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AL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20034

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STRUCTURAL DESIGN OF A 4000-TON STEEL SMALL WATERPLANE AREA TWIN HULL (SWATH) NAVAL SHIP

NATALE S. NAPPI

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COMPUTATION AND MATHEMATICS DEPARTMENT
RESEARCH AND DEVELOPMENT REPORT

NOVEMBER 1972

Report 3886

STRUCTURAL DESIGN OF A 4000-TON STEEL SWATH NAVAL SHIP

Report 3886

The Naval Ship Research and Development Center is a U. S. Navy center for laboratory effort directed at achieving improved sea and air vehicles. It was formed in March 1967 by merging the David Taylor Model Basin at Carderock, Maryland with the Marine Engineering Laboratory at Annapolis, Maryland.

Naval Ship Research and Development Center
Bethesda, Md. 20034

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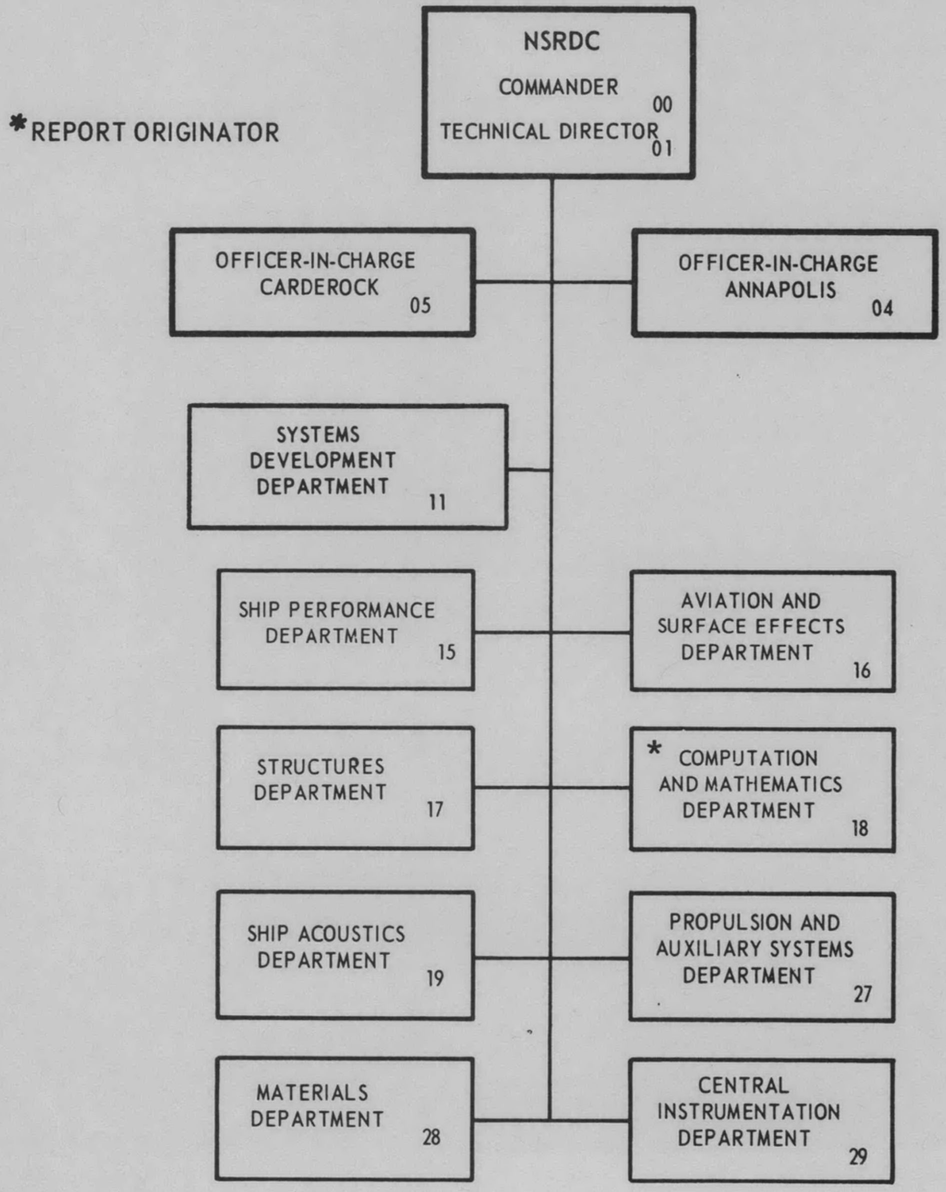

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DEPARTMENT OF THE NAVY
NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER
Bethesda, Maryland 20034

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ABSTRACT

This report describes the procedure used to perform a structural design and weight study for a 4000-ton Small Waterplane Area Twin Hull (SWATH) naval ship. This ship was designed to resist wave-induced and still water primary transverse and longitudinal bending moments. An approximate method for analysis was performed to check the design for torsional loads. Secondary loads consisted of slamming loads, external hydrostatic heads, arbitrary minimum shell pressure loads for shell plating not submersed, live loads, and structural dead loads. The studies were performed using different steel properties (MS, HTS, HY80, HY100) and different transverse frame spacings. The weights are summarized and a complete design is illustrated showing all the scantlings (plate pieces and tee beams) for the 2-foot transversely framed HTS SWATH ship.

ADMINISTRATIVE INFORMATION

This report is related to the structural design and loads studies for the Small Waterplane Area Twin Hull (SWATH) ship performed under the NSRDC in-house independent exploratory development program ZFXX412001, Element #62713.

I. INTRODUCTION

The Navy is currently investigating the small waterplane area twin hull (SWATH) ship structure in order to quantify and study the effect of changes in the structural weight of the ship. Both aluminum and steel structures are under study. Seaway loading conditions are also under investigation. This report is concerned with the design procedures used to optimize the structural weight for the steel ship.

The structural design and concomitant weight studies for the SWATH ship, shown in Figure 1., used the following major loading conditions:

- Transverse bending moments
- Longitudinal bending moments
- Torsional moment

The structural design study was performed in three phases, one for each loading condition. The minimum plate scantlings determined by the transverse bending load design study were used as the initial plate scantlings for the longitudinal bending load design study. The final set of minimum scantlings (plate and beams) provided by these design studies was used to determine the structural properties (e.g., moment of inertia, polar moment of inertia, area, etc.) needed to perform an approximate structural analysis for the torsional loads.

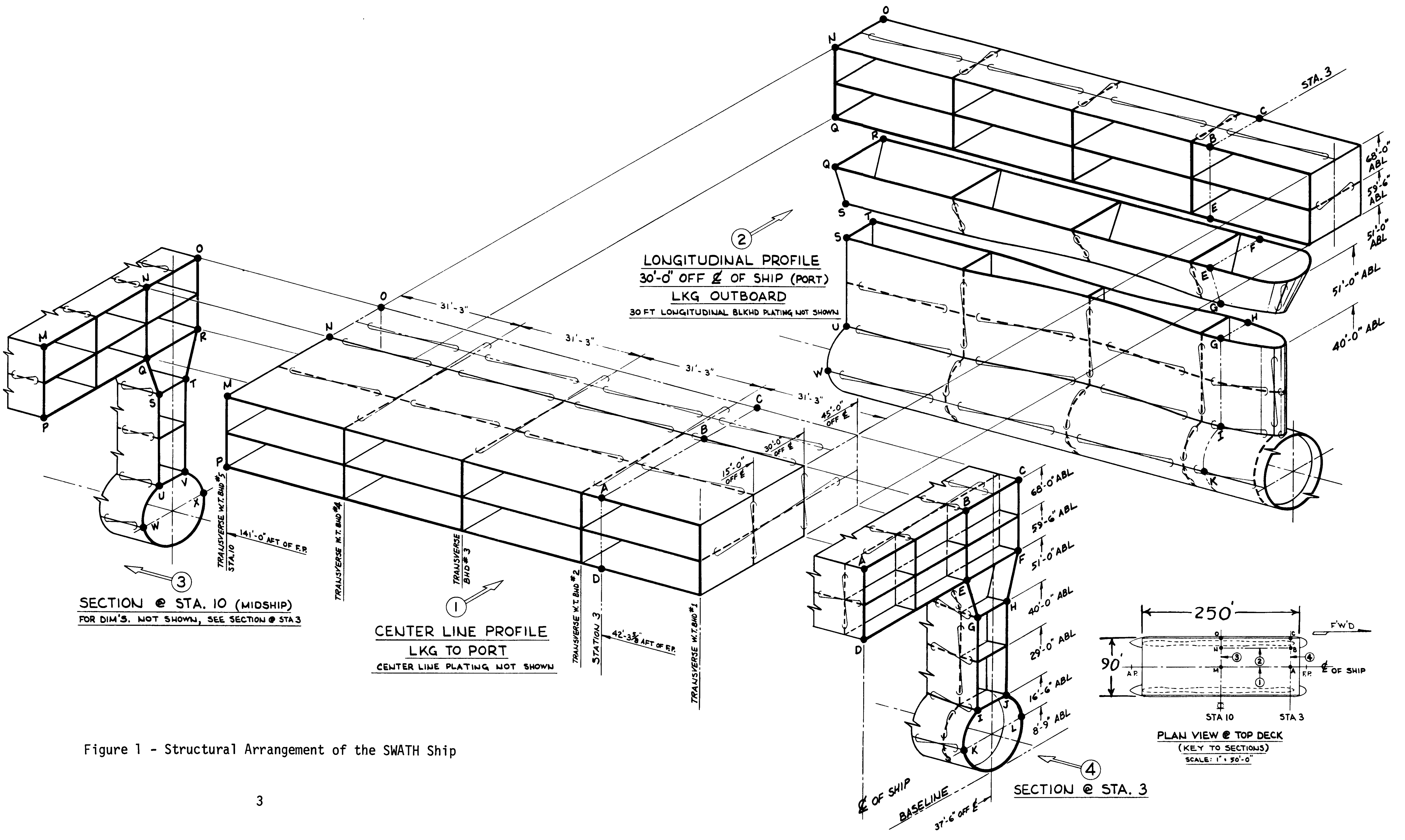

Figure 1 - Structural Arrangement of the SWATH Ship

The ship's structure was not designed or analysed for the following loads because the distribution and magnitude of these forces were not available at the time of this study:

- Combination of longitudinal and transverse bending moments.
- Wave-induced transverse vertical shear at the ends of the bridge structure.

Upon completion of the structural design and approximate torsional analysis, the weights and densities (lb/cu ft) were determined for the bridge structure, struts, and lower hulls.

Throughout the process (i.e., design, analysis, and weight studies) U.S. Navy-specified properties of the following steels were used:

- MS
- HTS
- HY80
- HY100

Different transverse beam spacings were also investigated for the HTS and HY100 materials.

The results of this study have been integrated into a systems design synthesis for a 4000-ton SWATH ship. This synthesis shows that conventional plate and stiffener construction techniques, using combinations of HTS and MS steel for the primary structure, result in ships which have acceptable useful payload plus fuel characteristics.

II. DESIGN PROCEDURE

A. PRINCIPAL DESIGN TOOL

1. Midship Section Computer Program

The principal design tool used on the SWATH ship structure for both the transverse and longitudinal bending loads is a modified version of the midship section design computer program, MIDSHIP.[1] This program contains the decisions necessary to determine an initial set of minimum weight scantlings for the shell, deck, and longitudinal bulkhead segments. The program then tests these scantlings to determine whether they comply with the design criteria, as defined by current U.S. Navy design practices, and increases the scantlings if the criteria are not satisfied. Modification of the scantlings continues until the scantlings developed do not change the primary stress assignment. The final scantlings are of minimum weight and structurally adequate.

A highly simplified diagram showing the design program modules in MIDSHIP[1] is given in Figure 2. Each module shown has an elaborate modular structure of its own. The tasks associated with these modules are:

- Read in data and print out these data for verification.
- Determine initial sizes for shell, deck, and longitudinal bulkhead scantlings.
- Select minimum weight scantlings and check the structure for stress consistency, i.e., whether the output primary stresses equal the input primary stresses to within a specified tolerance.

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[1] Nappi, N. S. and Lev, F. M.. "Midship Section Design for Naval Ships", NSRDC Report 3815 (1972).

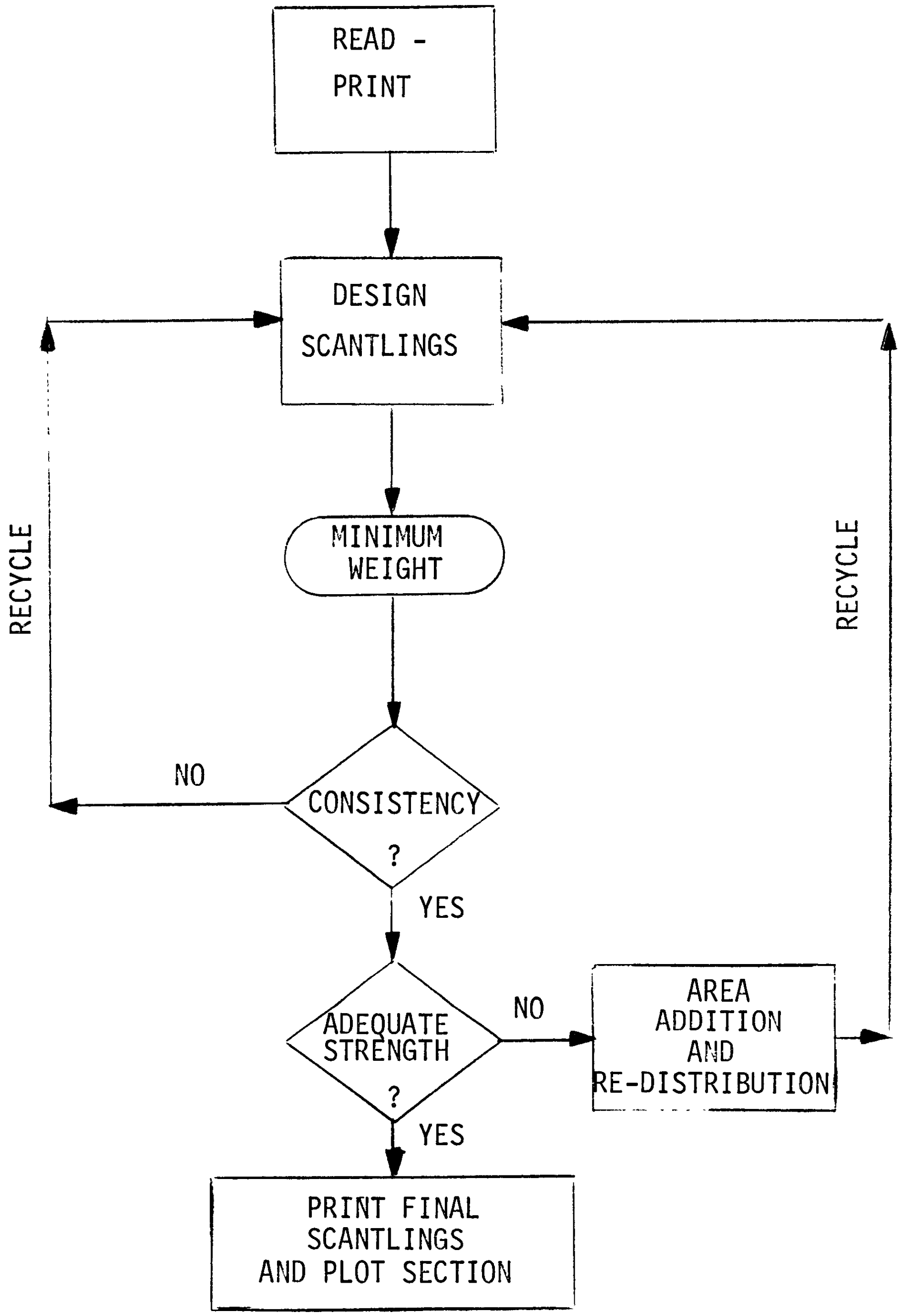


Figure 2 - Block Diagram of Midship Section Design Program Modules

- Once a stress-consistent design is achieved, check for adequate primary girder strength. If the structure is adequate, (i.e., if the primary stresses are below the limiting stress) cycling terminates and the results are printed. If the structure is inadequate, the area addition module is used to modify and redistribute the scantlings of the cross section.
- Iterate the design process (scantling refinement to assure compatibility) until the scantlings are minimum weight and structurally adequate.
- Produce a Stromberg-Carlson 4020 plot of the section, if requested, and a printout of the final section scantlings.

  (Note: For this design study the plot option was not elected.)

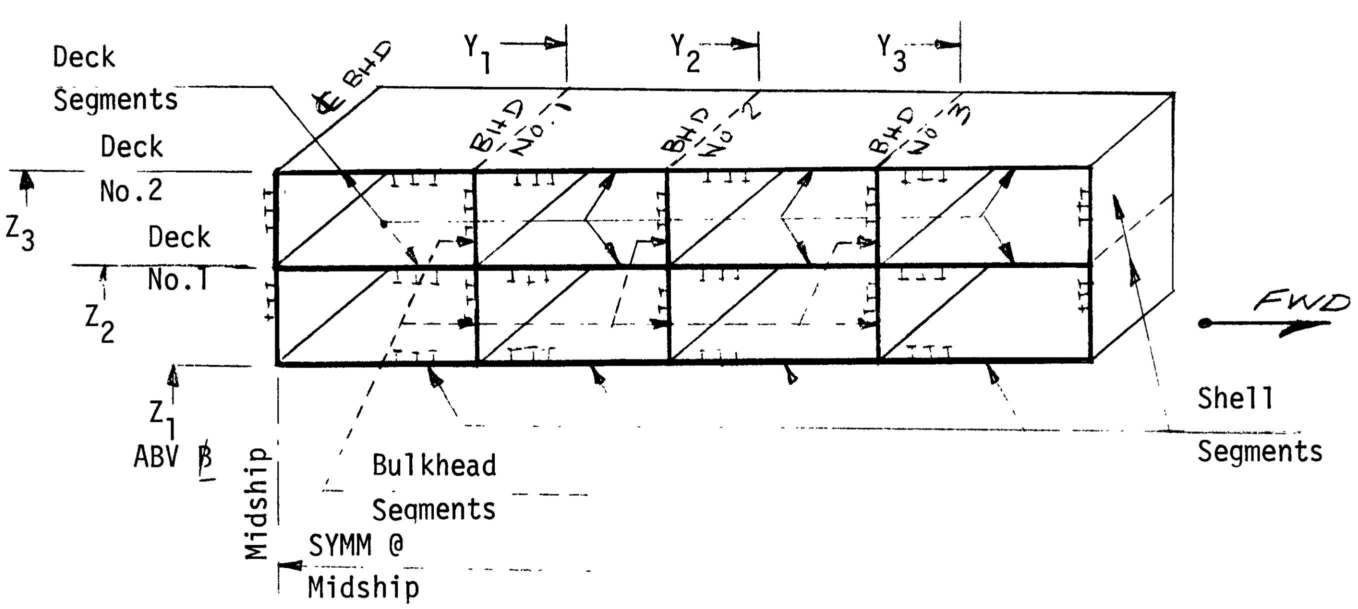
2. Main Structural Components

The program, MIDSHIP, is designed to treat any longitudinally framed, symmetrical cross section with any combination of decks, platforms, and longitudinal bulkheads (see Figures 3a and 3b). Major structural components (i.e., shell, longitudinal bulkhead, and deck) as well as the imposed design loads are described in the paragraphs which follow.

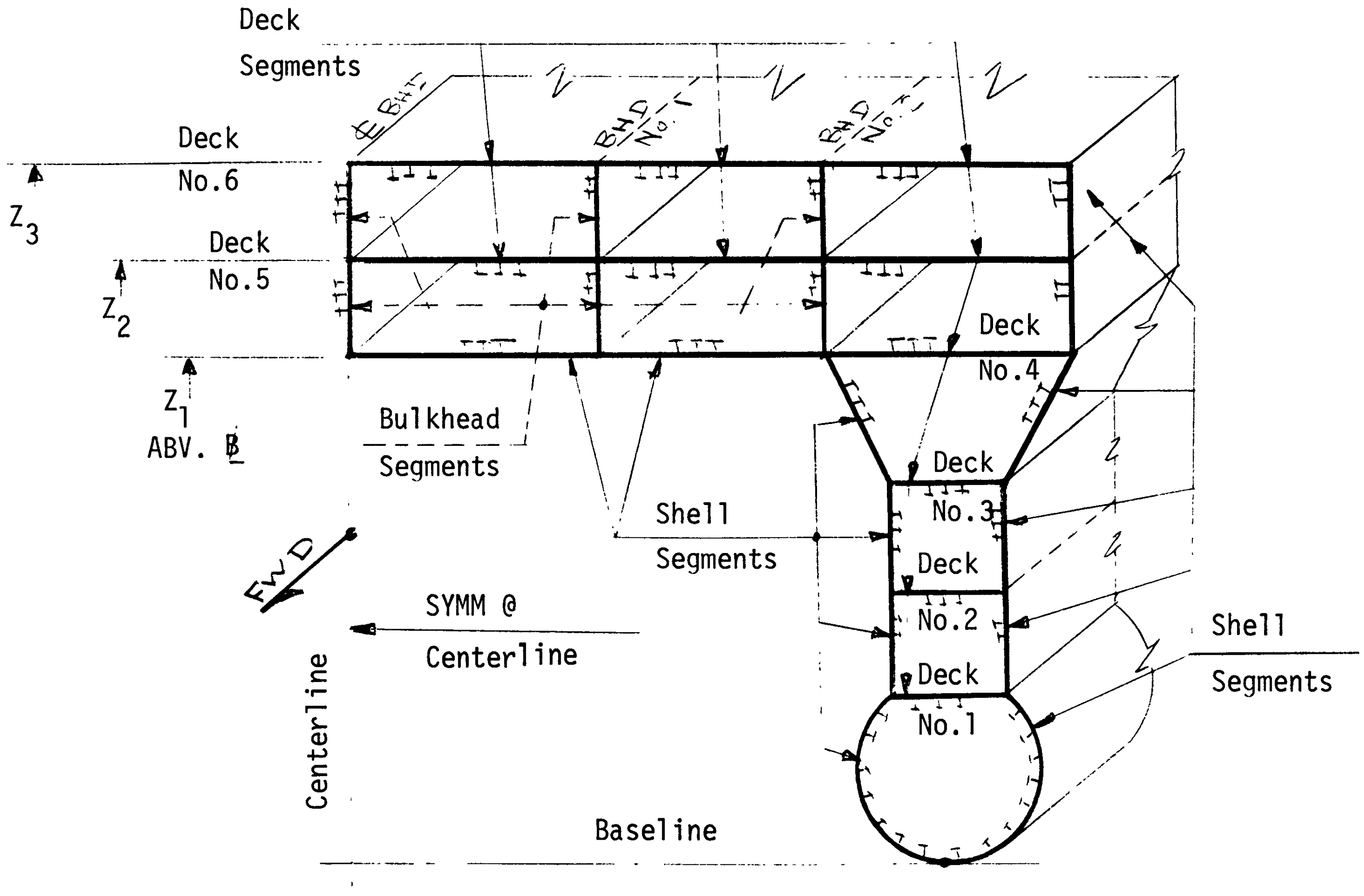
a. Shell Segments. Shell segments may be either straight or curved. MIDSHIP treats curved segments as either quadratic or cubic functions and computes the girths accordingly.

Each shell segment was designed to withstand the following loads:

1) Primary stresses plus external hydrostatic head.
2) Tank overflow head plus dead load (for shell segments bounding a tank).



a. Longitudinal Profile Section



b. Transverse Section

Figure 3 - Structural Element Combinations

b. Longitudinal Bulkhead Segments. Each longitudinal bulkhead segment was treated by MIDSHIP as a straight line on sectional drawings and was designed to withstand the following loads:

1. For bulkhead segments between normal and/or vital spaces:
    - Primary stresses plus on-half dead load
    - Damage head plus one-half dead load
2. For bulkhead segments between tanks and either normal or vital spaces:
    - Primary stresses plus tank top head plus one-half dead load.
    - Tank overflow head plus one-half dead load
    - Damage head plus one-half dead load
3. For bulkhead segments between two adjacent tanks:
    - Primary stresses plus tank top head plus one-half dead load
    - Tank overflow head plus one-half dead load

c. Deck Segments. Each deck and/or platform segment was treated by MIDSHIP as a straight line on sectional drawings and was designed to withstand the following loads:

1. For deck and platform segments between normal and/or vital spaces:
    - Primary stresses plus live loads plus dead load
    - Damage head plus dead load
2. For deck and platform segments between two tanks:
    - Primary stresses plus tank top head plus dead load
    - Tank overflow head plus dead load
3. For deck and platform segments with a tank below either a normal or vital space:
    - Primary stresses plus live loads plus dead load
    - Tank overflow head plus dead load
    - Damage head plus dead load
4. For deck and platform segments above either a normal or vital space:
    - Primary stresses plus tank top head plus dead load
    - Tank overflow head plus dead load
    - Damage head plus dead load

5. For weather deck segments:
    - Primary stresses plus live load (weather deck head) plus dead load

Platforms are designated as intercostal decks and scantlings are derived from local loads only. The primary stresses are set equal to zero.

Table 1 shows the maximum allowable number of structural elements per side for a symmetrical cross section.

TABLE 1 - MAXIMUM ALLOWABLE NUMBER OF ELEMENTS PER SIDE

Structural Element	Maximum Number
Shell segments	20
Longitudinal Bulkheads (including Centerline bulkhead if any)	7
Segments per Longitudinal Bulkhead	15
Decks and Platforms Combined	12
Segments per Deck or Platform	8

3. Program Operation

Using the minimum hull scantlings derived from the constant secondary (local lateral) loads and the assumed primary hull girder stresses, the properties of the section (e.g., moment of inertia, area, section moduli, location of the neutral axis, etc.,) are determined. The actual primary hull girder stresses are then determined using the supplied bending moments and the computed section moduli. The actual (output) primary stresses and the assumed (input) primary stress are then compared and, if these stresses are within the specified tolerance of each other, the structure is accepted. If they are not, a new stress schedule is developed and revised scantlings are determined. This process is repeated until the actual (output) stresses are within the specified tolerance of the assumed (input) stresses. The resulting section scantlings are considered structurally adequate if the primary stresses at the upper and lower flanges are below the limiting stress. For this study the limiting stress was assumed equal to the yield strength of the material.

B. DESIGN OF LONGITUDINAL SECTIONS TO RESIST TRANSVERSE BENDING MOMENTS

1. Cross Section Description

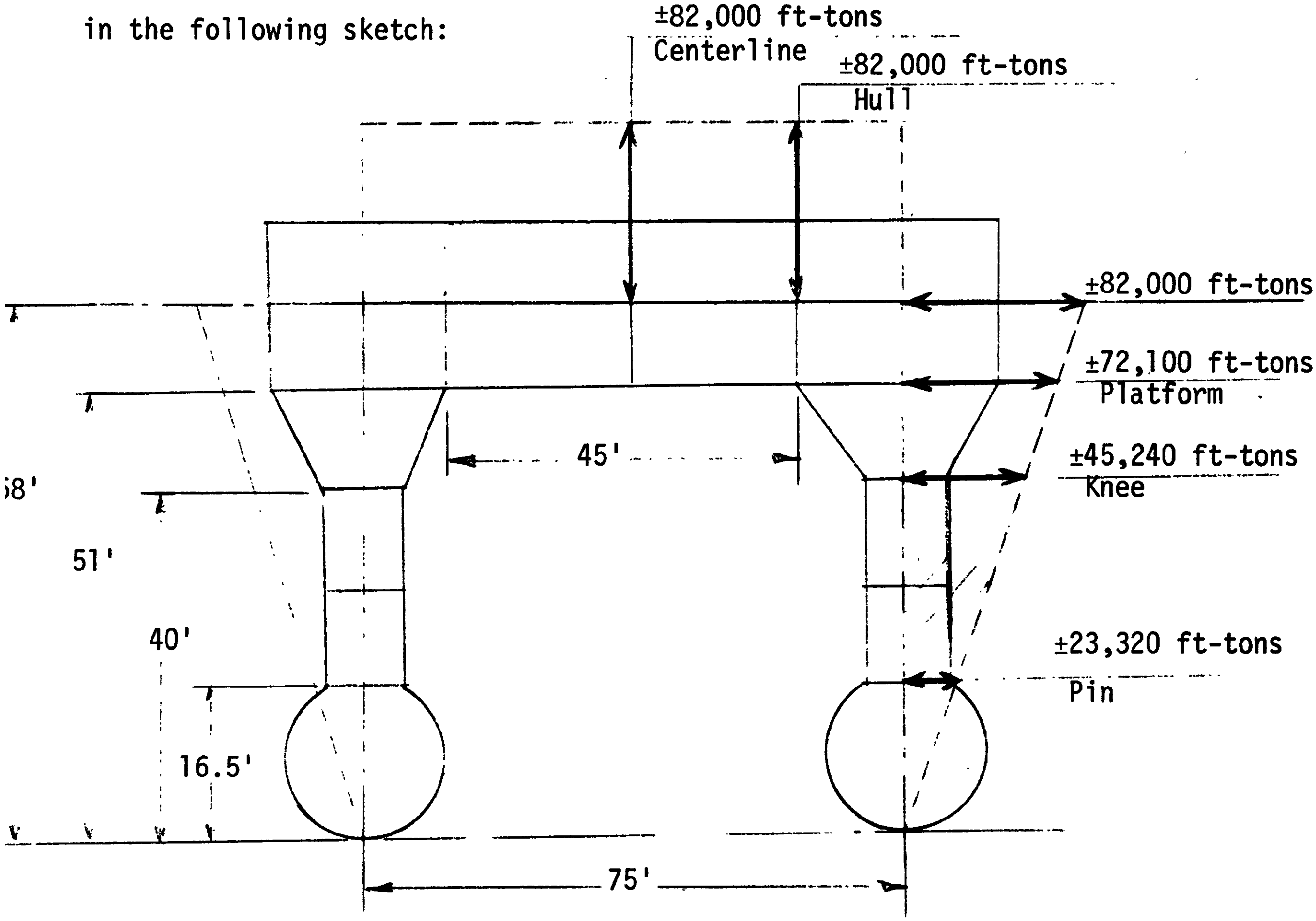
The ship was divided into five longitudinal sections for the transverse load study. These sections(see Figure 1) are defined as follows:

Centerline Section,	MADP	Bridge Structure
Hull Section,	NBEQ	
Platform Section,	QRFE	Struts
Knee Section,	STHG	
Pin Section,	UVJI	

The transverse bulkhead plating and the deck and/or shell plating were assumed to act as the webs and flanges, respectively, of a box girder for each section. These girders were designed to resist wave-induced bending moments with whipping, still water bending moments due to dead loads with inertia effects, secondary slamming loads, hydrostatic head, live loads, axial loads (where applicable), and shear loads (where applicable).

2. Design Loads (Primary and Secondary)

a. Primary Design Transverse Bending Moments. The wave-induced transverse bending moments (without whipping) were defined by Mr. John Andrews* (Code 1730). The moments were distributed as shown in the following sketch:



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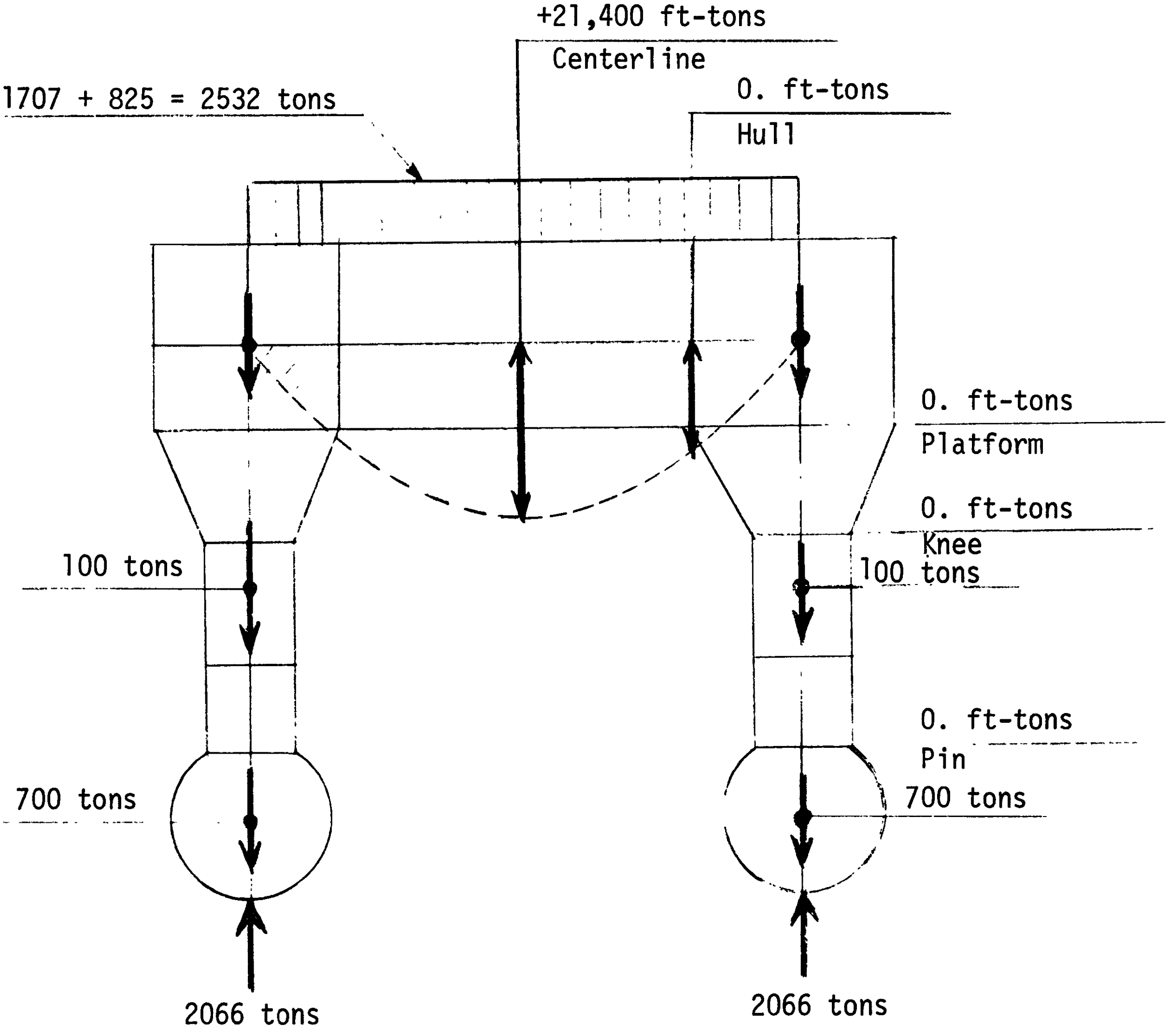
* Unpublished report by Andrews, J.N., "Load Estimates for the Low-Waterplane Catamaran Design," NSRDC, Feb 1972.

The still water bending moment (without heave) was determined using the static dead weight distribution. This bending moment was assumed to be distributed as shown here:



The combined design primary transverse bending moments used in MIDSHIP[1] are given in Table 2.

TABLE 2 - DESIGN PRIMARY BENDING MOMENTS (TRANSVERSE)

Section	Wave Induced Hog & Sag (ft-tons)	Still Water Sag (ft-tons)	Design Bending Moments* (ft-tons)	
			Hog	Sag
Centerline	±82,000	+21,400	- 93,000	+153,000
Hull	±82,000	0	-123,000	+123,000
Platform	±72,000	0	-108,000	+108,000
Knee	±45,240	0	- 68,000	+ 68,000
Pin	±23,320	0	- 35,000	+ 35,000

* Includes 50% increase due to whipping for the wave-induced loads and 40% increase due to heave for the still water loads.

b. Secondary Loads (Lateral). The secondary loads used in the longitudinal-section design study were assumed to be as follows:

1. For the shell
   - Slamming. Pressure was assumed to be 100 psi at the bow[2] (1/4L) tapering to 45 psi at midship. This pressure was used to design the plate panel only. It was not used in the design of the supporting structure.
   - A minimum shell pressure of 1000 psf was used to design the assembled plate panels and supporting structure not submerged.

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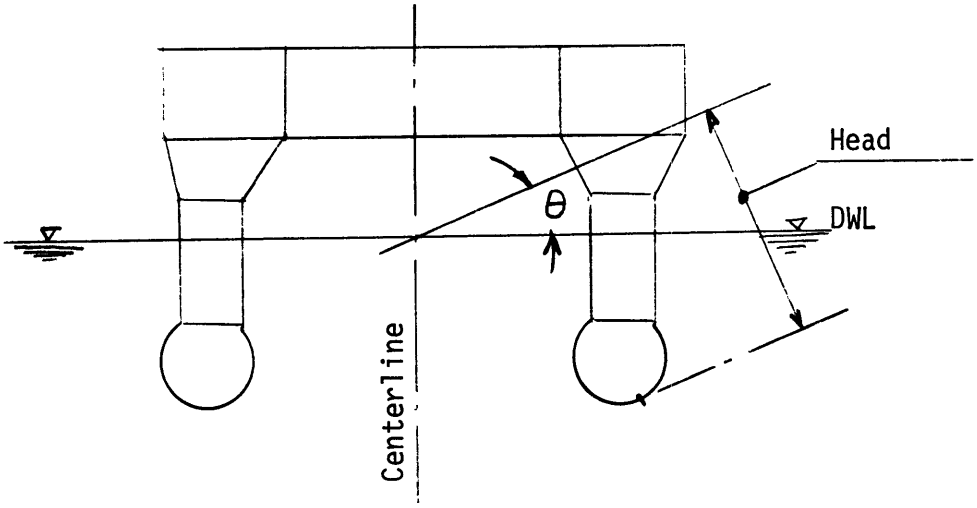
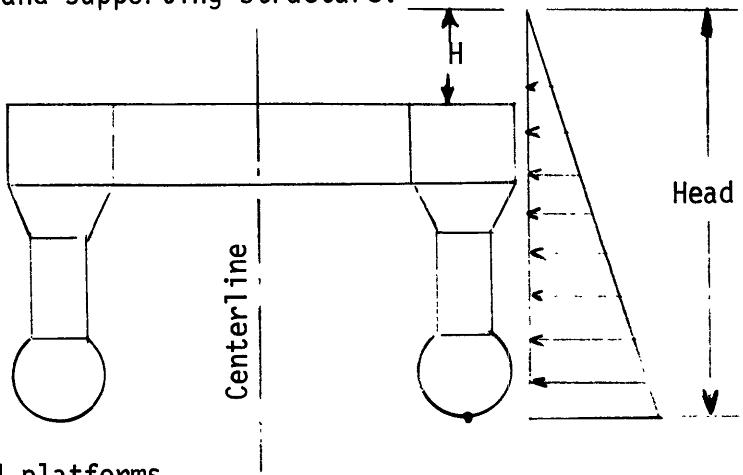
[2] Maniar, N.M. and Chiang, W.P., "Catamarans - Technological Limits to Size and Appraisal of Structural Design Information and Procedures", Final Report to the Ship Structures Committee of the National Academy of Science; on Project SR-192, "Catamaran Design", 1970.

- Submerged depth due to the roll of the ship. The resulting pressure (head of water) was used to design the plate panels and supporting structure.



- Head of water above the weather deck. The resulting head of water was used to design the assembled plate panels and supporting structure.



2. For decks and platforms
   - Live loads from the General Specification for Building Naval Ships. This load varied from 100 psf to 300 psf.
   - Normal or vital space damage heads
   - Dead loads due to the weight of the structure

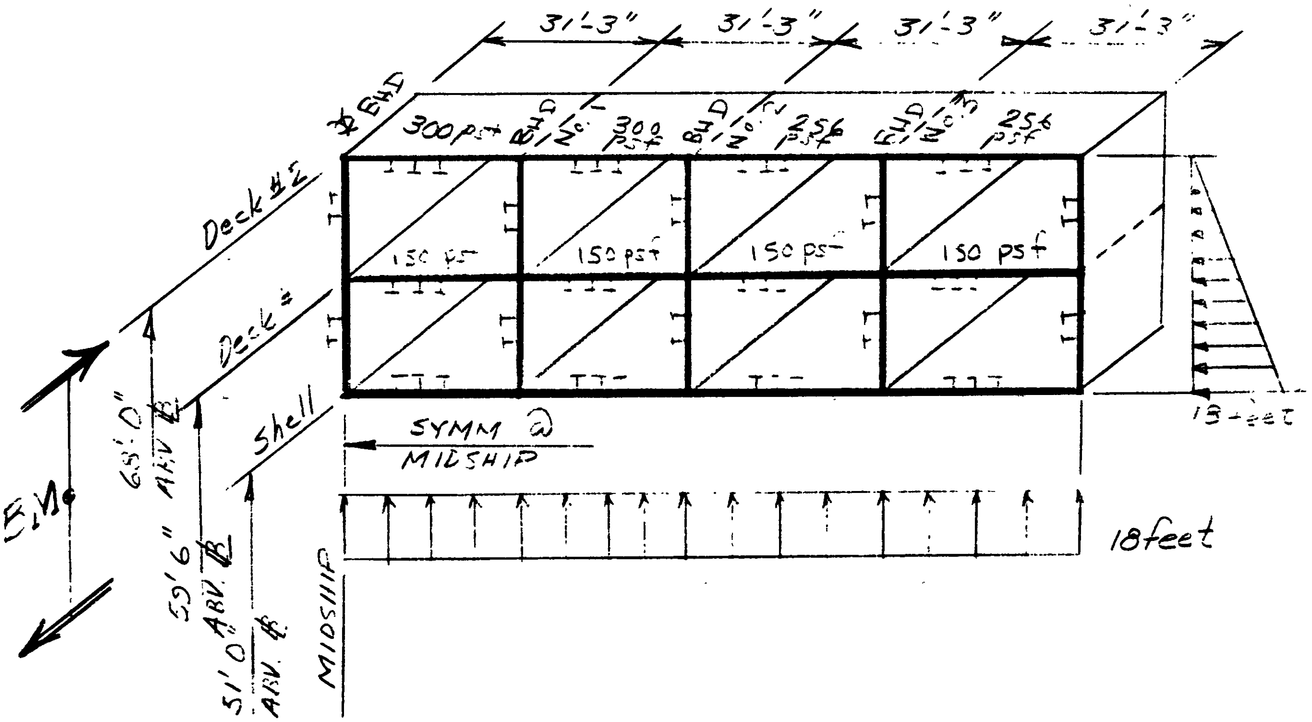
3. For bulkheads
   - Normal or vital space damage heads
   - Dead weight due to the weight of the structure

3. Design Example and Resulting Stresses

The design example given in this section used HTS material throughout and has 2-foot spacing between transverse beams:

a. Structural Arrangements and Loads

1. Section at Centerline



where BM is the combined bending moment (ft-tons)

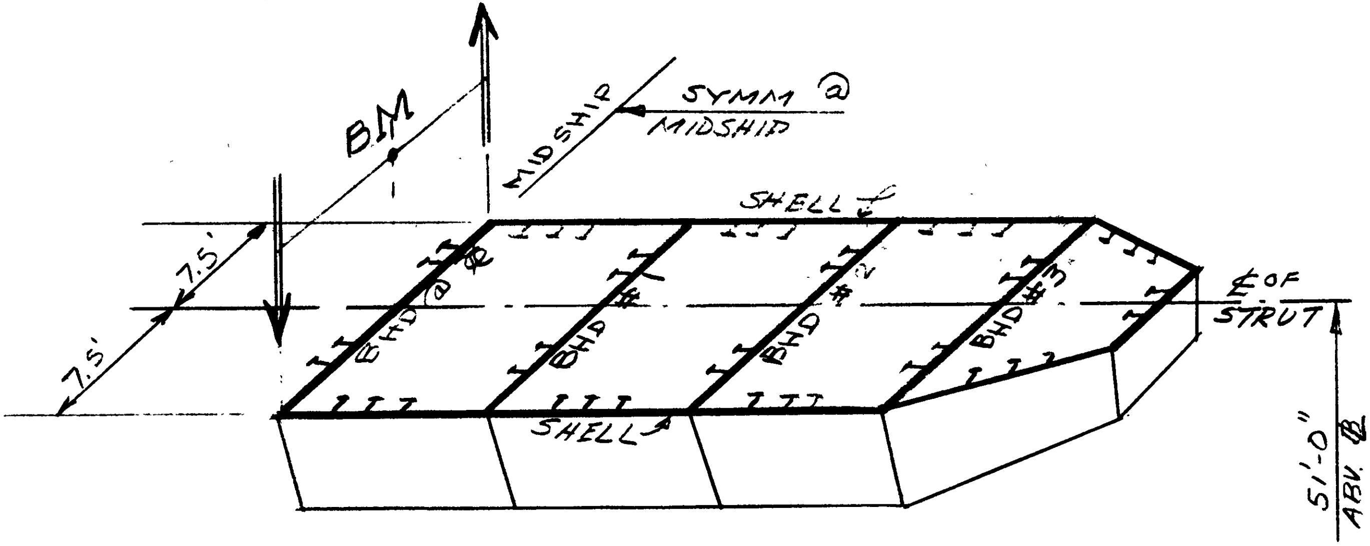
- Average head of water to lower shell = 18 feet
- BM (hog) = 93,000 ft-tons } (See Table 2)
- BM (sag) = 153,000 ft-tons } (See Table 2)
- Effective width of flanges = 100%, where the flanges are the upper deck and the shell

2. Section at Hull

Same as section at centerline, except

- BM (hog and sag) = 123,000 (see Table 2)
- Effective width of flanges - 50%

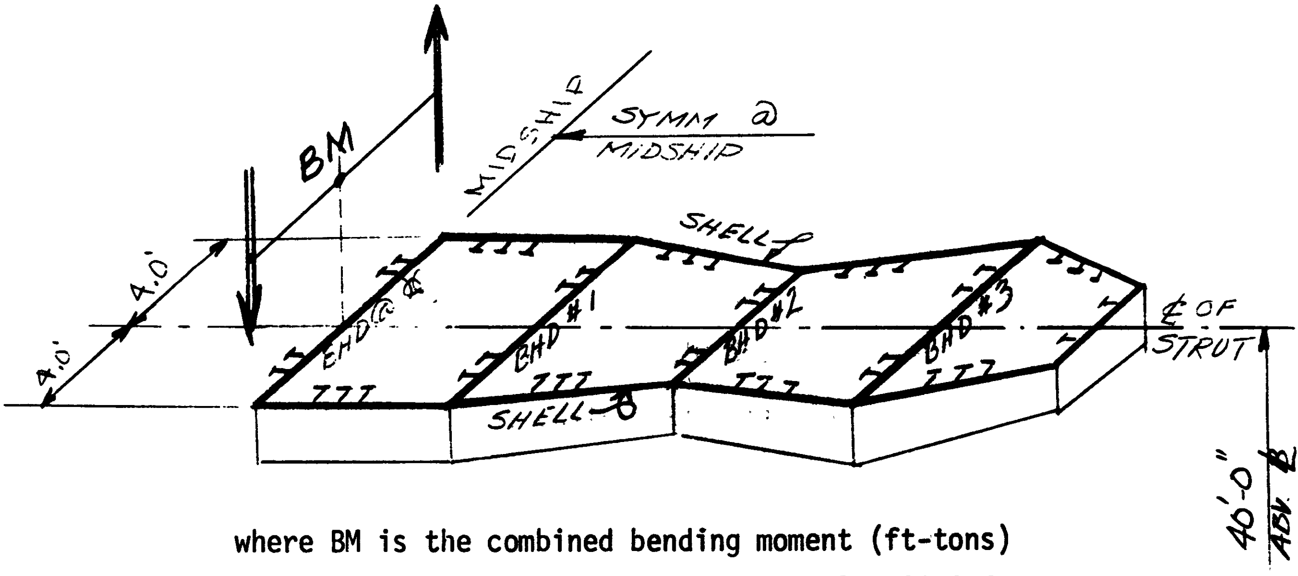
3. Section at Platform



where BM is the combined bending moment (ft-tons)

- Minimum shell pressure = 1500 psf
- Average head for bulkheads = 22.5 ft
- BM (hog and sag) = 108,000 ft-tons (see Table 2)
- Effective width of flanges = 100%

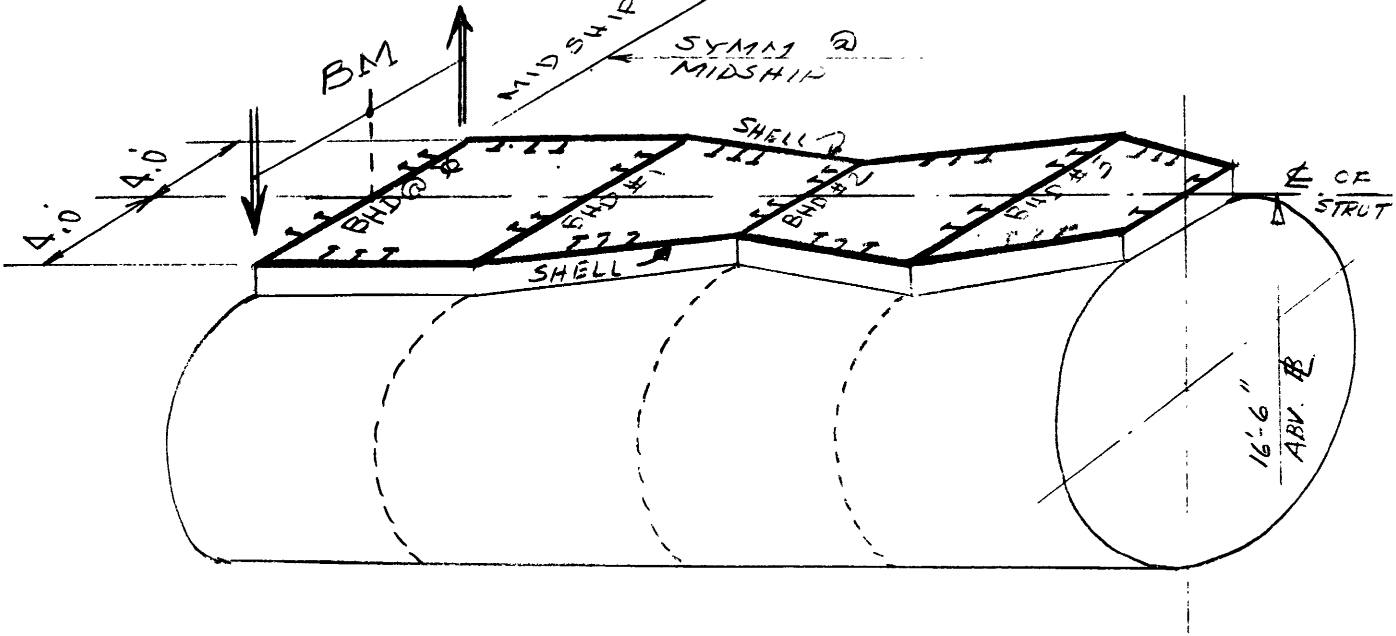
4. Section at Knee



where BM is the combined bending moment (ft-tons)

- Average design head for the shell = 28.0 ft
- Average design head for the bulkheads = 34 ft
- BM (hog and sag) = 68,000 ft-tons (see Table 2)
- Effective width of flanges = 100%

5. Section at Pin



where BM is the combined bending moment (ft-tons)

- Average design head for the shell = 53 ft
- Average design head for the bulkheads = 56 ft
- BM (hog and sag) = 35,000 ft-tons (see Table 2)
- Effective width of flanges = 100%

b. Resulting Stresses. The bending stresses computed by MIDSHIP[1] are summarized in Figure 4, where the axial stresses were determined as follows:

- Section at Centerline (P = ±2700 tons)
  P/A = ±2700(2240)/4516 = ±1339 psi
- Section at Hull (P = ±2700 tons)
  P/A = ±2700(2240)/2818 = ±2146 psi
- Section at Platform (P = +1250 tons)
  P/A = +1250(2240)/3155 = +887 psi
- Section at Knee (P = +1300 tons)
  P/A = +1300(2240)/3203 = +909 psi
- Section at Pin (P = 1400 tons)
  P/A = +1400(2240)/3448 = +909 psi

and the average shear stresses (fs_{avg}) were determined as follows:

- Section at Centerline ($V=0$)

  $fs_{avg} = 0$

- Section at Hull ($V = 1750$ tons)

  $fs_{avg} = 1750(2240)/516 = 7592$ psi

- Section at Platform ($V = 2700$ tons)

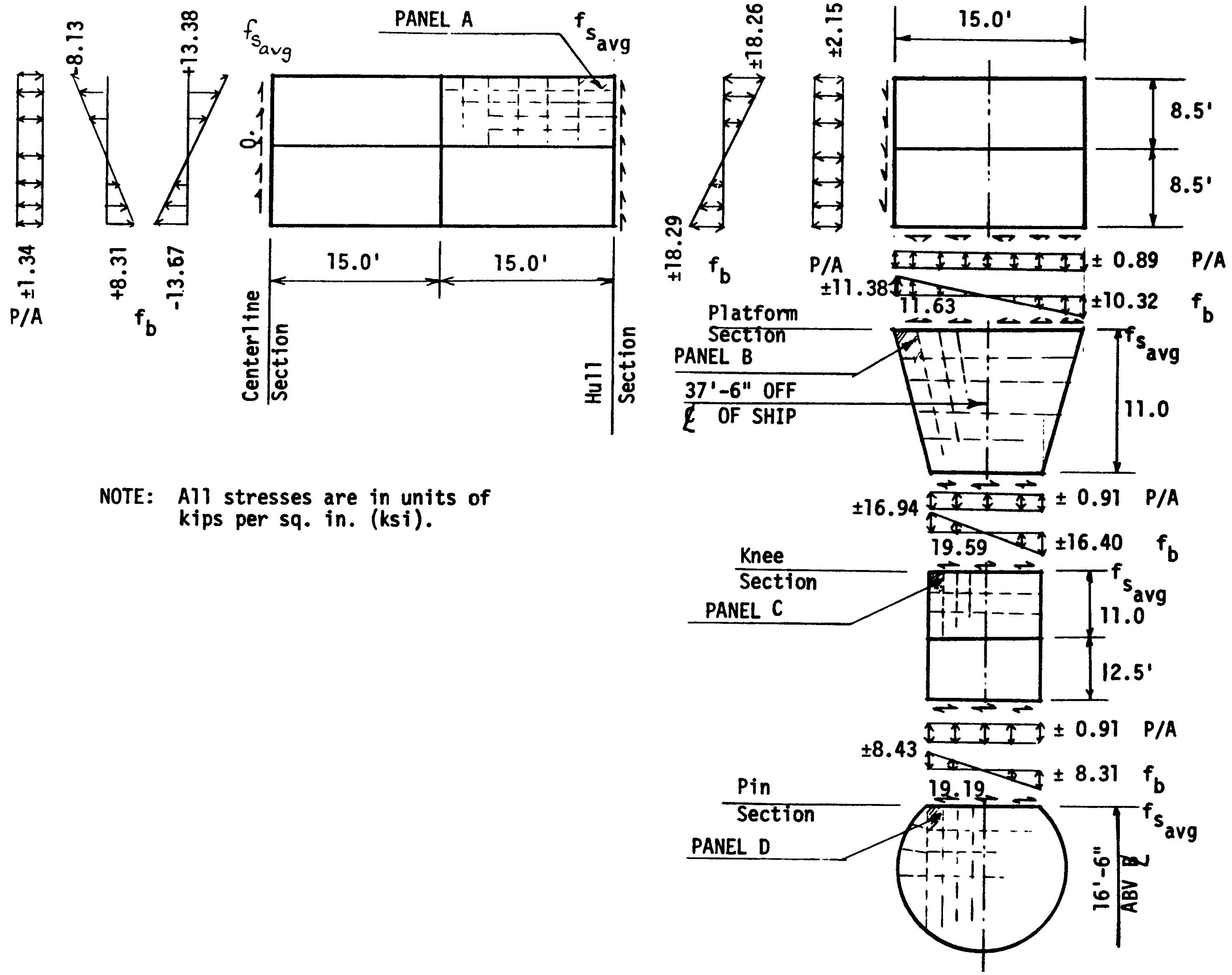
  $fs_{avg} = 2700(2240)/520 = 11,630$ psi

- Section at Knee ($V = 2700$ tons)

  $fs_{avg} = 2700(2240)/308 = 19,588$ psi

- Section at Pin ($V = 2700$ tons)

  $fs_{avg} = 2700(2240)/315 = 19,193$ psi

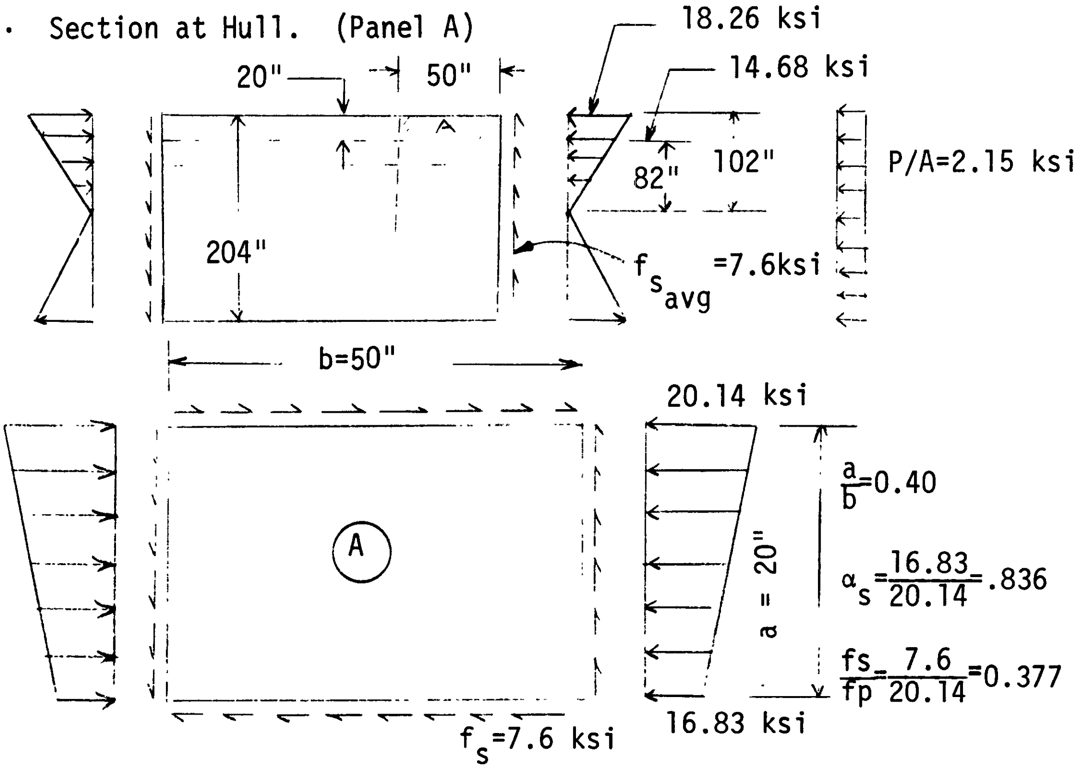


NOTE: All stresses are in units of kips per sq. in. (ksi).

Figure 4 - Stress Distribution Due to Transverse Bending Loads (Design Example)

c. Panel Design for Compressive and Shear Stresses. The MIDSHIP design computer program[1] does not have the ability to design a plate panel for combined compressive and shear stresses. Therefore, those critical plate panels subjected to compressive and shear stresses were analyzed by procedures described in the Navy Design Sheet, DDS 9110-4.[3]

- Section at Centerline. No shear stress analysis was performed at this section because the shear force is zero.
- Section at Hull. (Panel A)



From Fig 19 of the Navy's Design Data Sheet[3], K_{19} = 0.99 for α_s = 1.000

From Fig 20 of the Navy's Design Data Sheet[3], K_{20} = 0.79 for α_s = 0.0

Therefore, K = 0.957 for α_s = 0.836

Hence, the critical buckling stress (σ_{cr}) from Fig 17 of the Design Data Sheet[3] is σ_{cr} = 21 ksi for $K(^b/_t)$ = 68 and fs/fp = 0.377, and the panel as designed is adequate.

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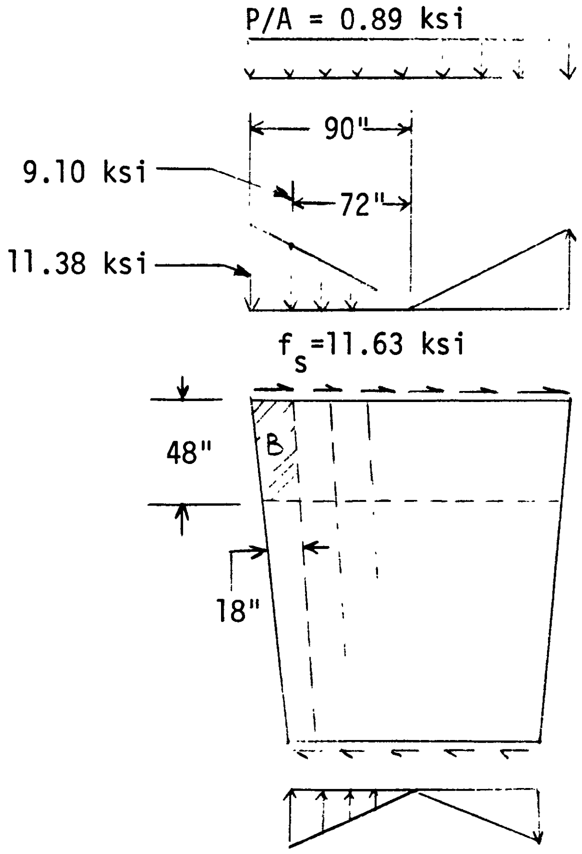
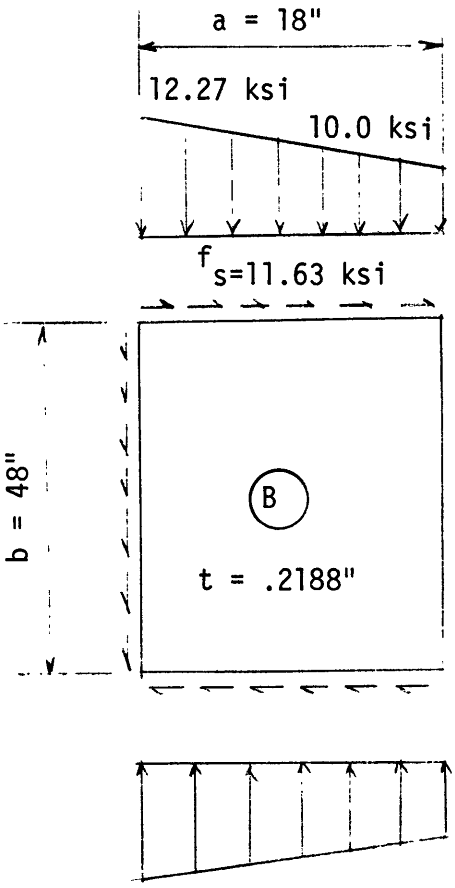
[3] "Strength of Structural Members," Design Data Book, Department of the Navy, Bureau of Ships Classification No. DDS 9110-4 (1956).

- Section at Platform (Panel B)





$$\frac{a}{b} = 0.375$$

$$\alpha_s = \frac{10.0}{12.27} = 0.815$$

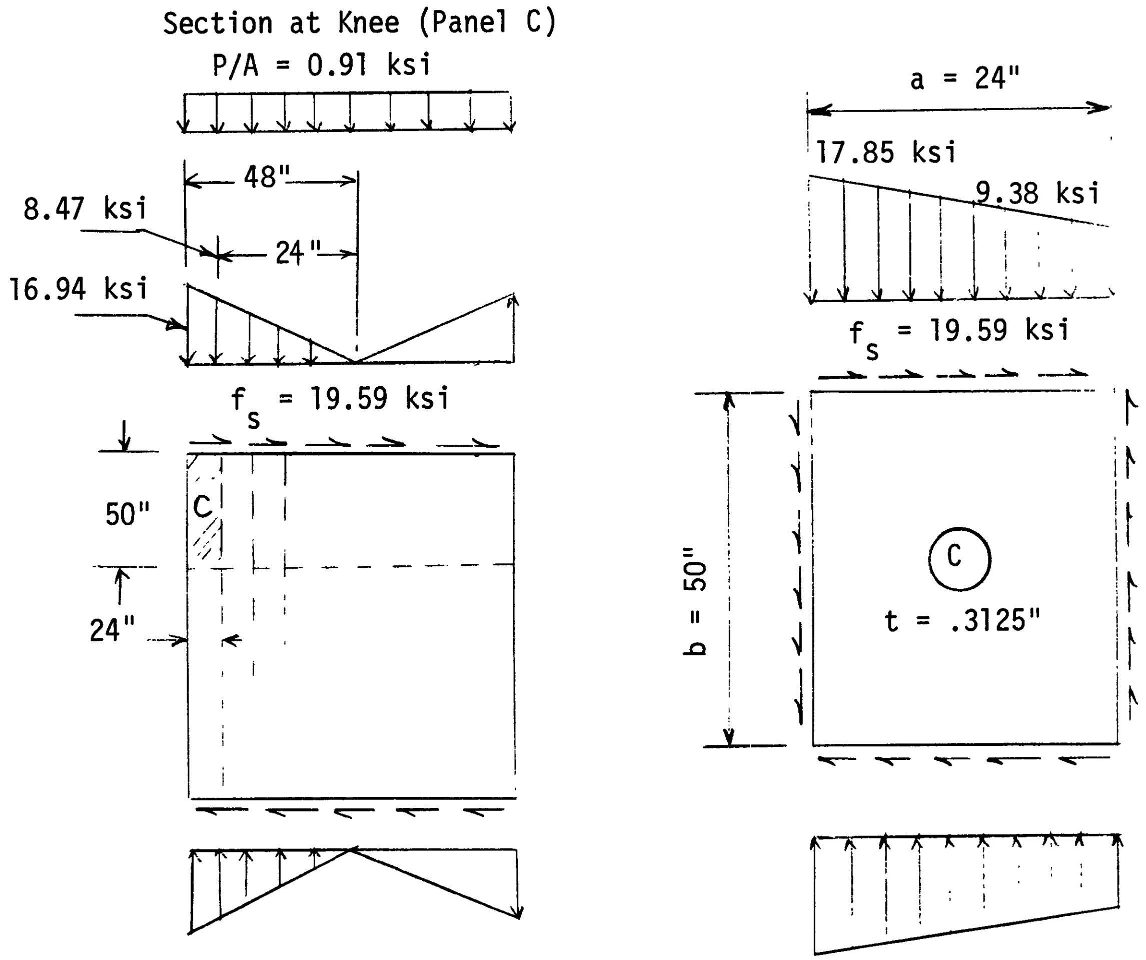
$$\frac{fs}{fp} = \frac{11.63}{12.27} = 0.95$$

From Fig 19 of the Design Data Sheet[3], $K_{19} = .98$ for $\alpha_s = 1.0$

From Fig 20 of the Design Data Sheet[3], $K_{20} = .825$ for $\alpha_s = 0$

Therefore, K = 0.951 for $\alpha_s = 0.815$

Hence, the critical bulking stress (σ_{cr}) is 12.5 ksi for $K(^b/_t) = 78$ and fs/fp = 0.95, and the panel as designed is adequate.



$$\frac{a}{b} = 0.48$$

$$\alpha_s = \frac{9.38}{17.85} = 0.525$$

Shear stress, f_s, is greater than compressive stress, f_p,

$$\therefore \frac{fp}{fs} = \frac{17.85}{19.59} = 0.91$$

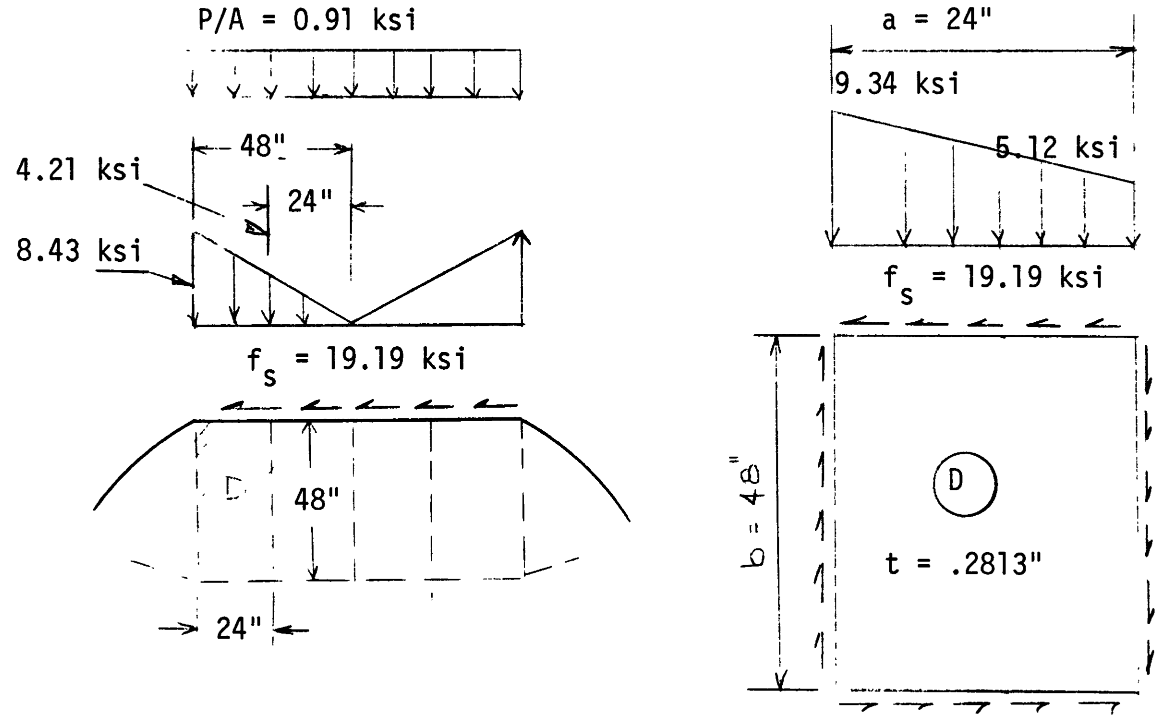
From Fig 19 of the Design Data Sheet[3] $K_{19} = 0.97$ for $\alpha_s = 1.00$

From Fig 20 of the Design Data Sheet[3] $K_{20} = 0.83$ for $\alpha_s = 0.0$

Therefore, $K = 0.903$ for $\alpha_s = 0.525$

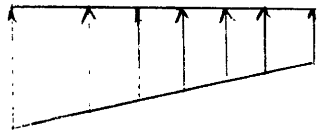
Hence, the critical shear buckling stress (F_s) from Figure 18 of the Navy Design Data Sheet[3] is 16.8 ksi for $K(^b/_t) = 69$ and fp/fs = 0.91, and the panel as designed is inadequate. Therefore, the panel width must be reduced by adding another vertical stiffener, making $F_s \approx 22$ ksi for $K(^b/_t) = 36$ and fp/fs = 0.91.

- Section at Pin (Panel D)



$\frac{a}{b} = 0.50$

$\alpha_s = \frac{5.12}{9.34} = 0.548$



Shear stress, f_s, is greater than compressive stress, f_p,

$\therefore \frac{fp}{fs} = \frac{9.34}{19.19} = 0.487$

From Fig 19 of the Navy's Design Data Sheet[3], $K_{19} = .945$ for $\alpha_s = 1.00$

From Fig 20 of the Design Data Sheet[3], $K_{20} = .860$ for $\alpha_s = 0$

Therefore, for $\alpha_s = .548$,

$$K = .860 + .548(.085) = 0.907$$

Hence, the critical shear buckling stress (F_s) from Fig 18 of the Design Data Sheet[3] with $K(^b/_t) = .907(\frac{24}{.2813}) = 77$ and fp/fs = 0.487, is F_s = 17.5 ksi and the panel as designed is inadequate.

Thus another vertical stiffener must be added to reduce the panel width and make F_s greater than fs_{avg}.

C. DESIGN OF TRANSVERSE SECTIONS TO RESIST LONGITUDINAL BENDING MOMENTS

1. Cross Section Description

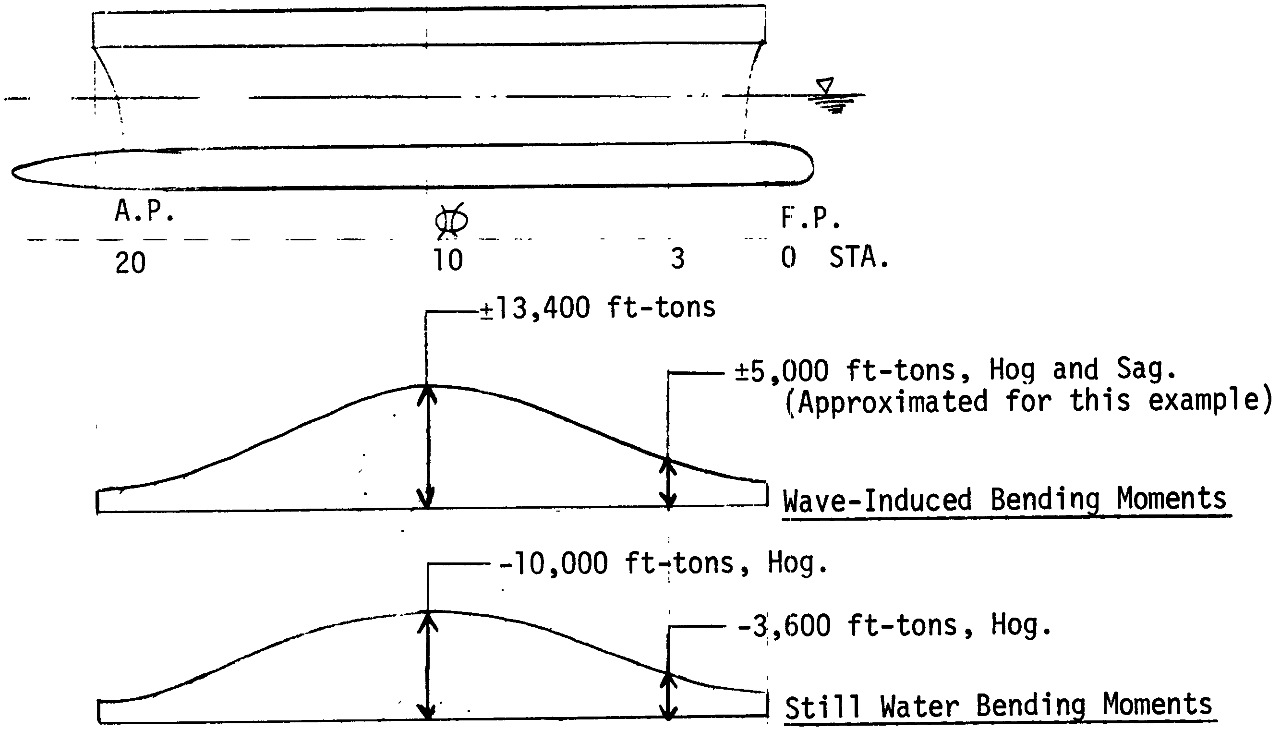
The ship was divided into two transverse sections for the longitudinal load study. These sections (see Figure 1) are defined as follows:

- Midship Section = > View ③
- 1/4 L Section = > View ④
  (Station 3)

The longitudinal bulkhead plating and the deck and shell plating were assumed to act as members of a box girder as they do in a monohull ship. These girder sections were designed to resist wave-induced bending moments with whipping, still water bending moments due to dead loads with inertia effects, secondary slamming loads, hydrostatic heads, and live loads.

2. Design Loads (Primary and Secondary)

a. Primary Design Longitudinal Bending Moments. The wave-induced longitudinal bending moments, without whipping, and the still water bending moments, without heave, were distributed as shown in this sketch:



The combined design primary longitudinal bending moments used in MIDSHIP[1] are shown in Table 3.

TABLE 3 - DESIGN PRIMARY BENDING MOMENTS (LONGITUDINAL)

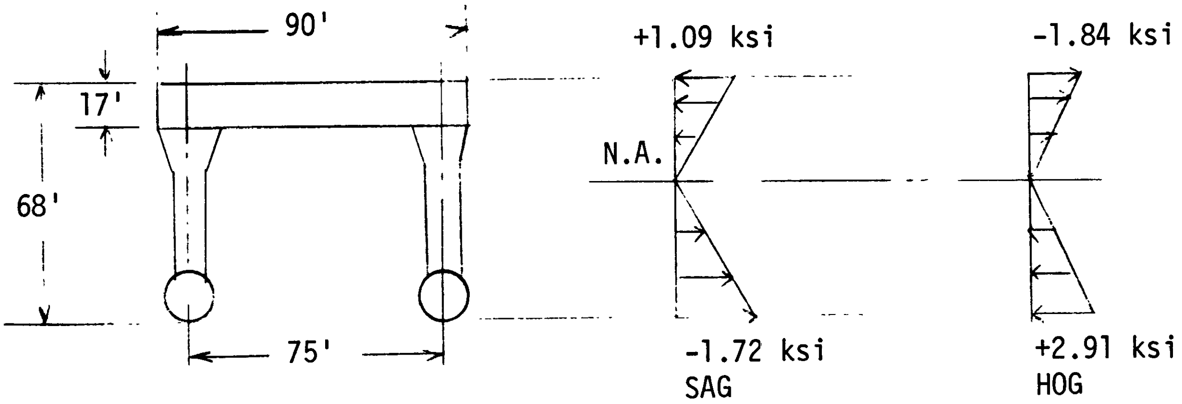
Section	Wave-Induced Hog & Sag (ft-tons)	Still Water Hog (ft-tons)	Design Bending Moments (ft-tons)	
			Hog	Sag
Midship	±13,400	-10,000	-34,000*	+6,100 (Use (+20,100))
Station 3	± 5,000	- 3,600	-12,530*	+2,460 (Use (+ 7,450))

* Includes 50% increase due to whipping for the wave-induced loads and 40% increase due to heave for the still water loads.

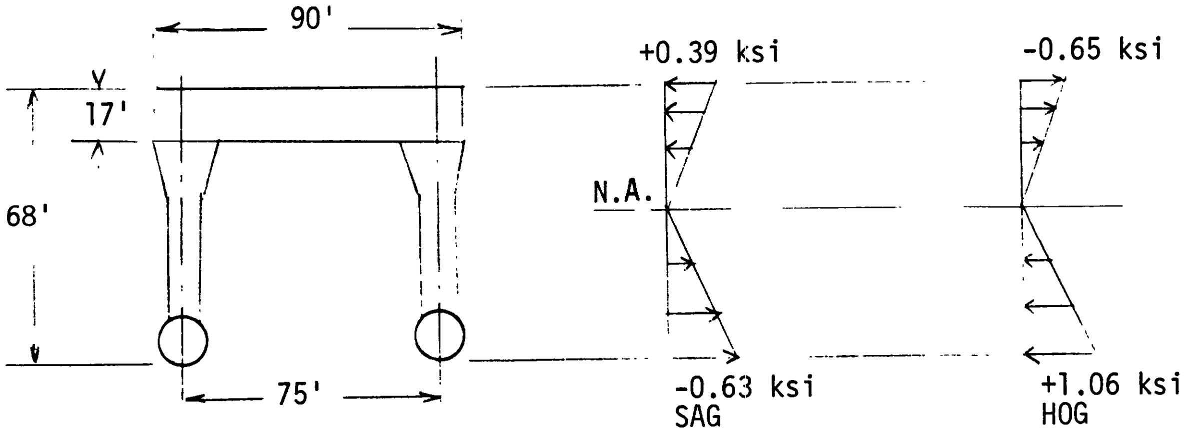
b. Secondary Loads (Lateral). The secondary loads used in the transverse-section design study were similar to those used in the longitudinal-section design study. See paragraph II.B.2.b of this report.

3. Typical Primary Stresses

The bending stresses computed by MIDSHIP[1] are summarized in Figure 5. The primary stresses depicted are those resulting from the study of the 2-foot transversely-framed ship using HTS material throughout.



a. Section at Midship



b. Section at Station 3

Figure 5 - Stress Distribution Due to Longitudinal Bending Loads

D. APPROXIMATE TORSIONAL ANALYSES

1. Types of Analysis

No suitable design procedure for torsional loads is available. Therefore, three separate approximate torsional analyses were performed using the scantling developed in the previous design procedures (i.e., transverse and longitudinal bending loads).

In the first analysis the cross section of the bridge structure was treated as a multicell box beam subjected to pure torsion with warping permitted. A further approximation was made during this analysis to simplify determination of the shear flow.

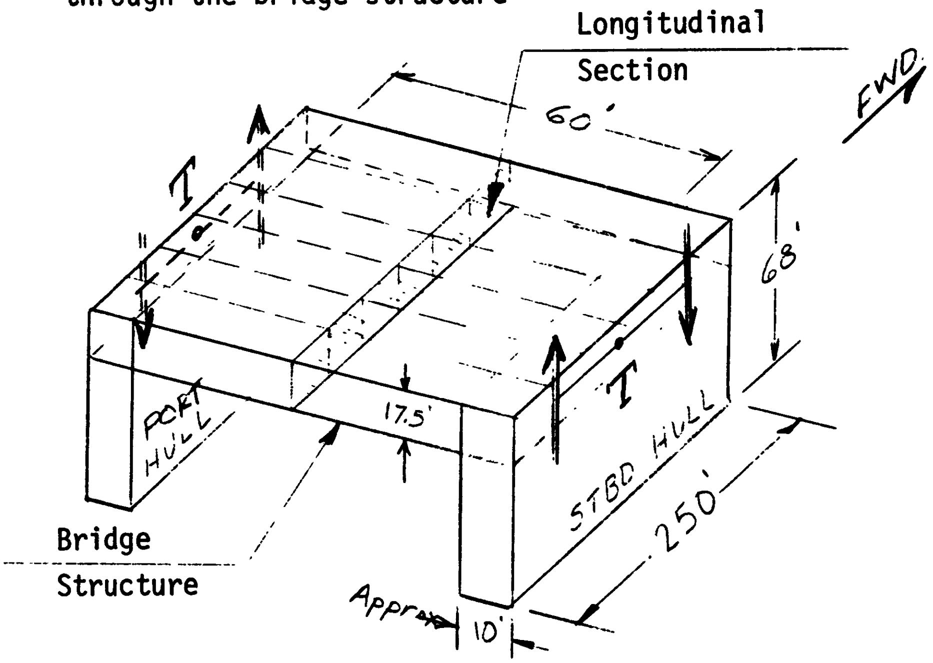
The second analysis treated the cross section of the bridge structure as a single cell box beam with warping prevented. The differential bending stresses were estimated, as well as the shear forces. The assumption of the single cell box beam structure was predicated upon the conclusions and results of the first approximate torsional analysis.

The third analysis assumed that each transverse girder in the bridge structure developed shear forces porportional to its distance from the center of torque (℄). These forces are oppositely applied at either end of a fixed-end beam. The resulting stresses (bending and shear) were then determined.

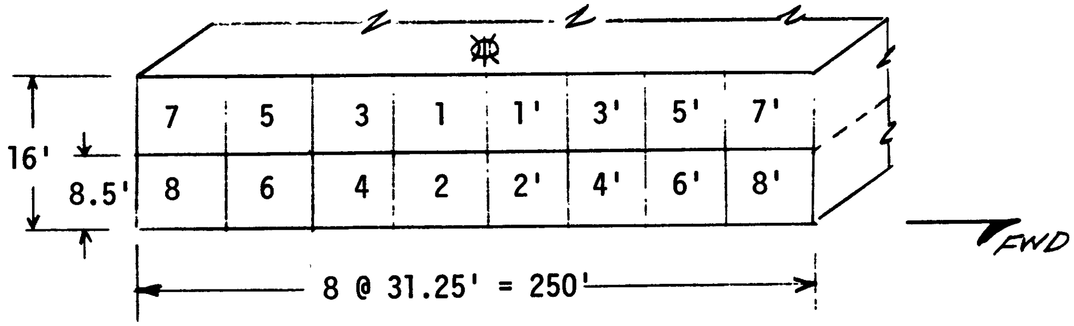
2. Multicell Box Beam (Warping Permitted)

a. Assumptions. For this analysis the following assumptions were made:

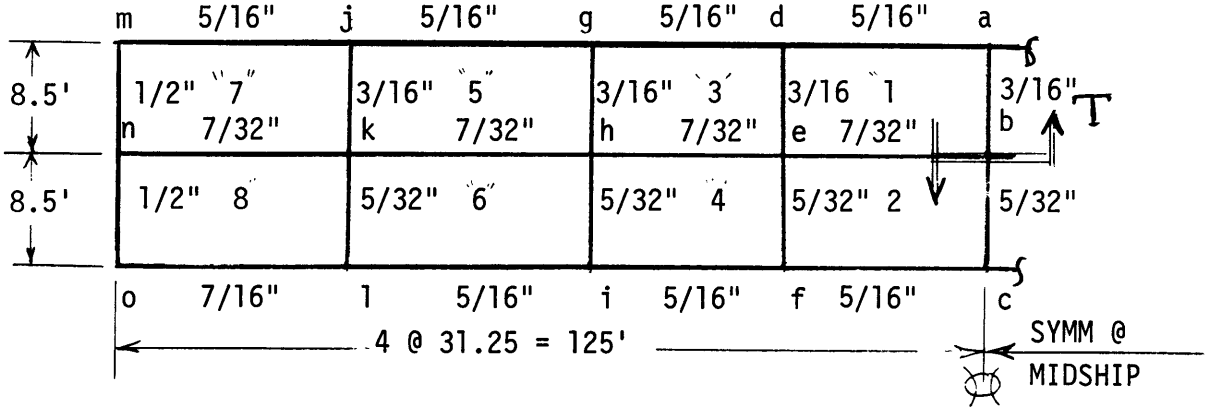
- The torque moment, T, is transmitted from the starboard hull to the port hull or vice versa through the bridge structure



- The port and starboard hulls are considered infinitely more rigid than the bridge structure
- The torsional moment, T, produces no axial stresses (i.e., warping due to twisting is not prevented)
- The longitudinal section through the bridge structure is considered a multicell box beam subjected to pure torsion (16 cells)



b. Analysis and Shear Stresses. The analysis for a multicell box beam subjected to a torsional moment was performed using the method of successive approximations as delineated in E. F. Bruhn's "Analysis and Design of Airplane Structures."[4] This method is similar to that of moment distribution. Carryover factors had to be computed and initial torque per cell had to be assumed and then distributed until a reasonable convergence was obtained. Advantage was taken of symmetry of geometry and loading. Therefore, only half of the cells (8) were used for this analysis. See the following sketch for the necessary dimension and plate thicknesses.

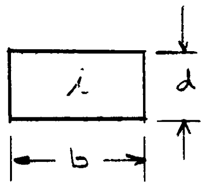


where T = 22,500 ft-tons (604,800 in-kips)

The initial shear flow, q_i, for each cell, i, was computed using the following formulas:

$$q_i = \frac{2Ai}{\Sigma(\frac{L}{t})\text{Cell } i} = (\text{lb per in.})$$

where Ai is the enclosed area of Cell i,



$A_i = (b\,d)_i$

$\Sigma(\frac{L}{t})_i$ is the summation of length divided by thickness for all segments around Cell i.

---

[4] Bruhn, E.F., "Analysis and Design of Airplane Structures," Tri-State Offset Company, Cincinnati, 1952.

The carryover factor, CO_{ij}, for each cell web member, ij, was determined using the following formula:

$$CO_{ij} = \frac{(\frac{L}{t}) \text{ web } ij}{\Sigma(\frac{L}{t}) \text{ Cell } i}$$

where $(\frac{L}{t})$ web ij is the length of the web between Cells i and j divided by the thickness of this web. Table 4 summarizes the constants required by the successive approximation method.

TABLE 4 - CONSTANTS REQUIRED BY SUCCESSIVE APPROXIMATION METHOD

Cell No.	A (inches^2)	$\Sigma(\frac{L}{t})$	Initial q (lb/in)
1	38,250	4002	19.12
2	"	4220	18.13
3	"	4002	19.12
4	"	4220	18.13
5	"	4002	19.12
6	"	4220	18.13
7	"	3662	20.89
8	"	3428	22.32

The successive approximation method is demonstrated in Table 5 which also gives the final shear flow (q) per cell.

The resulting shear force and shear stress in each web of the multicell box beam, diagrammed in the sketch below, are tabulated in Table 6.

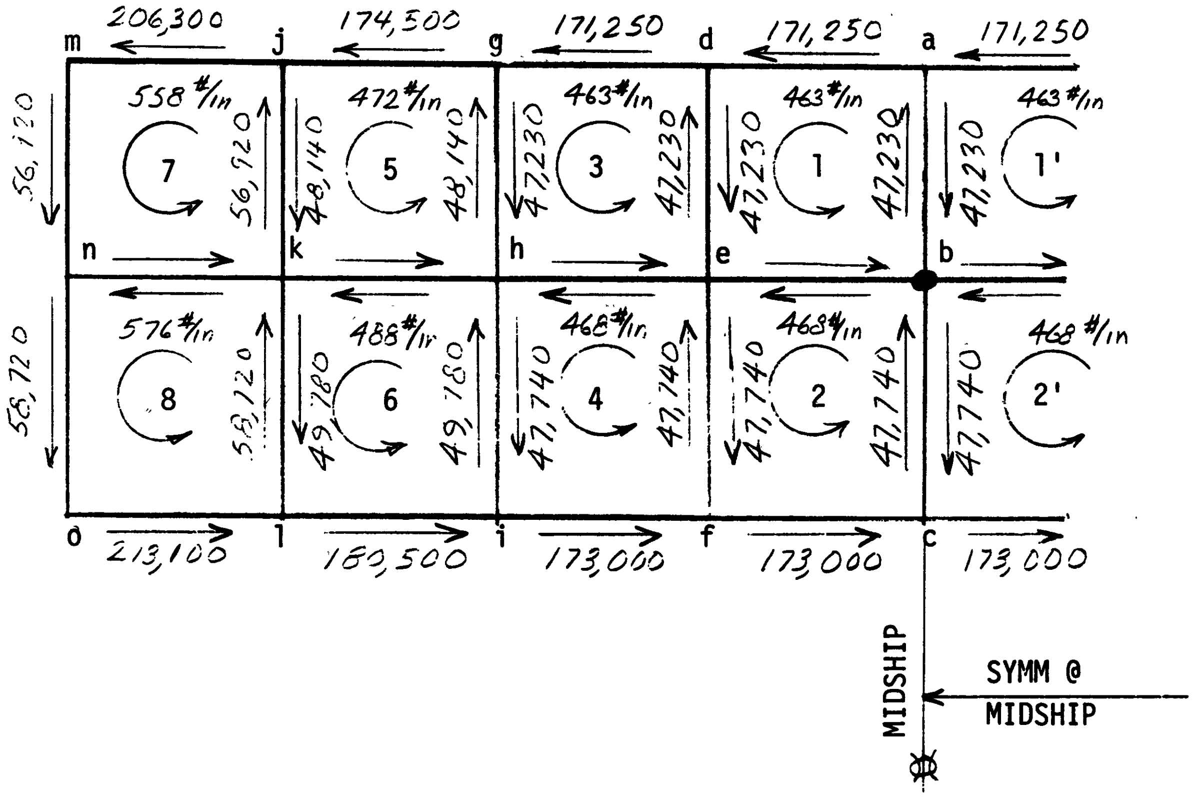


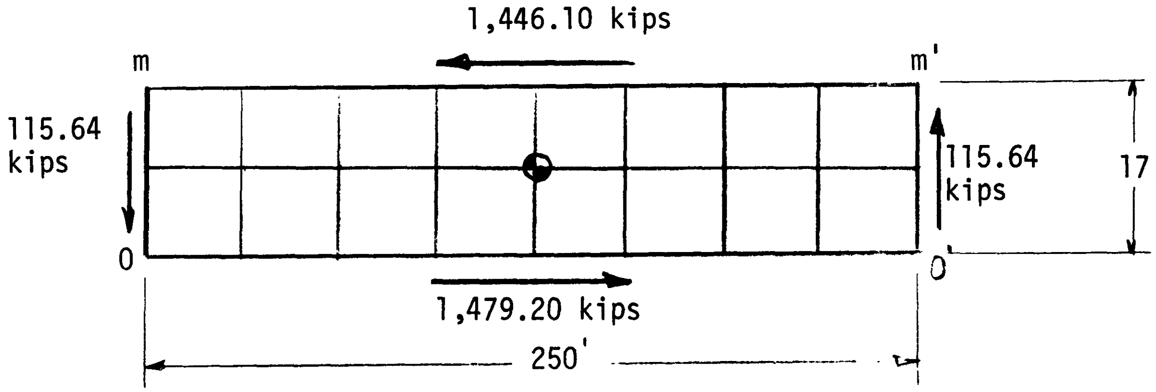
TABLE 5 - SUMMARY OF SUCCESSIVE APPROXIMATION METHOD

CELL	7		5			3			1			2			4			6			8	
MEM.CELL	7-8	7-5	5-7	5-6	5-3	3-5	3-4	3-1	1-3	1-1	1-2	2-1	2-2	2-4	4-2	4-3	4-6	6-4	6-5	6-8	8-6	8-7
C.O.	.500	.159	.136	.429	.136	.136	.429	.136	.136	.136	.429	.406	.154	.154	.154	.406	.154	.154	.406	.154	.191	.500
q ($\times 10^{-2}$)	2089		1912			1912			1912			1813			1813			1813			2232	
	1116	260	332	736	260	260	736	260	260	260	736	820	279	279	279	820	279	279	820	426	279	1045
	523	45	41	333	35	35	333	35	35	35	333	316	43	43	43	316	43	43	316	53	66	558
	279	6	7	128	5	5	128	5	5	5	128	143	7	7	7	143	7	7	143	13	8	262
	131	1	1	58	1	1	58	1	1	1	58	55	1	1	1	55	1	1	55	2	2	140
	70	-	-	22	-	-	22	-	-	-	22	25	-	-	-	25	-	-	25	-	-	66
	33			10			10				10	9				9			9			35
	18			4			4				4	4				4			4			17
	9			2			2				2	2				2			2			9
	5			1			1				1	1				1			1			5
	3			-			-				-	-				-			-			3
	1																					1
Σq ($\times 10^{-2}$)	4589		3888			3808			3808			3848			3848			4012			4728	
2Aq	3,510,585		2,974,320			2,913,120			2,913,120			2,943,720			2,943,720			3,069,180			3,616,920	
TOTAL/SIDE									24,884,685			(in-lb)										
TOTAL TORQUE FOR Σq ASSUMED =									49,769,370			(in-lb)										
q for T=22,500 (ft-tons) is equal to, $\frac{604,800,000}{49,769,370} = 12.152 \times \Sigma q$																						
	558 #/"		472 #/"			463 #/"			463 #/"			468 #/"			468 #/"			488 #/"			576 #/"	

TABLE 6 - MULTICELL TORSIONAL SHEAR FORCES AND STRESSES

Element	Force (lb)	Shear Stress (psi)
ab	0	0
ad	171,250 ←	1482
be	1,750 ←	23
bc	0	0
cf	173,000 →	1498
de	0	0
dg	171,250 ←	1482
eh	1,750 ←	23
ef	0	0
fi	173,000 →	1498
gh	910 ↑	48
gj	174,500 ←	1510
hk	6,000 ←	73
hi	2,040 ↑	128
il	180,500 →	1562
jk	8,780 ↑	459
jm	206,300 ←	1786
kn	6,800 ←	83
kl	8,940 ↑	560
lo	213,100 →	1317
mn	56,920 ↓	1116
no	58,720 ↓	1152

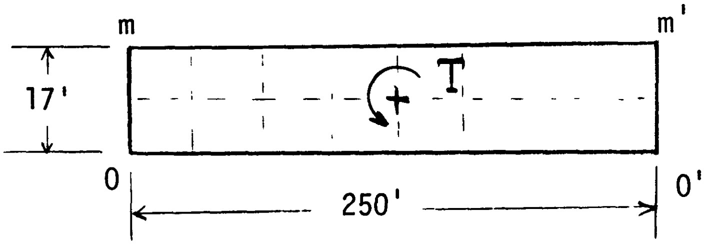
c. Simplified Method for Analyzing a Multicell Box Beam. The approximate torque developed by the outer skin from the previous analysis (successive approximation) is:



$$T \approx 115.64(250) + 1{,}446.1(8.5) + 1{,}479.2(8.5)$$

$$\approx 28{,}900 + 12{,}290 + 12{,}580 \approx 53{,}770 \text{ ft-kips or } 24{,}000 \text{ ft-tons}$$

The applied torque is 22,500 ft-tons. Therefore, for the multicell box beam, the applied torque can be assumed to be distributed along the outer skin. Hence, a simplified method for analyzing a multicell box beam is as follows:



T = 22,500 ft-tons

$$T = 2Aq$$

or

$$q = \frac{T}{2A} = \frac{22{,}500\ (2{,}240)\ (12)}{2(17 \times 12)\ (250)\ (12)} = 495 \text{ lb/in}$$

Therefore, force in plate member m o is

$$\approx 495(17 \times 12) \approx 101{,}000\,\text{lb}\downarrow\text{(Compare w/115,640 lb), and}$$

Force in plate member m' m' is

$$\approx 495(250 \times 12) \approx 1{,}485{,}000\,\text{lb}\leftarrow\text{(Compare w/1,446,100 lb)}$$

d. Still Water Bending Stresses.

1) Section at Centerline. The still water bending moment is 21,400 ft-tons (see Table 2). The resulting bending and shear stresses are:

$$f_{b_T} = \frac{21.40(1.4)\checkmark}{93} \times 8.13 = +2.63 \text{ ksi}$$

$$f_{b_B} = \frac{21.4(1.4)}{93} \times 8.13 = -2.67 \text{ ksi}$$

$$f_{s_{avg}} = 0$$

The maximum torsional shear stresses due to the torque load are 1500 psi and 1100 psi. Therefore, the maximum combined shear stress is 1500 psi. Hence, the section as designed is adequate.

2) Section at Hull. The still water bending moment is zero (see Table 2). The resulting bending stresses and shear stresses are:

$$f_{b_T} = 0$$

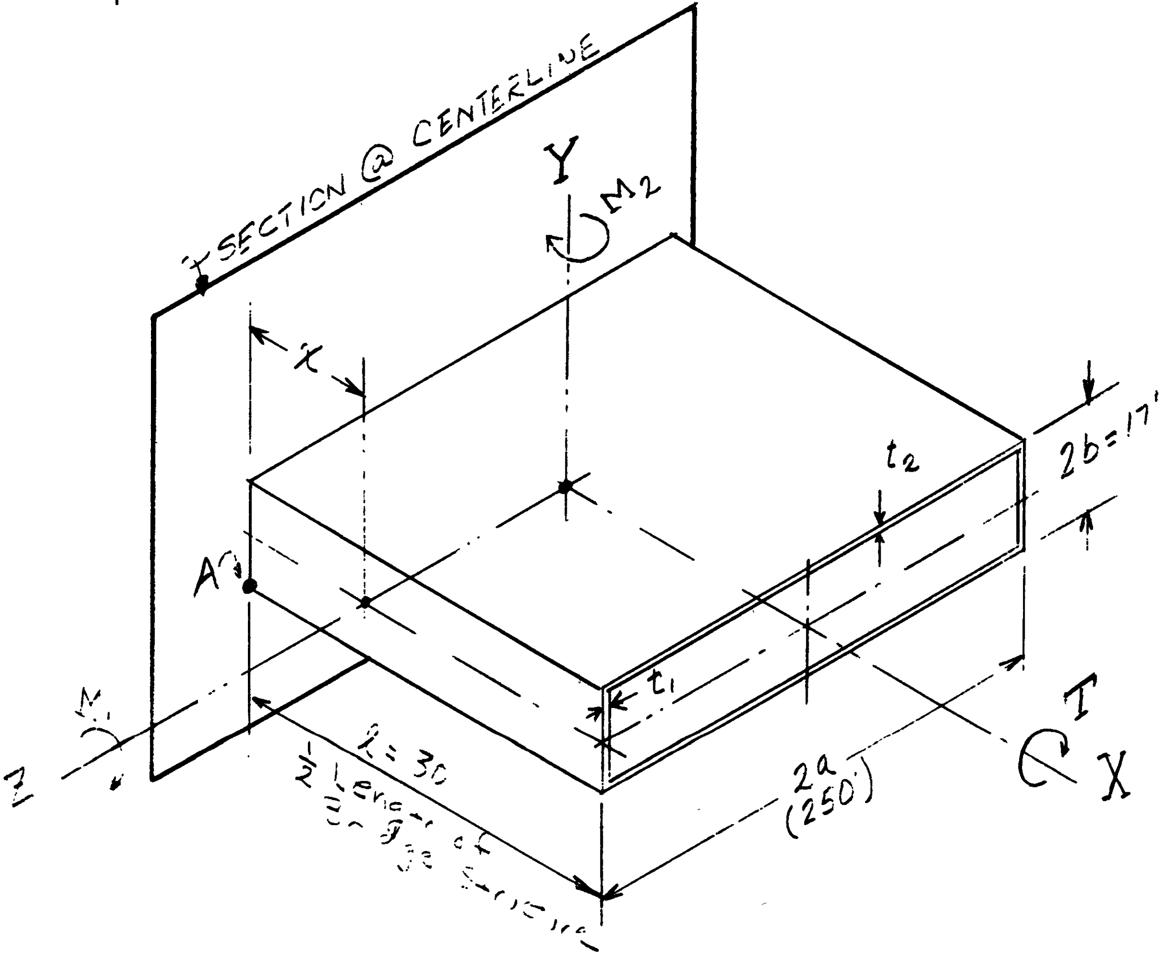
$$f_{b_B} = 0$$

$$f_{s_{avg}} = 7{,}590 \text{ psi}$$

The maximum torsional shear stresses due to the torque load are 1500 psi and 1100 psi. Therefore, the maximum combined shear stress is 8690 psi. Hence, the section as designed is adequate.

3. Single-Cell Box Beam - Differential Bending (Warping Prevented)

For this analysis, all the torque is assumed to be taken out by the outer plating of the bridge structure. It is further assumed that the cross section does not change its shape. See paragraph II.D.2 of this report for a justification of this assumption. The analysis that follows is based upon the formulas taken from the Chapter 9 of R.J. Roark's "Formulas for Stress and Strain."[5]



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[5] Roark, R.J., "Formulas for Stress and Strain", McGraw-Hill Incorporated, New York, 1954.

Bending moment M_1 in either vertical web:

At A:

$$M_1 = \frac{T}{2a} \cdot \frac{\eta K_1}{\mu} \tanh (\mu l)$$

Bending moment M_2 in either top or bottom flange:

At A:

$$M_2 = \frac{T}{-2b} \cdot \frac{\eta K_2}{\mu} \tanh(\mu l)$$

Vertical shear V_1 in either vertical web:

$$V = \frac{T}{4a} (1 + \frac{\cosh \mu \ (l-x)}{\cosh \mu l})$$

At $x = 0$:

$$V_1 = \frac{T}{4a} (1+\eta)$$

Transverse shear V_2 on either top or bottom flange:

At $x = 0$:

$$V_2 = \frac{T}{4b} (1-\eta)$$

Shear per linear inch along the junction of web and flange:

At $x = 0$:

$$S = \frac{T}{8ab} [1 - \eta(K_1 - K_2)]$$

For the above equations the several terms are defined as follows:

$$K_1 = \frac{a^2EI_1}{a^2E_1I_1+b^2E_2I_2}$$

$$K_2 = 1 - K_1$$

$$\eta = \frac{a^2\gamma_2-b^2\gamma_1}{a^2\gamma_2+b^2\gamma_1}$$

$$\gamma_1 = \frac{1}{2bt_1G_1} \quad ; \qquad \gamma_2 = \frac{1}{2at_2G_2}$$

$$\mu = \left[\frac{4a^2b^2}{(a^2E_1I_1+b^2E_2I_2)\ (a^2\gamma_2+b^2\gamma_1)}\right]^{1/2}$$

where I_1 is the moment of inertia of one web about axis ZZ;

I_2 is the moment of inertia of one flang about axis YY;

E_1 and E_2 are moduli of elasticity of material in webs and flanges, respectively;

G_1 and G_2 are shearing moduli of elasticity of materials in webs and flanges, respectively.

Therefore, for this analysis the following numerical results were obtained:

$2a = 3000''$; $2b = 204''$; $t_1 = 0.500''$; $t_2 = 0.3125''$

$I_1 = 0.3537 \times 10^6 \text{ in}^4$; $I_2 = 703.1 \times 10^6 \text{ in}^4$

$E_1 = E_2 = 30 \times 10^6$ psi ; $G_1 = G_2 = 12 \times 10^6$ psi

$\gamma_1 = 0.0817 \times 10^{-8}/\text{lb}$; $\gamma_2 = 0.00889 \times 10^{-8}/\text{lb}$

$\eta = 0.9185$

$\mu^2 = 0.01845 \times 10^{-4}/\text{in}^2$; $\mu = 0.1358 \times 10^{-2}/\text{in}^2$

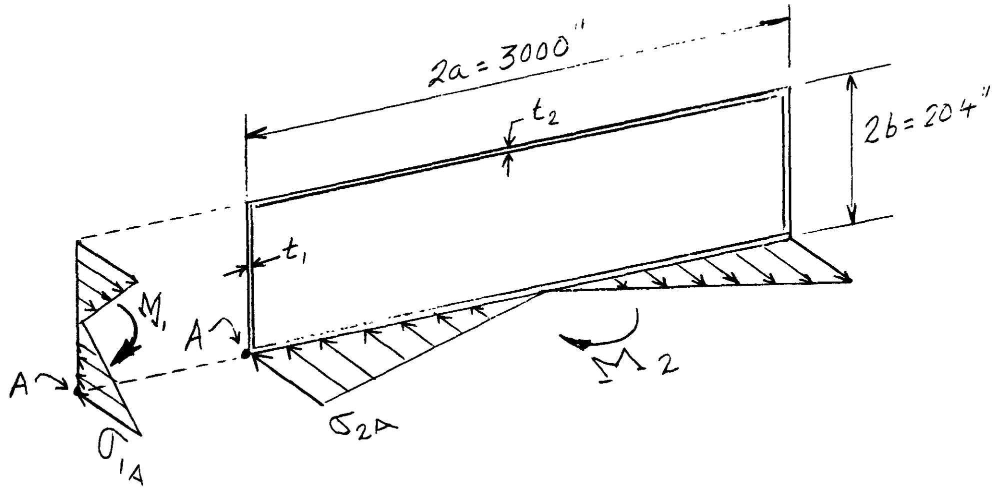
$K_1 = 0.098$

$K_2 = 0.902$

At A $\left\{ \begin{aligned} M_1 &= 6{,}069{,}700 \text{ in-lb.} \\ M_2 &= -82{,}150 \text{ in-lb.} \end{aligned} \right.$

At end A $\left\{ \begin{aligned} V_1 &= 193{,}400 \text{ lb } \downarrow\uparrow \\ V_2 &= 120{,}000 \text{ lb } \downarrow\uparrow \\ q &= 859 \text{ lb per in.} \rightleftarrows \end{aligned} \right.$

Hence, the bending and shear stresses at A are as follows:



Bending Stresses:

$$\sigma_{2a} = +\frac{M_2 a}{I_2} = 0.18 \text{ psi}$$

$$\sigma_{1a} = +\frac{M_1 b}{I_1} = 1{,}750 \text{ psi}$$

Shear Stresses:

In the web:

$$f_s = \frac{q}{t_1} = \frac{859}{.500} = 1718 \text{ psi}$$

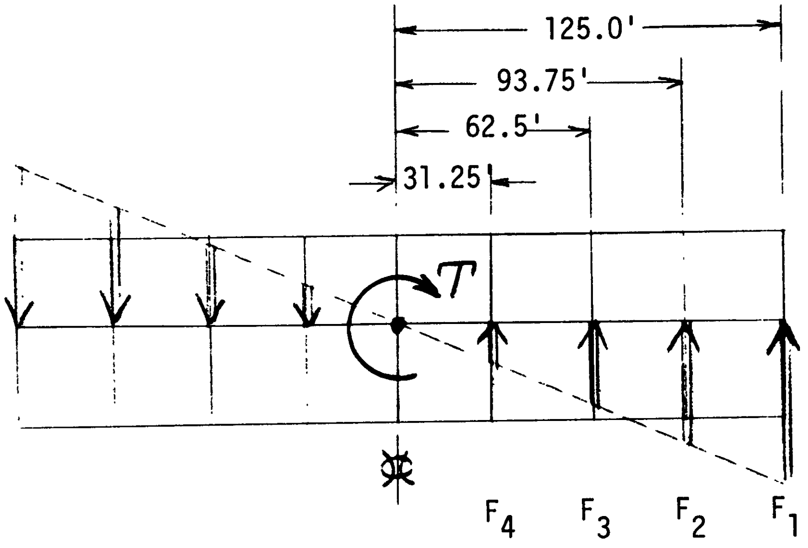
In the flanges:

$$f_s = \frac{q}{t_2} = \frac{859}{.3125} = 2748 \text{ psi}$$

If the still water bending and shear stresses are added to these stresses, the structures will still be adequate as designed. The torsional stresses are not considered high. The differential bending stresses usually occur as a local condition and their effects become negligible at a relatively short distance from the end. Furthermore, the value of shear flow, as previously calculated in paragraph II.D.2, was not seriously affected.

4. Bending and Shear Due to Displacements

a. Assumptions. In this analysis it is assumed that each transverse girder of the bridge structure will develop shear forces proportional to its distance from the center of torque (see sketch below) and the deck and shell plating will not develop any shear force.



T = 22,500 ft-tons at the intersection of the bridge structure and the hull, Port and Stbd.

b. Shear Forces. The resulting forces are as follows:

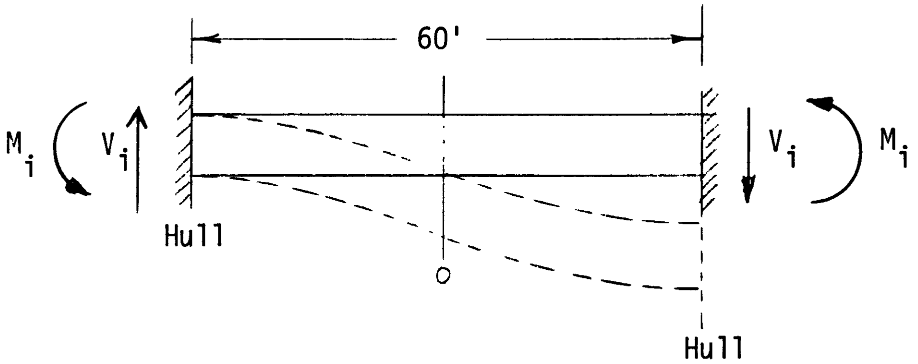
$$F_1 = 48 \text{ tons} = 4F_4$$

$$F_2 = 36 \text{ tons} = 3F_4$$

$$F_3 = 24 \text{ tons} = 2F_4$$

$$F_4 = 12 \text{ tons} = 1F_4$$

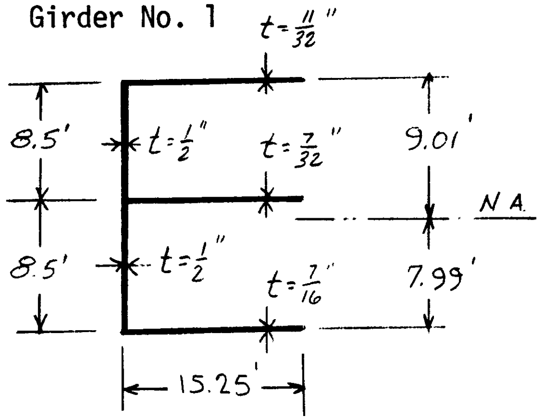
c. Bending Moments and Shear Forces. The resulting bending moment and shear forces on each girder due to the assumed distribution, are as follows:



Girder i	Shear V_i (ton)	Bending Moment M_i (ft-tons)
1	48	1440
2	36	1080
3	24	720
4	12	360

d. Bending and Shear Stresses (Due to Displacement).

- Girder No. 1



Area:

$A = 285 \text{ in}^2$

Shear Area:

$A_s = 102 \text{ in}^2$

Moment of Inertia:

$I_{NA} = 12{,}740 \text{ in}^2\text{-ft}^2$

Section Moduli:

Top: $Z_T = 1414 \text{ in}^2\text{-ft}$

Bottom: $Z_B = 1595 \text{ in}^2\text{-ft}$

Bending Stresses (@ Hull):

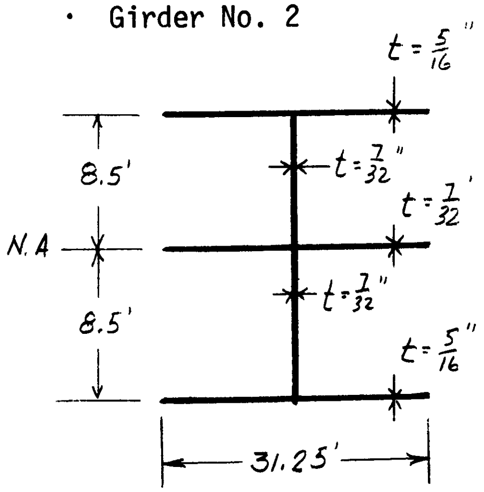
$$f_{b_T} = \frac{1440(2.24)}{1414} = 2.28 \text{ ksi}$$

$$f_{b_B} = \frac{1440(2.24)}{1595} = 2.02 \text{ ksi}$$

Shear Stress (Average):

$$f_{s_{avg}} = \frac{48(2.24)}{102} = 1.05 \text{ ksi}$$

- Girder No. 2



Area:

$A = 361 \text{ in}^2$

Shear Area:

$A_s = 45 \text{ in}^2$

Moment of Inertia:

$I_{NA} = 18{,}009 \text{ in}^2\text{-ft}^2$

Section Moduli:

Top: $Z_T = 2119 \text{ in}^2\text{-ft}$

Bottom: $Z_B = 2119 \text{ in}^2\text{-ft}$

Bending Stress (Hull):

$$f_{b_T} = -f_{b_B} = \frac{1080(2.24)}{2119} = 1.14 \text{ ksi}$$

Shear Stress (Average):

$$f_{s_{avg}} = \frac{36(2.24)}{45} = 1.80 \text{ ksi}$$

e. Total Stress (Still Water and Wave-Induced).

- Girder No. 1 at Centerline

$$f_{b_T} = +2.63 \text{ ksi}$$

$$f_{b_B} = -2.68 \text{ ksi}$$

$$f_{s_{avg}} = 1.05 \text{ ksi}$$

- Girder No 1. at Hull

$$f_{b_T} = \pm 2.28 \text{ ksi}$$

$$f_{b_B} = \pm 2.02 \text{ ksi}$$

$$f_{b_{avg}} = 7.59 + 1.05 = 8.64 \text{ ksi}$$

5. Conclusions and Recommendations

It is apparent that the torsional mode, for this SWATH ship, is not the critical loading condition because the stress levels are low regardless of the type of analysis employed. However, the results of these analyses indicate the lack of understanding of the actual behavior of a multicell box beam subject to torsional loads. There are no effective design procedures readily available. It is recommended that further research and/or testing be conducted in order to learn more about the torsional behavior of the SWATH multihull ship. These studies should be conducted for both static and vibratory loads.

III. WEIGHT AND DENSITY RESULTS

A. WEIGHT REPORT

The structural weights were computed and grouped into three categories:

- Bridge Structure
- Struts
- Lower Hulls

For each category the weight was further divided into longitudinal and transverse material. The entire transverse cross section (i.e., plating and beams) was used for computing the weight in the longitudinal direction. In the transverse direction, all transverse bulkheads (plate and beams) and only deck and shell beams were used for computing the weights. The resulting weights are summarized in Tables 7 and 8. Table 7 shows the results of the weight study for HY100 steel using various transverse beam spacing (i.e., 16.2 feet, 5 feet, 4 feet, 3 feet, and 2 feet). Table 8 summarizes the weight study for the 3-foot transversely framed HTS ship.

The weights shown in Table 7 and 8 are for the ship structure required to resist the specified design loads used in this design. These weights may increase if the loads are changed or if additional design criteria are specified (i.e., docking loads, grounding loads, helicopter landing loads, wave-induced transverse vertical shear, etc.). No additional weight allowances were made at all for such things as welding, inserts, brackets, or lugs, etc.

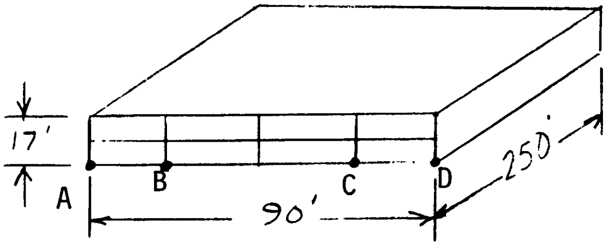
The resulting larger weights of the HY100 and HY80 ships are due primarily to the following factors:

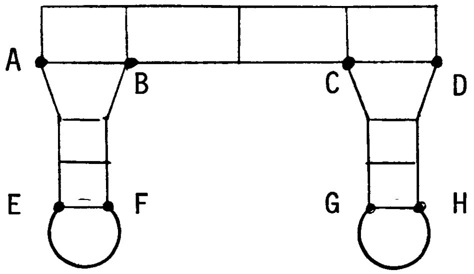
- The effective width of plating used in plate-beam property calculations is small. A narrower width of plate results in a smaller flange area, hence a larger tee beam is required by the plate and the beam combination to resist the secondary loads.
- The shape properties (i.e., thickness, depth, width, etc.) of the tee beams as rolled are based on the requirements of mild steel. These tee beams are not compatible with HY100 and HY80 plating. There is a definite need for developing tee beams with dimensions based on the properties of the higher yield material if more efficient structural designs are to be made.

B. DENSITY REPORT

The densities for the three categories (i.e., bridge structure, struts and lower hulls) were determined using the weights (as computed in paragraph III.A.) divided by the volumes as shown below.

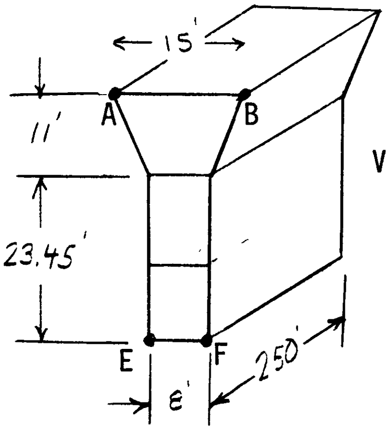
- Bridge Structure





Volume = 90 x 17 x 250 = 382,500 cu ft

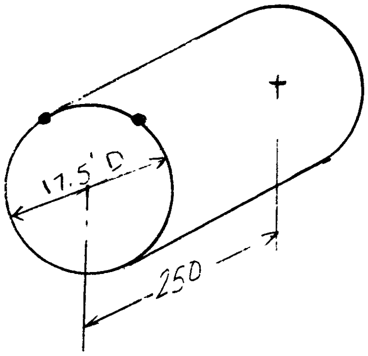
- Struts



$$\text{Volume} = 2[23.45 \times 8 \times 250 + (\frac{8 + 15}{2}) \times 11 \times 250]$$

$$= 157{,}050 \text{ cu ft}$$

Lower Hulls



$$\text{Volume} = 2\left(\frac{\pi \times \overline{17.5}^{2}}{4} \times 250\right)$$

$$= 120{,}203 \text{ cu ft}$$

- Total Volume = 659,753 cu ft

The weight densities for the various studies are reported in Tables 7 and 8.

C. DISCUSSION OF RESULTS

The weight densities shown in Table 8 could be used to estimate the structural weights of SWATH ships whose geometry and/or displacement are somewhat different from those of the ship studied in this report. For example, the results of a weight study performed for a SWATH ship having a displacement of 8000 tons, a length of 292 feet, a breadth of 106 feet, a depth of 76 feet, a draft of 36 feet, a diameter of lower hull of 22 feet, H.T.S. material, and 2-foot nominal frame spacing revealed the following increases in the weight densities:

Bridge Structure	2%
Struts	8%
Lower Hulls	13%

Since this project is a continuing task, periodic updating of the weight densities for the 4000-ton SWATH ship and alternative configurations will be made. These future results will reflect the research and development efforts in other areas where work is presently underway.

TABLE 7 - SUMMARY OF WEIGHTS AND DENSITIES FOR HY100
AND DIFFERENT TRANSVERSE FRAME SPACINGS

NOMINAL TRANSVERSE BEAM SPACING (FT)	WEIGHT IN LBS (TONS)				DENSITY (LBS/CU FT)			
	BRIDGE STRUCTURE	STRUTS	LOWER HULLS	TOTAL	BRIDGE STRUCTURE	STRUTS	LOWER HULLS	TOTAL
16.2	2,527,478 (1128)	1,486,256 (664)	1,420,189 (634)	5,433,923 (2426)	6.61	9.46	11.81	8.24
5.0	2,510,242 (1121)	1,201,518 (536)	715,116 (319)	4,426,876 (1976)	6.56	7.65	5.95	6.71
4.0	2,243,209 (1001)	1,081,478 (483)	678,569 (303)	4,003,256 (1787)	5.86	6.89	5.65	6.07
3.0	2,200,694 (982)	994,813 (444)	667,775 (298)	3,863,282 (1725)	5.75	6.33	5.56	5.86
2.0	2,312,755 (1032)	907,665 (405)	673,206 (301)	3,893,626 (1738)	6.05	5.78	5.60	5.90

TABLE 8 - SUMMARY OF WEIGHTS AND DENSITIES FOR DIFFERENT
MATERIALS AND 3-FOOT TRANSVERSE FRAME SPACING

TYPE OF MATERIAL	WEIGHT IN LBS (TONS)				DENSITY (LBS/CU FT)			
	BRIDGE STRUCTURE	STRUTS	LOWER HULLS	TOTAL	BRIDGE STRUCTURE	STRUTS	LOWER HULLS	TOTAL
MS	1,948,101 (870)	1,192,857 (533)	848,699 (379)	3,989,657 (1782)	5.09	7.60	7.06	6.05
HTS	1,887,698 (843)	1,051,971 (470)	730,851 (326)	3,670,520 (1639)	4.94	6.70	6.08	5.56
HTS (2 ft)*	1,817,756 (811)	940,625 (420)	667,155 (299)	3,425,536 (1530)	4.75	6.00	5.55	5.19
HY80	1,967,657 (878)	1,009,166 (451)	688,982 (308)	3,665,805 (1637)	5.14	6.43	5.73	5.56
HY100	2,200,694 (982)	994,813 (444)	667,775 (298)	3,863,282 (1725)	5.75	6.33	5.56	5.86

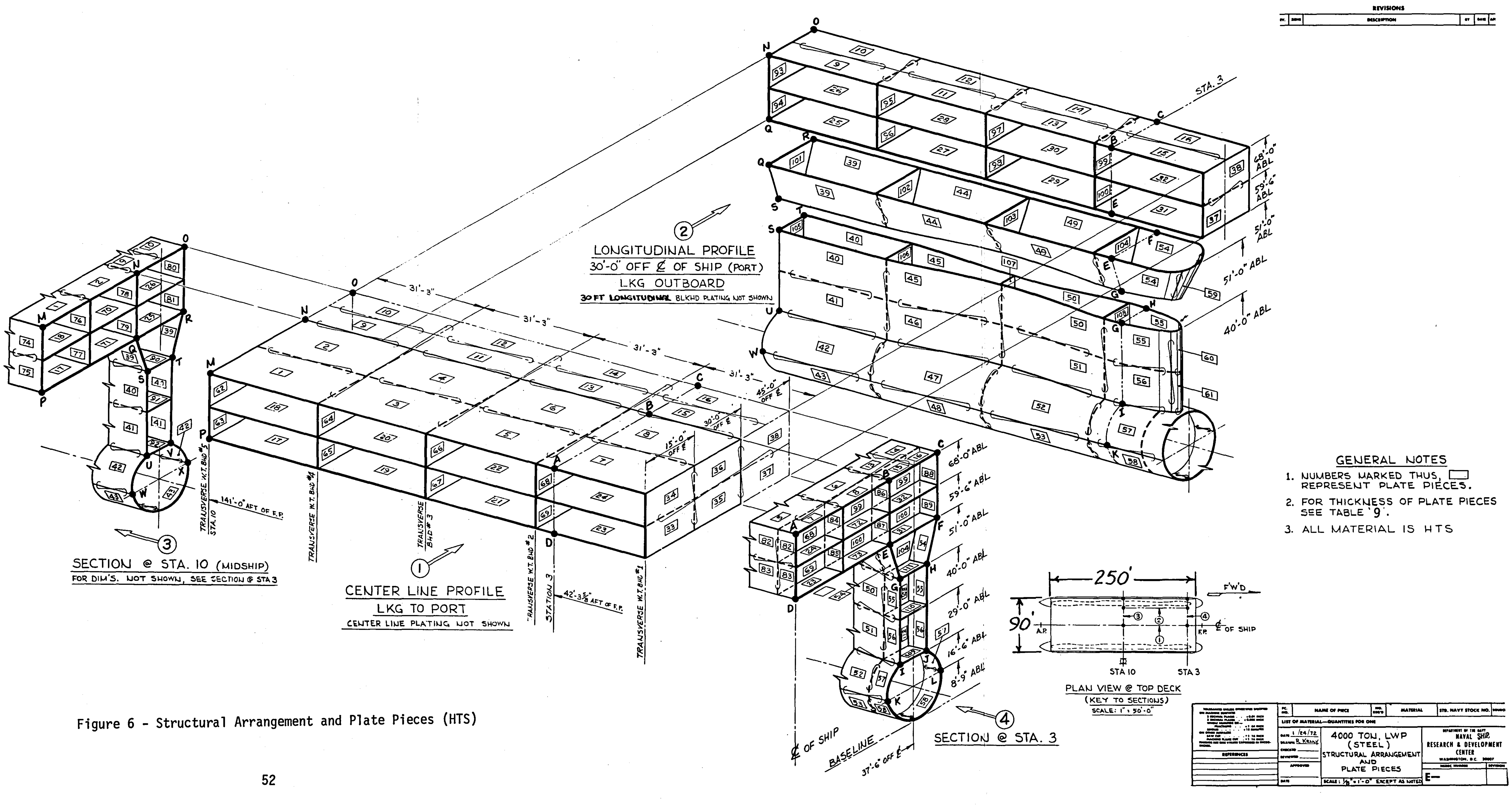
* Results of study for 2-foot transverse frame spacing.

IV. SUMMARY OF STRUCTURAL SCANTLINGS (DESIGN EXAMPLE)

The structural arrangements of plate pieces and stiffeners are shown in Figures 6 and 7. This ship has 2-foot transverse beam spacing and uses HTS material throughout. The thickness of the plate pieces shown in Figure 6 is given in Table 9. The nominal size and spacing of the transverse and longitudinal stiffeners shown in Figure 7 are given in Tables 10 and 11, respectively.

Cross sections consisting of a combination of materials (hybrid sections) were not investigated in this study. The computer program MIDSHIP[1] presently prohibits the use of hybrid sections, and therefore only studies using the same material throughout the cross section were conducted. These studies revealed that the use of HTS steel throughout the cross section will produce scantlings of minimum weight and structurally adequate to resist the local loads, wave-induced loads, etc.

For larger SWATH ships, it is reasonable to assume that local load design will play a secondary role and that the use of higher strength steels at the extreme fibers will be required to resist the wave-induced loads. Hence, hybrid sections may be required in order to keep the structural weights at reasonable levels.



GENERAL NOTES

1. NUMBERS MARKED THUS, ☐ REPRESENT PLATE PIECES.
2. FOR THICKNESS OF PLATE PIECES SEE TABLE '9'.
3. ALL MATERIAL IS HTS

Figure 6 - Structural Arrangement and Plate Pieces (HTS)

TABLE 9 - THICKNESS OF PLATE PIECES(HTS AND 2-FOOT SPACING)

PC. NO.	INCH	LBS/SQFT	PC. NO.	INCH	LBS/SQFT	PC. NO.	INCH	LBS/SQFT	PC. NO.	INCH	LBS/SQFT
1	5/16	12.75	29	7/32	8.93	57	11/32	14.03	85	1/8	5.1
2	3/8	15.3	30	1/8	5.1	58	11/32	14.03	86	1/8	5.1
3	5/16	12.75	31	7/32	8.93	59	5/8	25.5	87	1/8	5.1
4	3/8	15.3	32	1/8	5.1	60	5/8	25.5	88	7/16	17.85
5	5/16	12.75	33	1/2	20.4	61	5/16	12.75	89	7/16	17.85
6	11/32	14.03	34	1/2	20.4	62	3/16	7.65	90	1/8	5.1
7	5/16	12.75	35	1/2	20.4	63	5/32	6.38	91	1/8	5.1
8	11/32	14.03	36	1/2	20.4	64	3/16	7.65	92	3/16	7.65
9	7/32	8.93	37	1/2	20.4	65	5/32	6.38	93	7/32	8.93
10	7/32	8.93	38	1/2	20.4	66	3/16	7.65	94	7/32	8.93
11	7/32	8.93	39	5/16	12.75	67	5/32	6.38	95	7/32	8.93
12	7/32	8.93	40	11/32	14.03	68	3/16	7.65	96	7/32	8.93
13	7/32	8.93	41	11/32	14.03	69	5/32	6.38	97	7/32	8.93
14	5/32	6.38	42	11/32	14.03	70	7/32	8.93	98	7/32	8.93
15	7/32	8.93	43	11/32	14.03	71	11/32	14.03	99	7/32	8.93
16	5/32	6.38	44	5/16	12/75	72	7/32	8.93	100	7/32	8.93
17	5/16	12.75	45	11/32	14.03	73	7/16	17.85	101	7/32	8.93
18	7/32	8.93	46	11/32	14.03	74	1/8	5.1	102	7/32	8.93
19	5/16	12.75	47	11/32	14.03	75	1/8	5.1	103	7/32	8.93
20	7/32	8.93	48	11/32	14.03	76	1/8	5.1	104	7/32	8.93
21	5/16	12.75	49	5/16	12.75	77	1/8	5.1	105	5/16	12.75
22	7/32	8.93	50	11/32	14.03	78	1/8	5.1	106	5/16	12.75
23	7/16	17.85	51	11/32	14.03	79	1/8	5.1	107	1/4	10.2
24	7/32	8.93	52	11/32	14.03	80	9/32	11.48	108	1/4	10.2
25	7/32	8.93	53	11/32	14.03	81	9/32	11.48	109	3/16	7.65
26	1/8	5.1	54	7/16	17.85	82	1/8	5.1	110	1/8	5.1
27	7/32	8.93	55	7/16	17.85	83	1/8	5.1	111	1/8	5.1
28	1/8	5.1	56	11/32	14.03	84	1/8	5.1	112	1/4	10.2

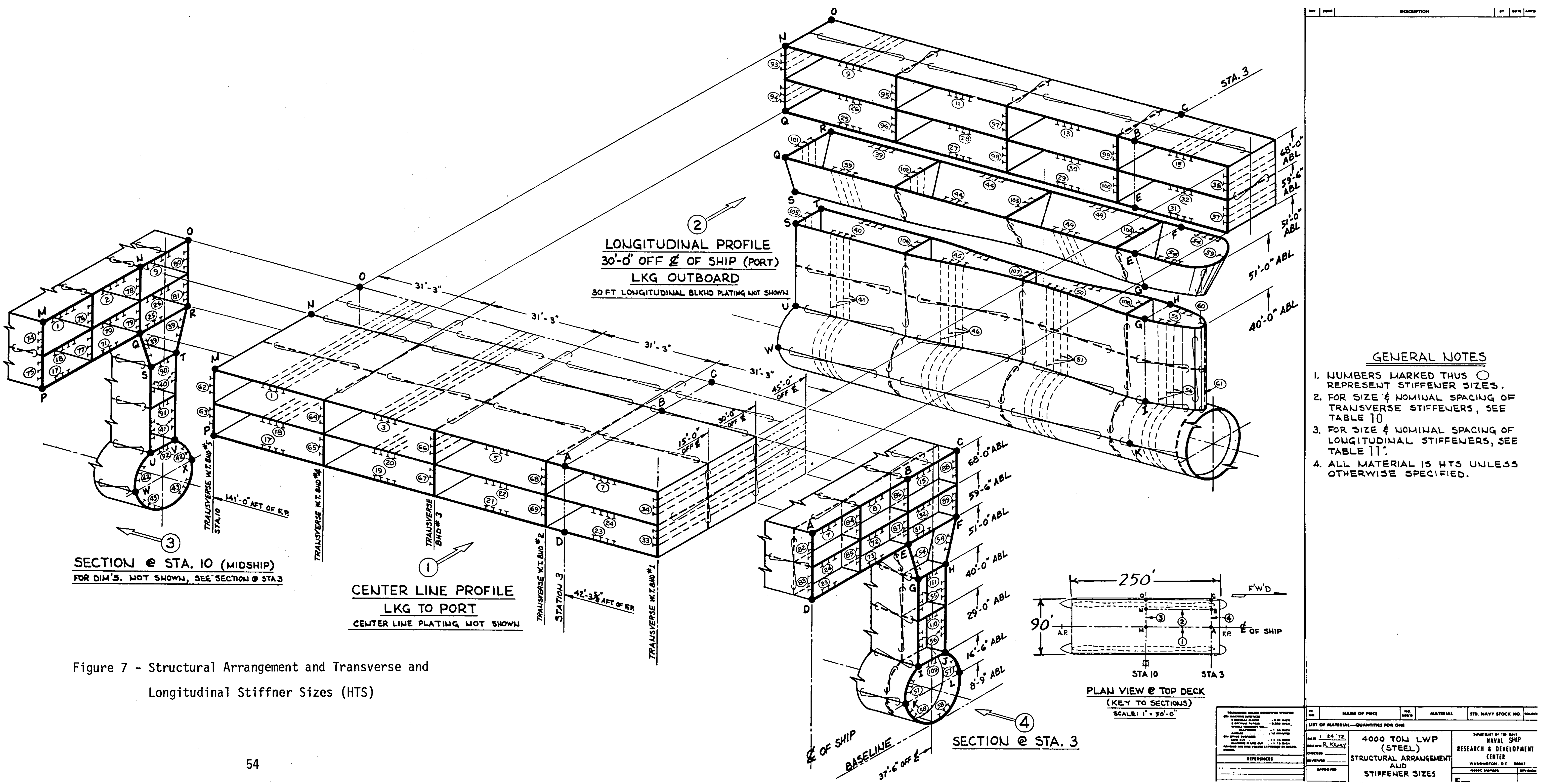


Figure 7 - Structural Arrangement and Transverse and Longitudinal Stiffner Sizes (HTS)

TABLE 10 - SIZE AND NOMINAL SPACING OF TRANSVERSE STIFFNERS

PC. NO.	SIZE	NOMINAL SPACING (INCHES)
1	7x6 3/4x15#T	24
3	DO	24
5	DO	24
7	DO	24
9	8x6 1/2x24 I-T	24
11	DO	24
13	DO	24
15	DO	24
17	7x6 3/4x15 T	24
18	4x5 1/4x8.5 T	24
19	7x6 3/4x15 T	24
20	4x5 1/4x8.5 T	24
21	7x6 3/4x15 T	24
22	4x5 1/4x8.5 T	24
23	7x6 3/4x15 T	24
24	4x5 1/4x8.5 T	24
25	12x6 1/2x27 I-T	24
26	4x5 1/4x8.5 T	24
27	12x6 1/2x27 I-T	24
28	4x5 1/4x8.5 T	24
29	12x6 1/2x27 I-T	24
30	4x5 1/4x8.5 T	24
31	12x6 1/2x27 I-T	24
32	4x5 1/4x8.5 T	24
33	6x6 1/2x13.5 T	20
34	7x6 3/4x15 T	20
37	8x6 1/2x24 I-T	20
38	8x6 1/2x24 I-T	20
39	8x5 1/4x17 I-T	24
40	10x5 3/4x25 I-T	24
41	12x6 1/2x31 I-T	24
44	8x5 1/4x17 I-T	24
45	10x5 3/4x25 I-T	24
46	12x6 1/2x31 I-T	24

PC. NO.	SIZE	NOMINAL SPACING (INCHES)
49	8x5 1/4x17#I-T	24
50	10x5 3/4x25 I-T	24
51	12x6 1/2x31 I-T	24
54	8x5 1/4x17 I-T	24
55	10x5 3/4x25 I-T	25
56	12x6 1/2x31 I-T	25
59	8x5 1/4x17 I-T	24
60	10x5 3/4x21 I-T	24
61	12x6 1/2x31 I-T	24
62	4x5 1/4x8.5 T	20
63	3x4 x6 T	20
64	4x5 1/4x8.5 T	20
65	3x4 x6 T	20
66	4x5 1/4x8.5 T	20
67	3x4 x6 T	20
68	4x5 1/4x8.5 T	20
69	3x4 x6 T	20
93	8x4 x13 T	20
94	DO	20
95	DO	20
96	DO	20
97	DO	20
98	DO	20
99	DO	20
100	DO	20
101	6x4 x3.5 T	18
102	DO	18
103	8x4 x13 I-T	20
104	DO	20
105	8x5 1/4x17 I-T	24
106	DO	24
107	DO	21
108	DO	19

TABLE 11 - SIZE AND NOMINAL SPACING OF LONGITUDINAL STIFFENERS

PC. NO.	SIZE	NOMINAL SPACING (INCHES)
1	3x1 7/8x2.2 LB. T	51
2	DO	51
7	DO	51
8	DO	51
9	3x1 7/8x2.2 LB. T	51
15	4x2 1/4x3.25 LB. T	51
17	3x1 7/8x2.2 LB. T	23
18	DO	51
23	DO	23
24	DO	51
25	3x1 7/8x2.2 LB. T	51
26	DO	26
31	DO	51
32	7x2 1/8x5.5 LB. I-T	51
39	3x1 7/8x2.2 LB. T	23
40	DO	26
41	4x2 1/4x3.25 LB. T	50
42	6x1 7/8x4.4 LB. I-T	58
43	DO	45
54	3x1 7/8x2.2 LB. T	23
55	DO	22
56	4x2 1/4x3.25 LB. T	50
57	7x2 1/8x5.5 LB. I-T	58
58	DO	45
70	3x1 7/8x2.2 LB. T	51
71	3x1 7/8x2.2 LB. T	30
72	DO	51
73	DO	23
74	3x1 7/8x2.2 LB. T	34
75	DO	26
76	DO	34
77	DO	26
78	DO	34
79	DO	26
80	3x1 7/8x2.2 LB. T	20
81	DO	20
82	DO	34
83	DO	26
84	DO	34
85	3x1 7/8x2.2 LB. T	26
86	DO	34
87	DO	26
88	DO	20
89	DO	20
90	4x2 1/4x3.25 LB. T	51
91	6x1 7/8x4.4 LB. I-T	51
92	3x1 7/8x2.2 LB. T	26
109	DO	26
110	6x1 7/8x4.4 LB. I-T	51
111	4x2 1/4x3.25 LB. T	51

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13. ABSTRACT

This report describes the procedures used to perform a structural design and weight study for a 4000-ton Small Waterplane Area Twin Hull (SWATH) Naval ship. This ship was designed to resist wave-induced and still water primary transverse and longitudinal bending moments. An approximate method for analysis was performed to check the design for torsional loads. Secondary loads consisted of slamming loads, external hydrostatic heads, arbitrary minimum shell pressure loads for shell plating not submersed, live loads, and structural dead loads. The studies were performed using different steel properties (MS, HTS, HY80, HY100) and different transverse frame spacings. The weights are summarized and a complete design is illustrated showing all the scantlings (plate pieces and tee beams) for the 2-foot transversely framed HTS SWATH ship.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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