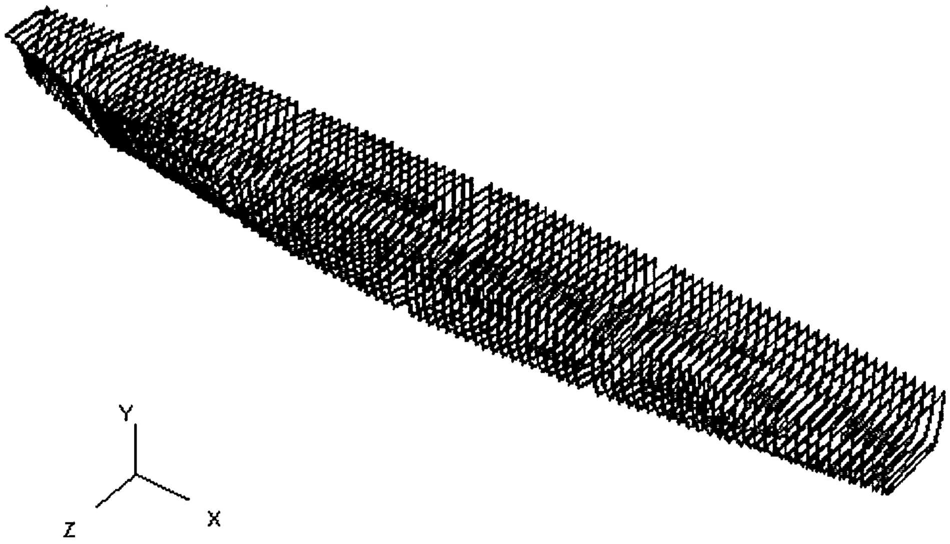

Figure 5: MAESTRO Model Tranverse Frames

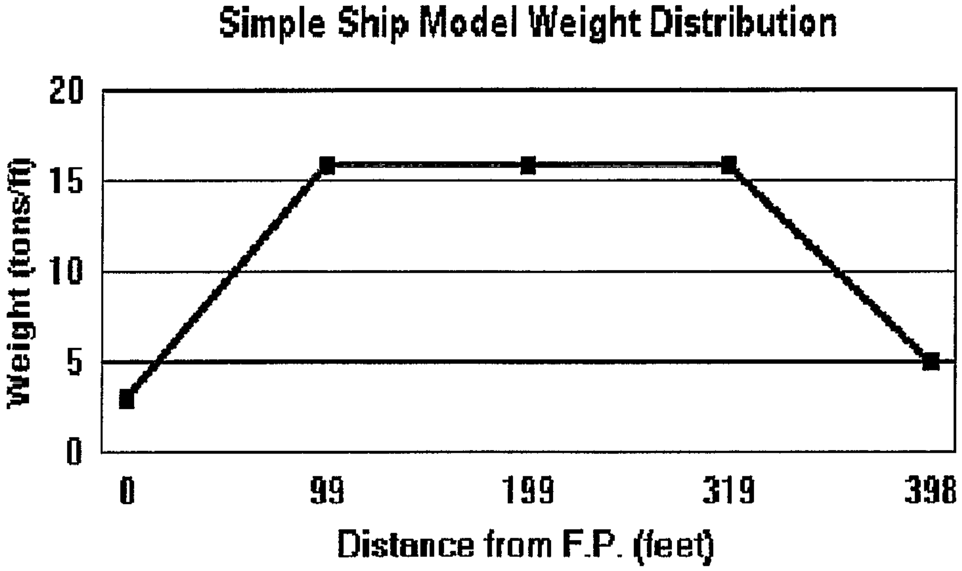

Figure 6: Structural and Non-Structural Weight Distribution

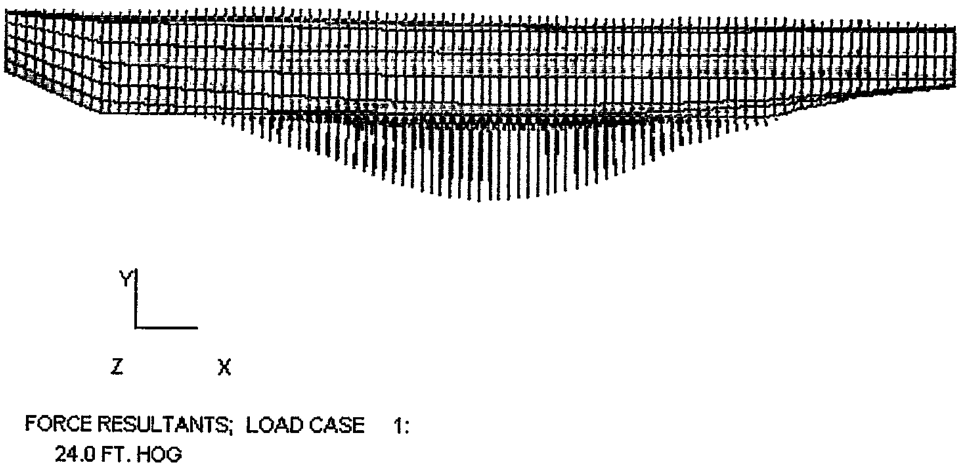

Figure 7: Longitudinal Load Distribution on the Model

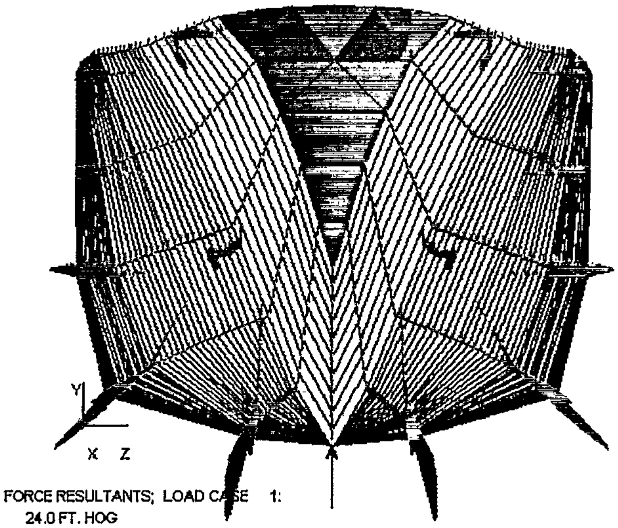

Figure 8: Tranverse Load Distribution on the Model

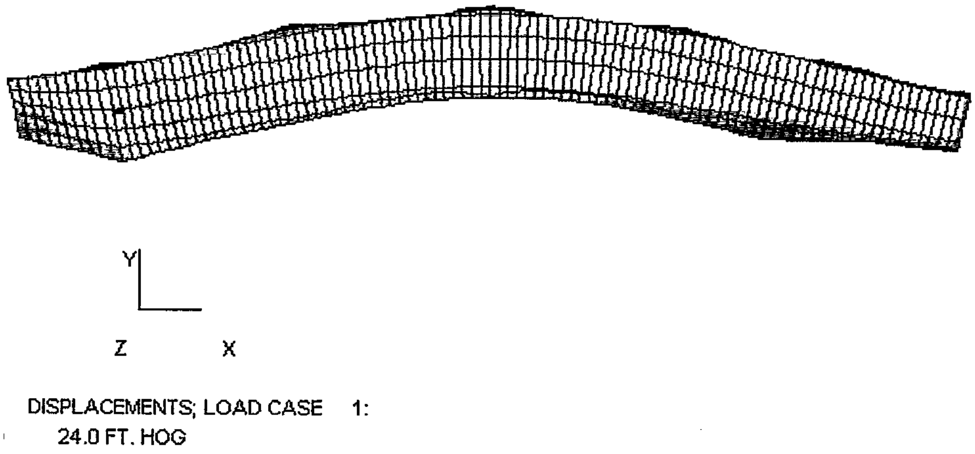

Figure 9: Hogging Displacement of the Model(magnified)

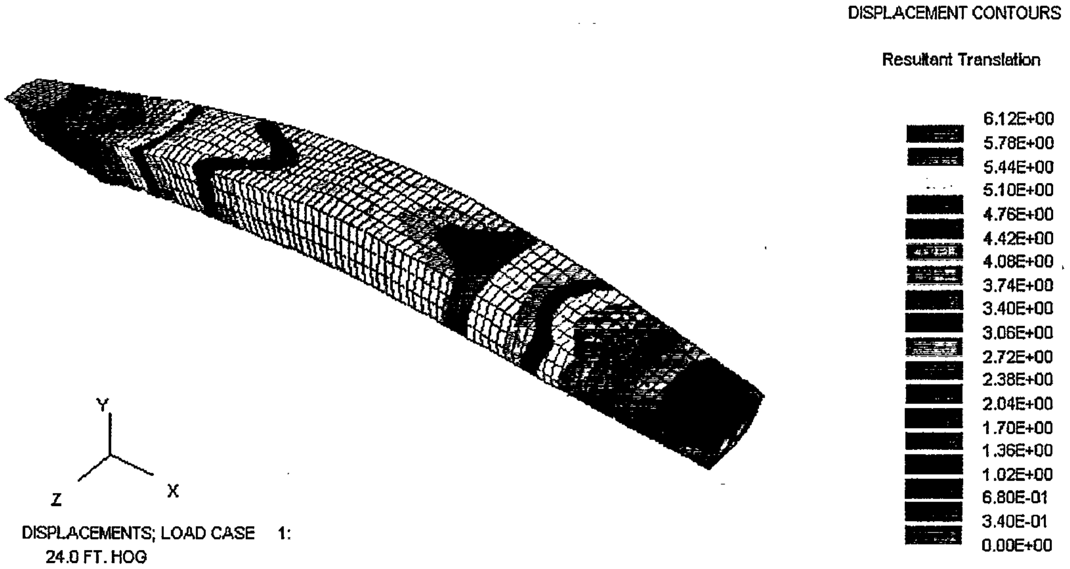

Figure 10: Displacements Contours (inches)

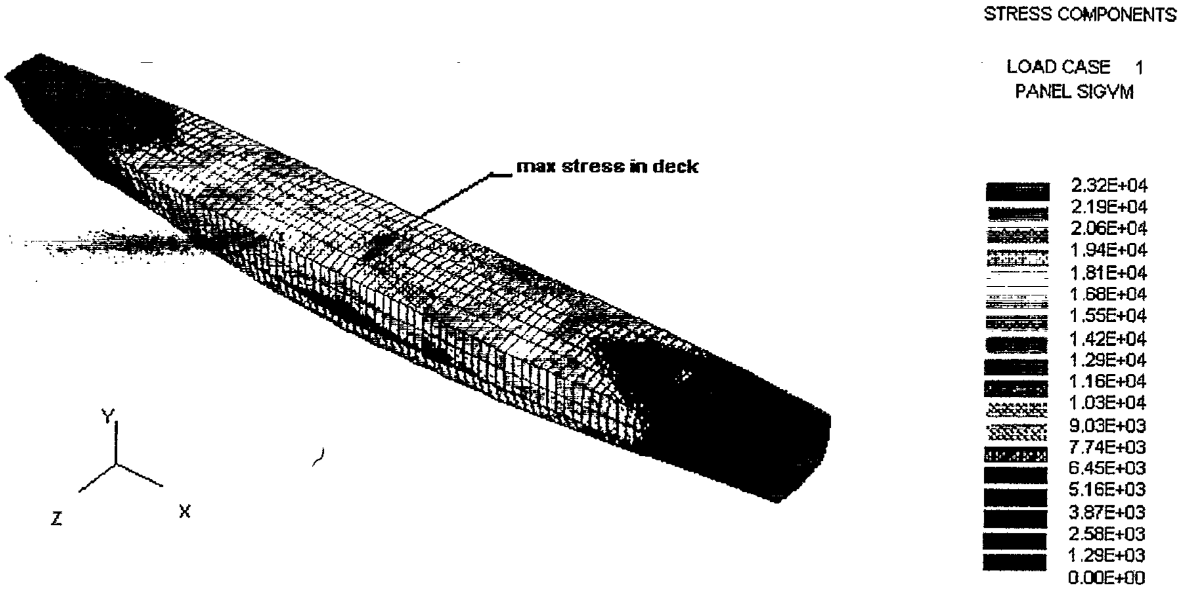

Figure 11: Von Mises Stresses (psi) in the Deck for Balance-on-a-Wave Loading

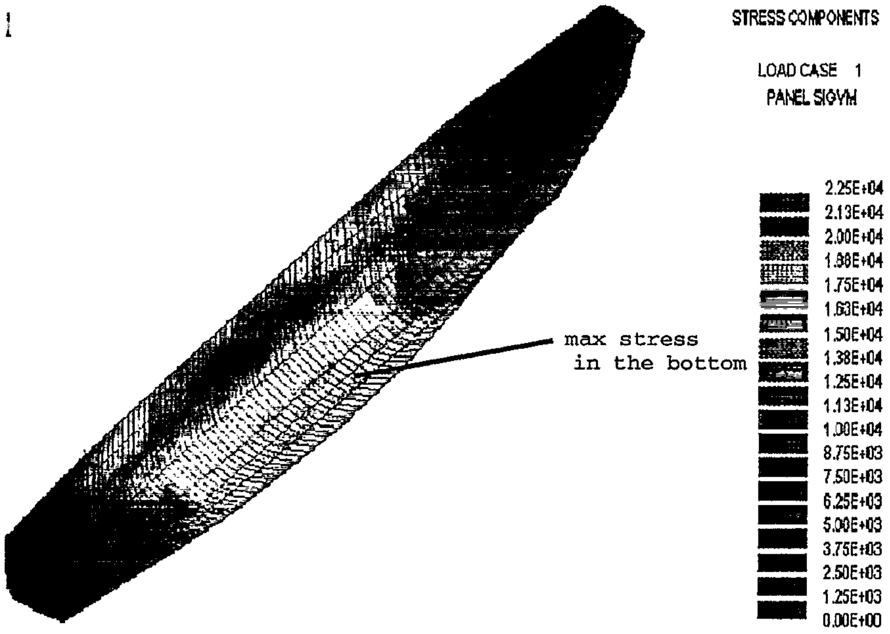

Figure 12: Von Mises Stresses (psi) in the Bottom for Balance-on-a-Wave Loading

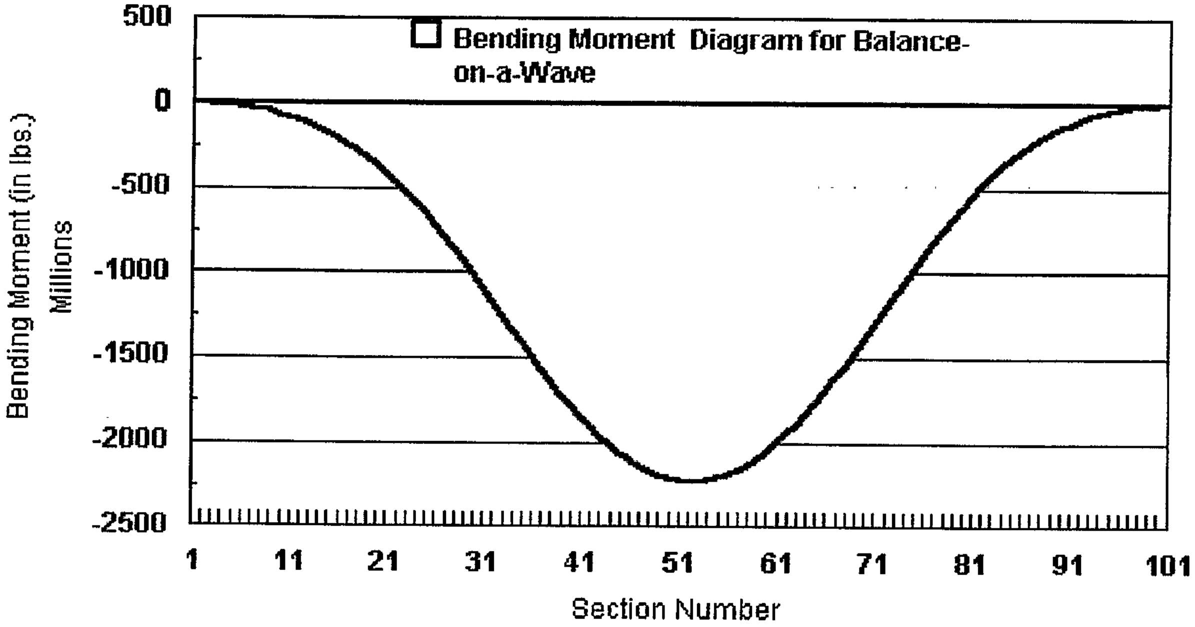

Figure 13: Bending Moment Diagram for Balance-on-a-Wave Loading

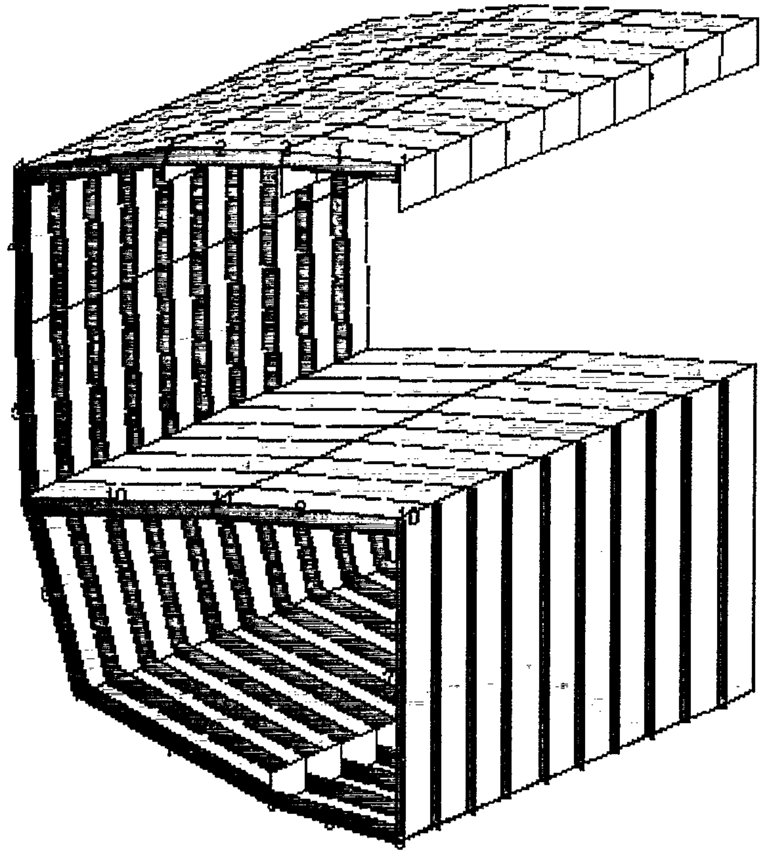

Figure 14: Half Section of Module 2 Substructure 2 Showing Strake Locations

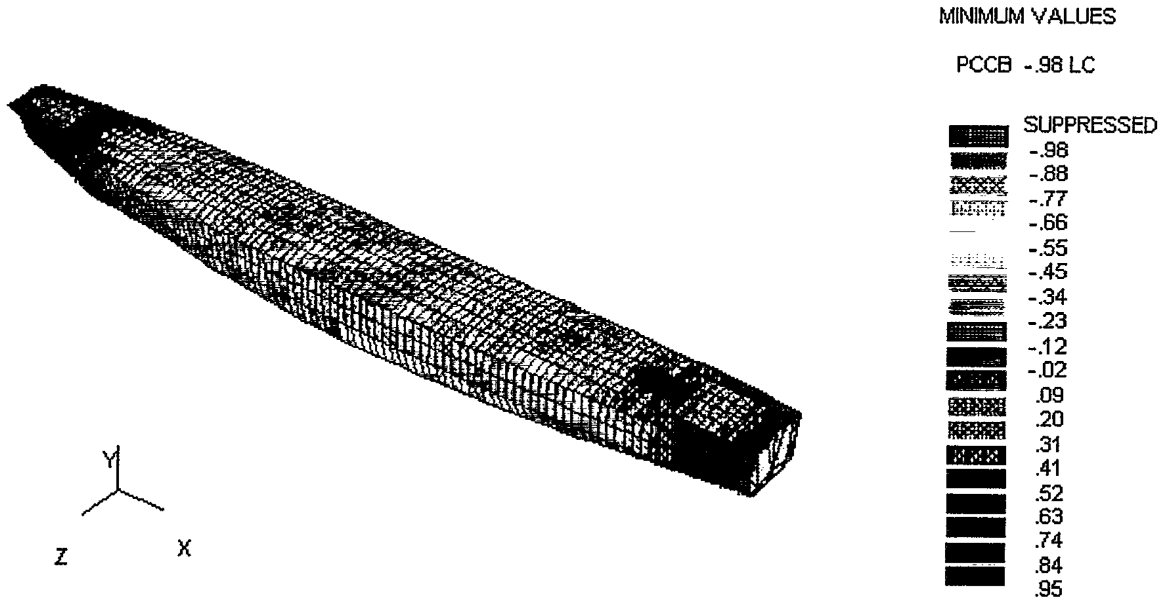

Figure 15: Minimum Adequacy Parameters in Hull for Balance-on-a-Wave Loading

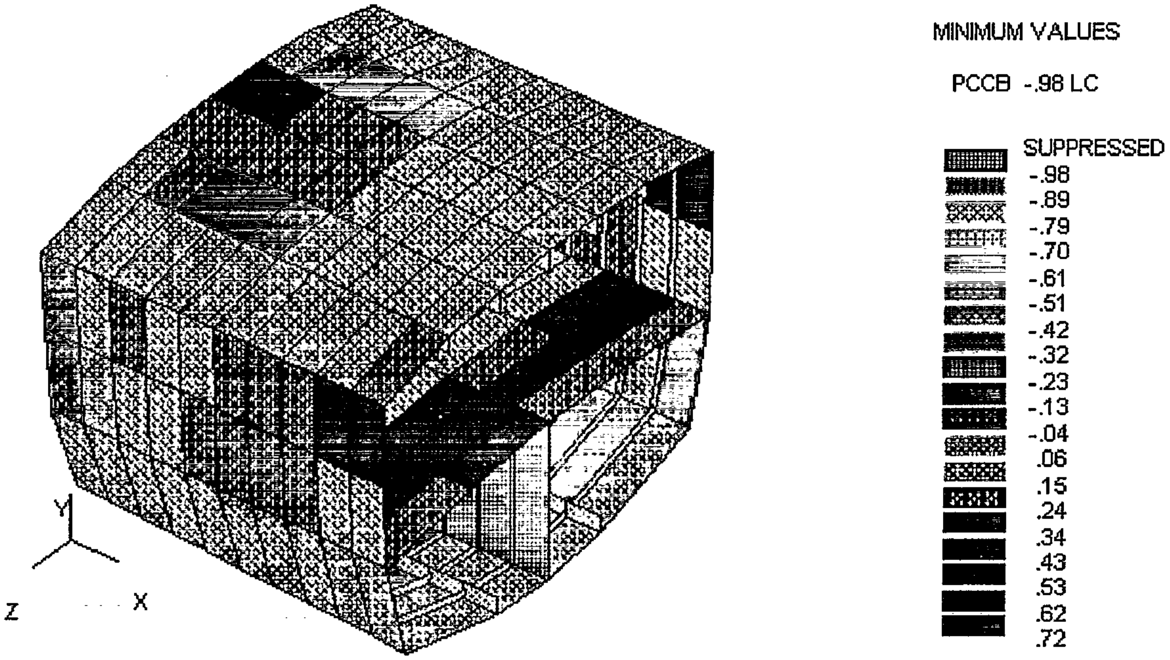

Figure 16: Minimum Adequacy Parameters on Deck of Module 2 Substructure 2

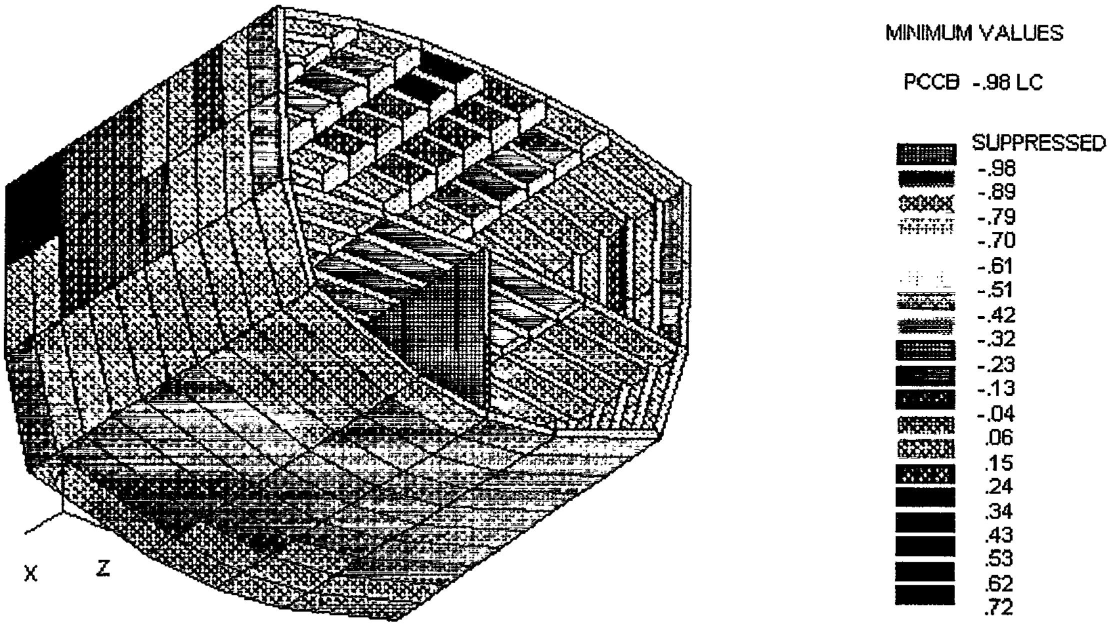

Figure 17: Minimum Adequacy Parameters on Bottom of Module 2 Substructure 2

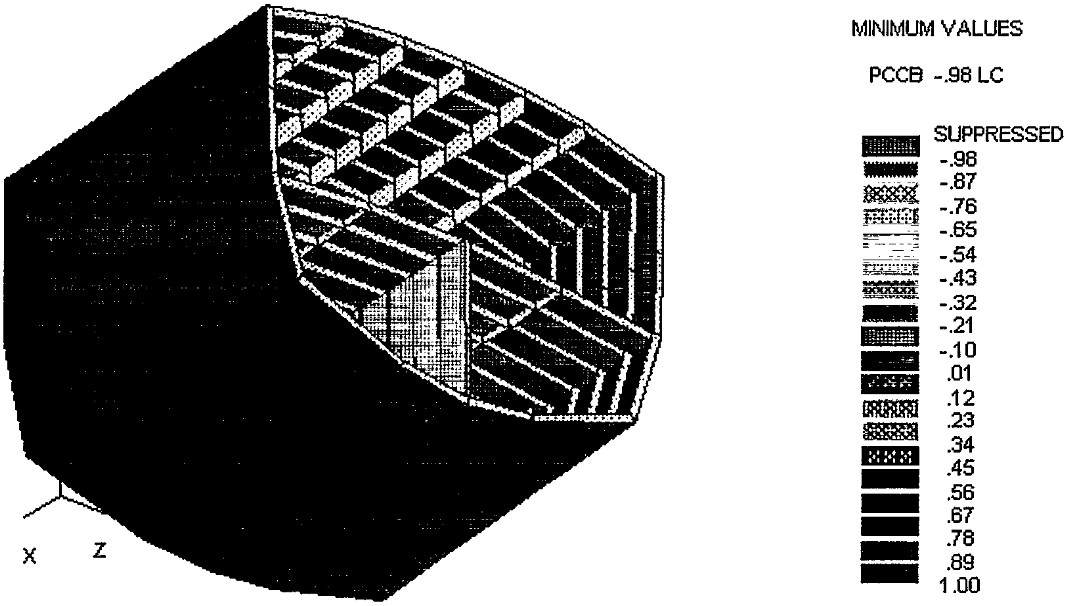

Figure 18: Adequacy of Longitudinal Bulkhead in Panel Collapse-Combined Buckling

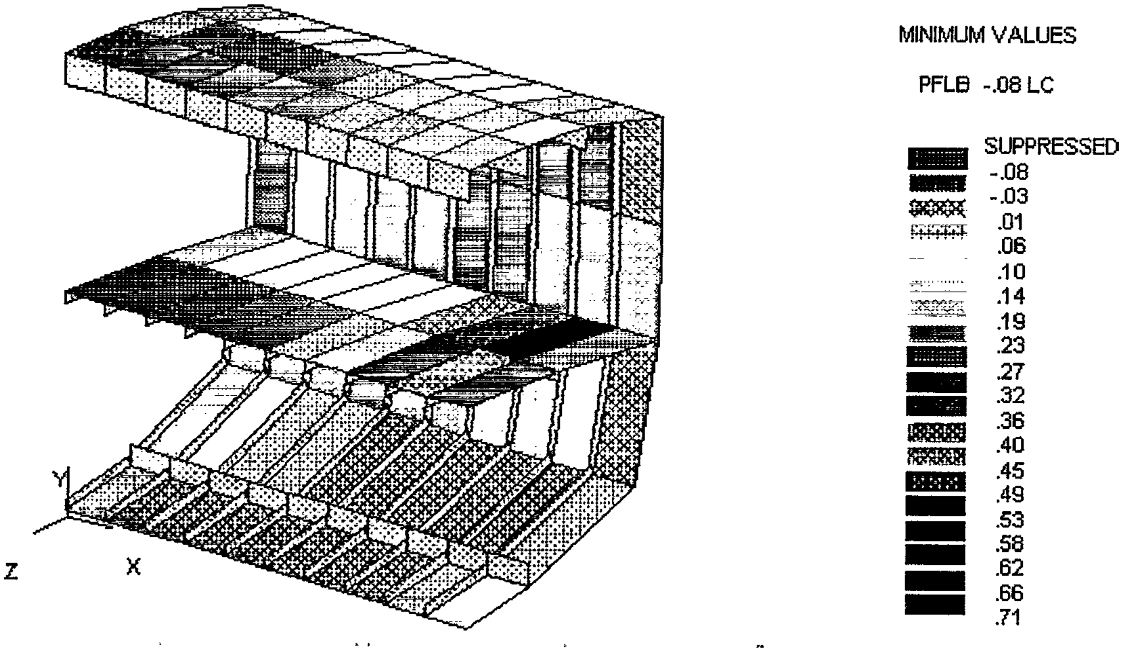

Figure 19: Minimum Adequacy Parameters of the Strakes without the Longitudinal Bulkhead

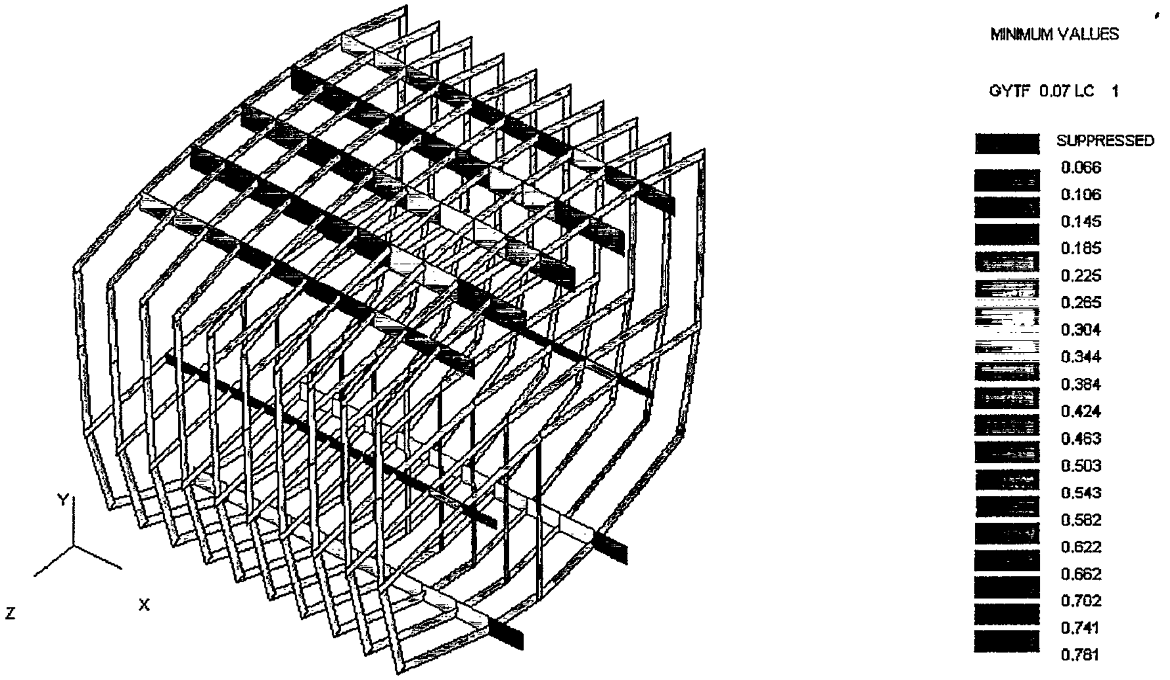

Figure 20: Minimum Adequacy Parameters of the Girders

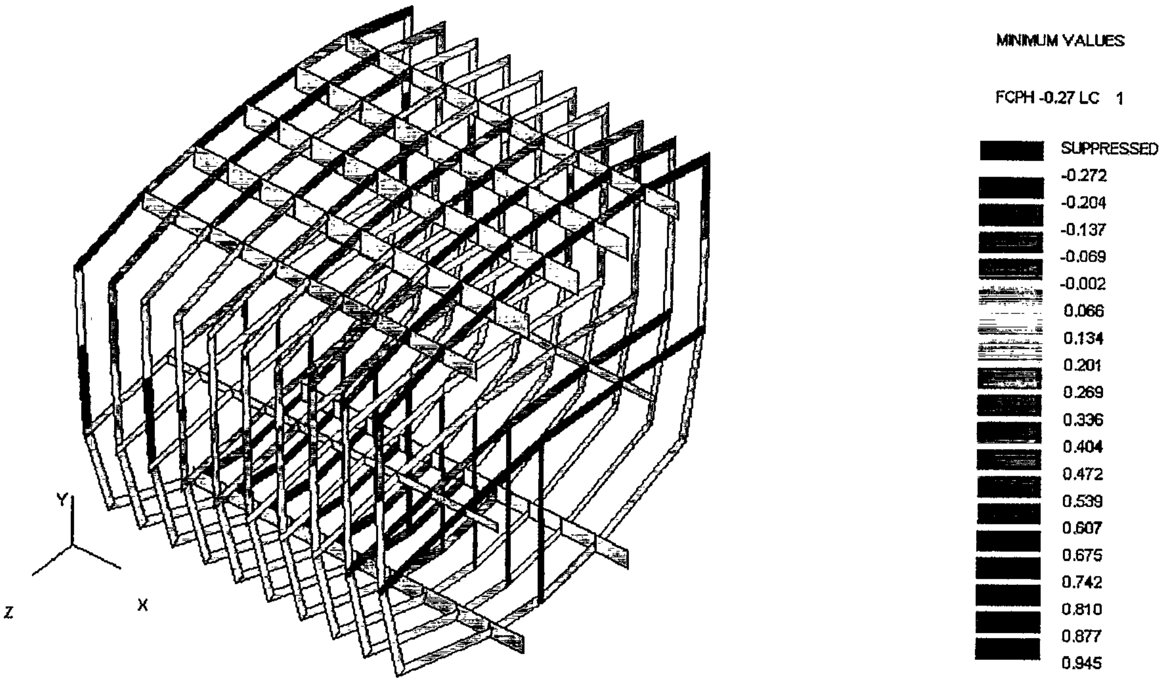

Figure 21: Minimum Adequacy Parameters of the Frames

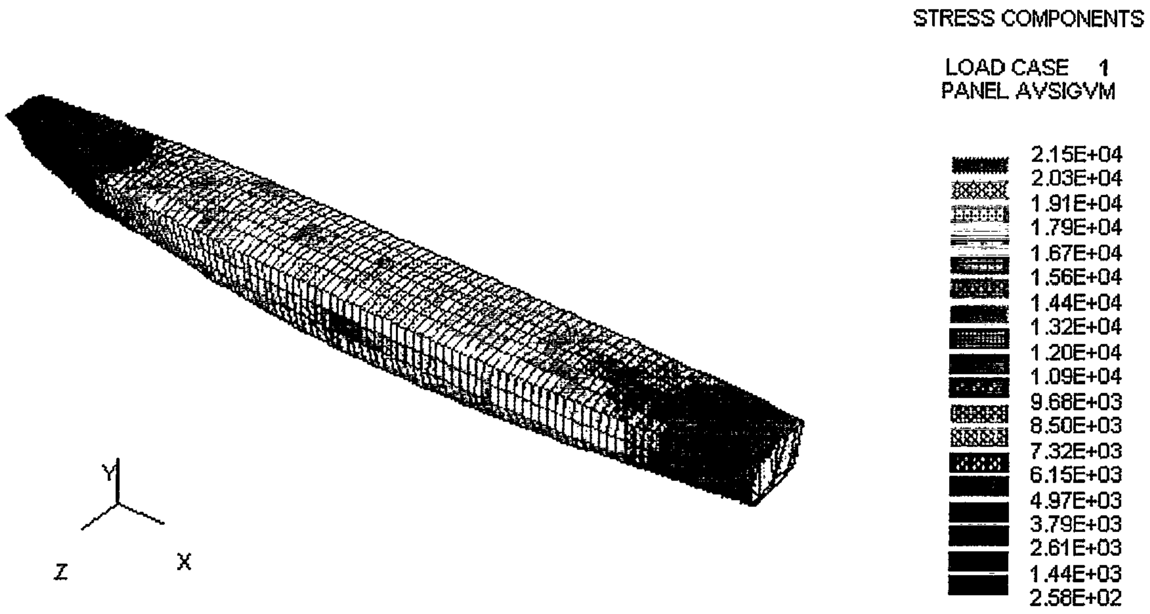

Figure 22: Von Mises Stresses (psi) in Deck of the Optimized Model

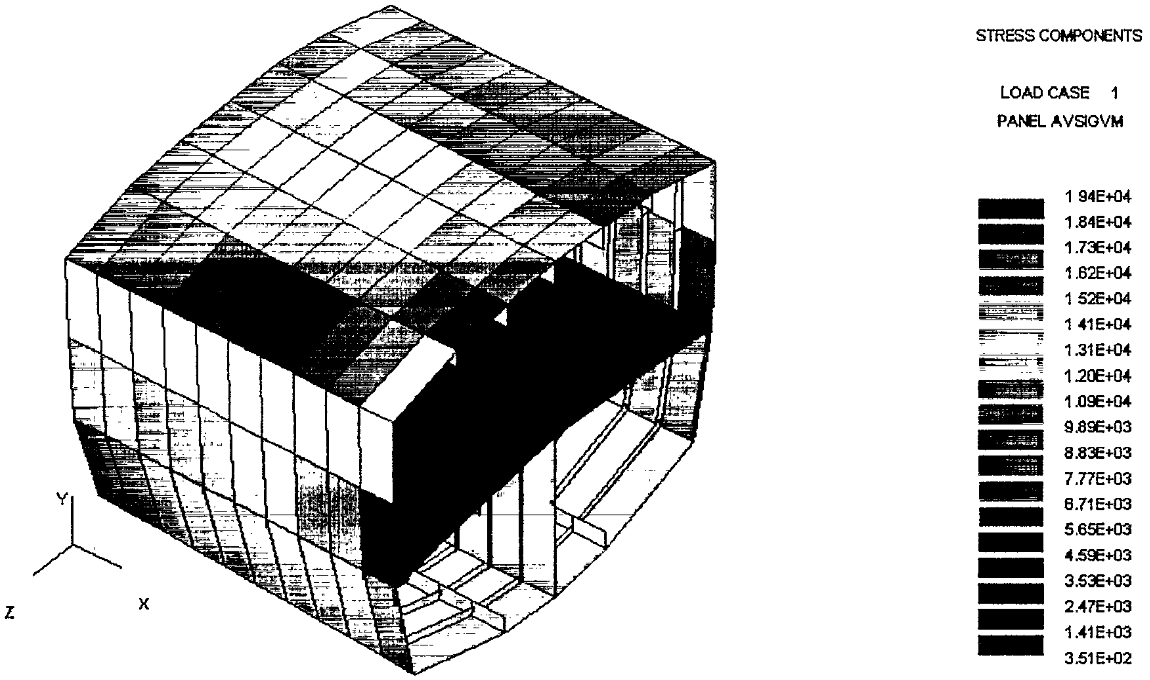

Figure 23: Von Mises Stresses (psi) in the Deck of Module 2 of Substructure 2

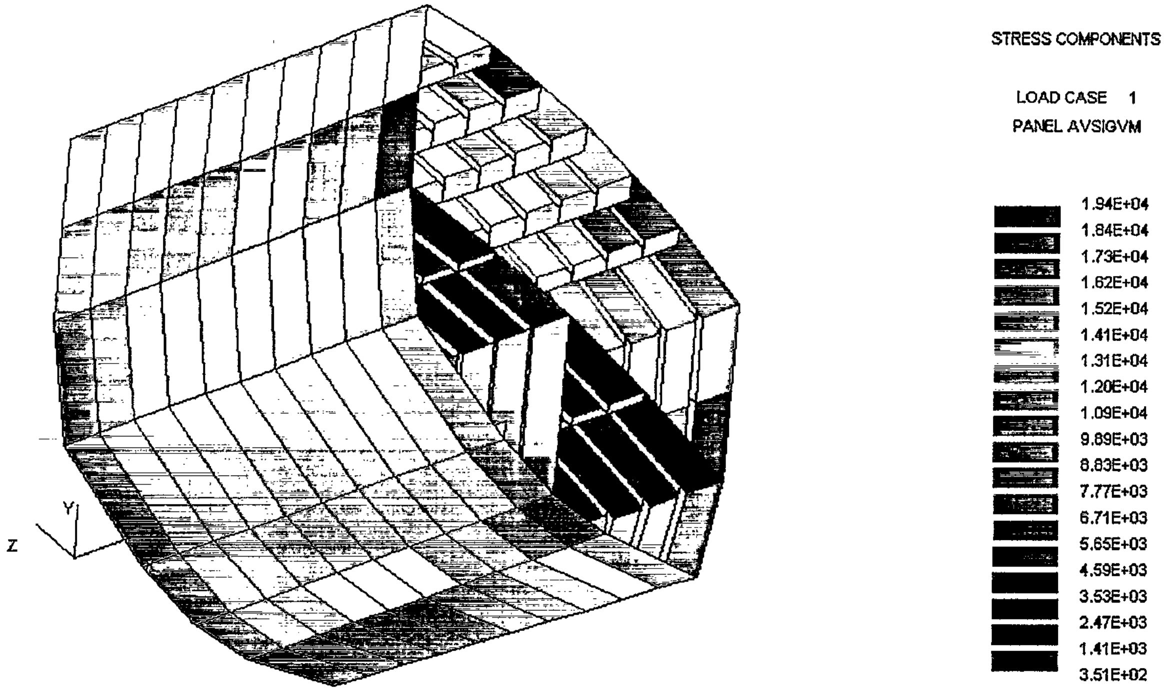

Figure 24: Von Mises Stresses (psi) in the Bottom of Module 2 of Substructure 2

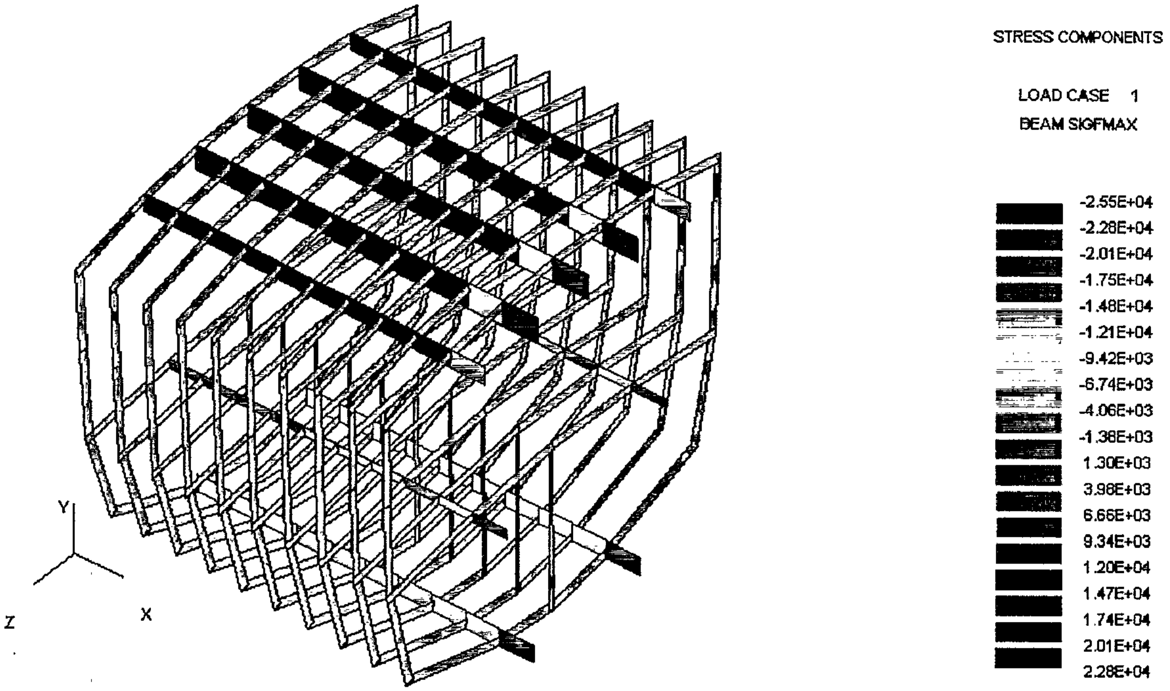

Figure 25: Maximum Combined Stresses in the Girder Flanges of Module 2 of Substructure 2

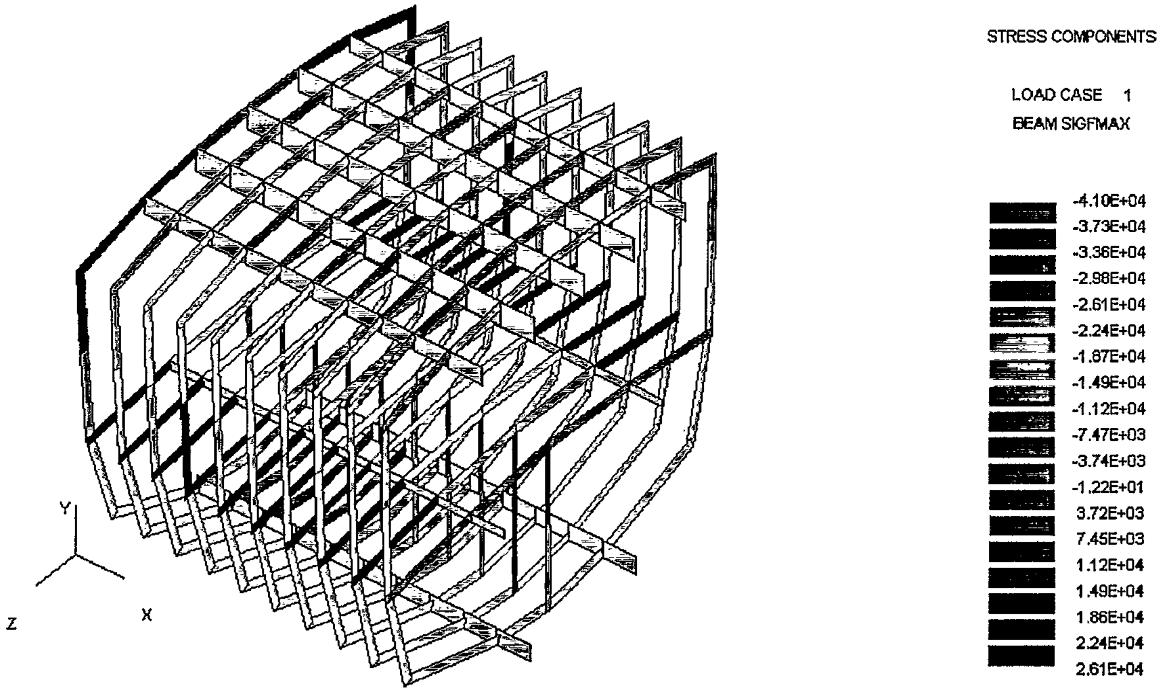

Figure 26: Maximum Combined Stresses in the Frame Flanges of Module 2 of Substructure 2

References

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[2] “MAESTRO/DSA,”Martec Ltd. Halifax, Nova Scotia.

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Optimization of a Simple Ship Structural Model Using MAESTRO

4. AUTHORS (Last name, first name, middle initial. If military, show rank, e.g. Doe, Maj. John E.)

D.R. Smith

5. DATE OF PUBLICATION (month and year of publication of document)

March 1999

6a. NO .OF PAGES (total containing information Include Annexes, Appendices, etc).

40

6b. NO. OF REFS (total cited in document)

2

7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered).

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9a. PROJECT OR GRANT NO. (if appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant).

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W7707-7-4749

10a ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity. This number must be unique to this document.)

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wave loading
optimization
adequacy parameters
stress analysis
ship design

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